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Implementing Lean Production: A Behavioral Perspective

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Abstract

Over the last decades, manufacturing companies have been exposed to increasing global competition and, consequently, the ongoing pressure to continuously improve their processes and lower their costs. Against this backdrop, the popularization of lean production since 1990 including the promise to reduce waste and significantly improve firm performance seemed to come along just in time, especially for the Western world. Soon, the lean philosophy, principles, and practices have been widely adopted by manufacturers all over the world and even an independent field of lean research has emerged.

Numerous manufacturers managed to improve their processes thanks to lean, but up until today, still, many firms are having issues with gaining or sustaining positive results from the implementation of their lean programs. Among the most frequently mentioned critical success factors for implementing lean production are leadership and managerial commitment. However, behavioral lean research is in its infancy and has, so far, studied managerial behaviors and their impact on lean programs only superficially. After starting with a bibliometric study that reviews the full body of lean literature, this dissertation aims to fill the above-mentioned research gap by contributing two empirical studies on the influence of managers in lean programs.

The first study of this dissertation takes stock of the current state of knowledge in the field of lean research. Various bibliometric techniques have been employed to achieve that goal and provide what is considered to be the most comprehensive lean literature review done ever. While citation and frequency analyses identify the most influential and active areas of lean research including past and current trends, a co-citation analysis draws a big picture of the lean literature knowledge structure. The second study analyzes how different managerial practices moderate the effectiveness of a lean program. Using survey data collected in the pharmaceutical industry, regression analysis is employed to study interaction effects between single social lean practices and the lean practice-performance link. The results yield both positive and negative moderators of that relationship. The third study takes a closer look at the hierarchical levels of managers and how individual managers' perceptions permeate throughout the organization and manifest themselves in individual managers' and organizational behavior. The results show that both top managers and middle managers depend on each other when implementing lean.

This dissertation makes a significant scientific contribution, as it provides a comprehensive review of the overall academic lean literature. As part of the review, it indicates current trends, which can help shape the direction of future lean research and guide lean scholars. In addition,

it depicts the landscape of knowledge groups within the lean literature, which can help researchers identify themselves with certain knowledge groups, but also open up perspectives for lean scholars to venture into new research directions. Further, this dissertation is – to the best of the author's knowledge – among the first, if not the first, empirical lean study that investigates the moderation effects of management behaviors on the lean-performance relationship. The main contribution of the third study is a unique empirical documentation of perceptual differences between top and middle managers with regards to lean program effectiveness and how these affect organizational behavior and the success of lean programs.

Besides the academic insights it yields, this dissertation also provides important implications for practitioners. On the one hand, practitioners can learn and gain inspiration from the bibliometric review about the manifold fields of lean applications and the current trends, such as lean's application to support sustainability. On the other hand, this dissertation offers managers knowledge about empirically tested relationships between essential concepts for a successful lean implementation, such as specific management practices or organizational practices that help build a lean-supportive organizational infrastructure.

Zusammenfassung

In den letzten Jahrzehnten waren produzierende Unternehmen einem zunehmenden globalen Wettbewerb und damit dem ständigen Druck ausgesetzt, ihre Prozesse laufend zu verbessern und Kosten zu senken. Vor diesem Hintergrund kam die Popularisierung des Lean Managements seit 1990 mit dem Versprechen, Verschwendung zu reduzieren und die Unternehmensleistung deutlich zu verbessern, gerade rechtzeitig – insbesondere für die westliche Welt. Schon bald wurden die Lean-Philosophie, -Grundsätze und -Praktiken von Herstellern auf der ganzen Welt übernommen, und es entstand sogar ein eigenständiger Bereich der Lean-Forschung.

Zahlreichen Herstellern gelang es, ihre Prozesse dank Lean zu verbessern, aber bis heute haben viele Firmen nach wie vor Probleme, positive Ergebnisse aus der Umsetzung ihrer Lean-Programme zu erzielen oder aufrechtzuerhalten. Zu den am häufigsten genannten kritischen Erfolgsfaktoren für die Umsetzung der schlanken Produktion gehören Führung und Engagement des Managements. Die verhaltenswissenschaftliche Lean-Forschung steckt jedoch noch in den Kinderschuhen und hat sich bisher nur oberflächlich mit dem Verhalten von Führungskräften und dessen Auswirkungen auf Lean-Programme beschäftigt. Die vorliegende Dissertation beginnt mit einer bibliometrischen Studie, in der die gesamte Lean-Literatur gesichtet wird, woraufhin die oben identifizierte Forschungslücke mit zwei empirischen Studien über den Einfluss von Führungskräften auf Lean-Programme geschlossen wird.

Die erste Studie dieser Dissertation nimmt eine Bestandsaufnahme des aktuellen Wissensstandes auf dem Gebiet der Lean-Forschung vor. Um dieses Ziel zu erreichen, wurden verschiedene bibliometrische Techniken angewandt, um die wohl umfassendste Literaturübersicht zum Thema «Lean» zu erstellen. Während Zitations- und Häufigkeitsanalysen die einflussreichsten und aktivsten Bereiche der Lean-Forschung einschliesslich vergangener und aktueller Trends identifizieren, zeigt eine Ko-Zitationsanalyse ein Gesamtbild der Wissensstruktur innerhalb der Lean-Literatur auf. In der zweiten Studie wird untersucht, wie unterschiedliche Managementpraktiken die Wirksamkeit eines Lean-Programms beeinflussen. Anhand von Umfragedaten, die in der pharmazeutischen Industrie erhoben wurden, werden mit Hilfe der hierarchischen linearen Modellierung Interaktionseffekte zwischen einzelnen sozialen Lean-Praktiken und dem Zusammenhang zwischen Lean-Praktiken und der operativen Unternehmensleistung untersucht. Die Ergebnisse zeigen sowohl positive als auch negative Moderatoren für diese Beziehung. In der dritten Studie werden die Hierarchieebenen der Manager und die Art und Weise, wie die Wahrnehmungen der einzelnen Manager das gesamte Unternehmen durchdringen und sich im Verhalten der einzelnen Manager oder der Organisation manifestieren, näher betrachtet. Die

Ergebnisse zeigen, dass sowohl Top-manager als auch mittlere Manager bei der Umsetzung von Lean voneinander abhängig sind.

Diese Dissertation leistet einen wichtigen wissenschaftlichen Beitrag, da sie einen umfassenden Überblick über die gesamte akademische Lean-Literatur gibt. Dabei werden aktuelle Trends aufgezeigt, die für die künftige Lean-Forschung richtungsweisend sind und den Lean-Forschern als Orientierung dienen können. Darüber hinaus wird die Landschaft der Wissensgruppen innerhalb der Lean-Literatur dargestellt, was Forschern helfen kann, sich mit bestimmten Wissensgruppen zu identifizieren, aber auch Perspektiven für Lean-Wissenschaftler eröffnet, um neue Forschungsrichtungen einzuschlagen. Darüber hinaus ist diese Dissertation - nach bestem Wissen des Autors - eine der ersten, wenn nicht sogar die erste empirische Lean-Studie, die Moderationseffekte des Managementverhaltens auf die Lean-Performance-Beziehung untersucht. Der Hauptbeitrag der dritten Studie ist eine einzigartige empirische Dokumentation der Wahrnehmungsunterschiede zwischen Top-Managern und mittleren Managers hinsichtlich der Effektivität von Lean-Programmen und wie diese das Organisationsverhalten und den Erfolg von Lean-Programmen beeinflussen.

Neben den wissenschaftlichen Erkenntnissen liefert diese Dissertation auch wichtige Schlussfolgerungen für die Praxis. Einerseits können Praktiker aus dem bibliometrischen Überblick über die vielfältigen Anwendungsbereiche von Lean und die aktuellen Trends, wie z. B. die Anwendung von Lean zur Förderung der Nachhaltigkeit, lernen und sich inspirieren lassen. Andererseits bietet diese Dissertation Managern Wissen über empirisch getestete Beziehungen zwischen wesentlichen Konzepten für eine erfolgreiche Lean-Implementierung, wie z. B. spezifische Managementpraktiken oder organisatorische Praktiken, die zum Aufbau einer Lean-unterstützenden organisatorischen Infrastruktur beitragen.

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List of Abbreviations

5S	Seiri, Seiton, Seiso, Seiketsu, and Shitsuke
AC	Automation in Construction
AMJ	Academy of Management Journal
AMR	Academy of Management Review
ASQ	Administrative Science Quarterly
BPMJ	Business Process Management Journal
B.Sc.	Bachelor of Science
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CI	Continuous Improvement
Coeff.	Coefficient
Covid	Coronavirus disease
DMAIC	Define, Measure, Analyze, Improve, Control
DISS.	Dissertation
Dr.Sc.	Doctor of Sciences
D-MTEC	Department of Management, Technology and Economics
EJOR	European Journal of Operations Research
ETH	Eidgenössische Technische Hochschule
EurOMA	European Operations Management Association
FT	Financial Times
HBR	Harvard Business Review
HR	Human Resources
IJAMT	International Journal of Advanced Manufacturing Technology
IJLSS	International Journal of Lean Six Sigma
IJOPM	International Journal of Production and Operations Management
IJPDLM	International Journal of Physical Distribution & Logistics Management
IJPE	International Journal of Production Economics
IJPPM	International Journal of Production and Performance Management
IJPR	International Journal of Production Research
IJQRM	International Journal of Quality & Reliability Management
IMDS	Industrial Management & Data Systems

IW	Industry Week
JAP	Journal of Applied Psychology
JCEM	Journal of Construction Engineering and Management
JCP	Journal of Cleaner Production
JMTM	Journal of Manufacturing Technology Management
JOM	Journal of Operations Management
JSCM	Journal of Supply Chain Management
LEI	Lean Enterprise Institute
MIT	Massachusetts Institute of Technology
MPI	Manufacturing Performance Institute
MS	Management Science
M.Sc.	Master of Science
NO.	Number
NUMMI	New United Motor Manufacturing, Inc.
OLS	Ordinary Least Squares
OM	Operations Management
OPEX	Operational Excellence
Org.	Organizational
OS	Organization Science
PCA	Principal Component Analysis
PDCA	Plan, Do, Check, Act
PDSA	Plan, Do, Study, Act
Ph.D.	Doctor of Philosophy
POM	Production and Operations Management
POMS	Production and Operations Management Society
PPC	Production Planning and Control
ppm	parts per million
RFT	Right First Time
RMSEA	Root mean square error of approximation
RWTH	Rheinisch Westfälische Technische Hochschule
SD	Standard deviation
SEM	Structural Equation Model
SMED	Single-Minute Exchange of Die
SMJ	Strategic Management Journal

SMR	Sloan Management Review
TLI	Tucker-Lewis Index
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
TQMBE	Total Quality Management & Business Excellence
TQMJ	Total Quality Management Journal
UK	United Kingdom
UN	United Nations
Univ.	University
US	United States
USA	United States of America
USD	United States Dollar
UTD	University of Texas at Dallas
Vs.	Versus
WoS	Web of Science

Chapter 1

1. Introduction

1.1. Motivation and Research Objectives

Starting with the use of bare hands and rudimentary tools in the Early Stone Age, humans have continuously been making progress in how they manufacture goods. The three industrial revolutions represent milestones for this evolution and the fourth one is already ongoing (Schwab, 2018). While these events have been primarily characterized by major advancements in production technology, such as the *steam engine*, *electricity*, or *automation*, progress in the management and organization of human work and manufacturing processes has also added to significant productivity gains (Roser, 2017). Famous examples are the *division of labor* (Smith, 1776), *scientific management* (Taylor, 1911), and *statistical process control* (Deming, 1982).

One of the latest management paradigms has emerged from the Toyota Production System (TPS) (Ohno, 1988). Also known as *lean production, lean management*, or just *lean*, this management approach has become popular in the Western world after a group of MIT researchers conducted the International Motor Vehicle Program (IMVP), a benchmarking study to probe the automotive value chain. The findings were published under the title "The Machine that Changed the World" (Womack et al., 1990), which adequately captures the impact production systems have on our society. They occur to be a major reason why everyday goods have become cheaper and cheaper to produce, leading to a constant surge in the quality of life for billions of people (Schwab, 2018). The fact that most people can nowadays afford a car, cell phone, or computer and thus get access to mobility, communication, or education is directly related to the progress made in industrial productivity (Dombrowski & Mielke, 2015).

The success of lean production goes back to Japan's post-World War II efforts of rebuilding its economy. Specifically, automotive manufacturer Toyota Motor Company (hereafter, just "Toyota" for short) had to cut costs to catch up with American manufacturers. Consequently, Toyota took inspiration from other firms' management techniques and complemented them by also developing their own ways of designing processes and managing their workforce, and continuously improving them (Ohno, 1988). In doing so, Toyota has put much focus on quality, removing waste (e.g., inventory), and fostering respect for people, among others. This way, Toyota has managed to outperform other car manufacturers and ultimately surpassed General Motors (GM) in 2008, becoming the largest automobile manufacturer in the world in terms of sales rank (Liker & Convis, 2012).

As outlined above, Toyota's success has not long remained unrecognized and soon researchers and practitioners became aware of the new management approach. In 1984, the New United Motor Manufacturing, Inc. (NUMMI), a joint venture between GM and Toyota, was launched in Fremont, California. There, Toyota has instilled its culture into the plant and turned it from a troubling workplace into GM's best-performing automobile factory in terms of quality (Adler, 1995; Holweg, 2007). Later, the plant was sold to Tesla, Inc. because of GM's financial problems, but what has initially started as an experiment turned out to be a demonstration that Toyota's way of management works beyond the borders of Japan.

Since advancements in transportation and communication technology drove globalization over the past decades, Western manufacturers have started to experience more and more competition. One major reason for the increased pressure has been low production costs in low-wage countries, which have ultimately led to lower margins and sales figures. According to data from the UN Statistics Division, the Republic of China overtook the USA in 2010 in terms of manufacturing output, reaching almost 30% of the global output in 2019 (Richter, 2021). Further trends and developments, such as decarbonization, shorter product life cycles, increased customization, or material shortages pose additional challenges to today's manufacturing firms (Westkämper & Zahn, 2009).

To remain competitive and keep their national economies intact, high-wage countries have thus been dependent on improving their production systems and reducing costs (Brecher et al., 2011). To illustrate, with a gross value added of around 139.9 billion Swiss francs and 645,400 employees in 2021, the manufacturing industry counts as one of the largest economic sectors and employers in Switzerland (Statista Research Department, 2022). Lean production systems, with their potential to increase efficiency and value creation, have therefore gained significant attention among manufacturers all around the globe, particularly in the Western world (Dombrowski & Mielke, 2015; Holweg, 2007).

After now more than 30 years of research on lean production systems and despite all the promises of significant performance gains, manufacturing companies have still been struggling to gain or sustain positive results from the implementation of their lean programs (Holweg, Staats, et al., 2018; McLean et al., 2017; Sadun et al., 2017). An IW/MPI survey from 2007 reported that 74% of US companies were not making good progress implementing lean (Pay, 2008). More recently, Negrão et al. (2017) reviewed 83 studies dealing with the relationship between lean practices and organizational performance. They found that most initiatives resulted in a positive effect on performance, but still identified five studies indicating a contrary relationship. In addition to these scientific and practical reports, it has been my personal experience as a researcher and supervisor of many industrial theses that manufacturing companies today are still having trouble transforming their business and sustainably improving their processes according to ideas of lean management.

But why do manufacturing companies struggle with the implementation of lean? This appears to be a valid question in light of many abandoned lean programs. Achanga et al. (2006) conducted a study in the SME sector and found *leadership* and *management commitment* to be the most critical success factor for a successful lean project. Supporting factors were *funding*, *organizational culture*, and *skills and expertise*. In a more recent study, Netland (2016) surveyed 83 manufacturing plants about critical success factors for implementing lean production and identified 24 of them. The most frequently occurring ones were *active leadership*, *personal participation* by managers, and *education of employees*. On a more general level, Kotter (1995) lists eight critical mistakes organizations can make when transforming their businesses. Among others, these include the failure to create a *sense of urgency*, the lack of a *vision*, and insufficient *empowerment of employees*. Many more studies of that kind exist, which study success factors of lean implementation in specific contexts, such as food processing (Dora et al., 2016), or the implementation of similar types of production systems, such as Total Quality Management (TQM) (Wali et al., 2003). Notably, almost all of them agree on the importance of leadership and human aspects of the organization.

Although human aspects of lean have been viewed as relevant from the early start (Ohno, 1988; Sugimori et al., 1977), leadership and organizational behavior have been rather superficially treated in the scholarly literature for most of the time, with just a few exceptions (e.g., Liker, 2004; Rother, 2010; Spear, 2004). Only recently, researchers have started to more strongly focus on the behavioral and cultural underpinnings of lean (Cusumano et al., 2021). Illustrative examples are, among others, the separation of technical *hard lean practices* and people-related *soft lean practices* by Bortolotti et al. (2015), the analysis of a supportive organizational infrastructure for CI projects by Galeazzo et al. (2017), and the identification of managerial behaviors for effective lean implementation by Camuffo and Gerli (2018). Lately, also research on cognitive aspects and their effects on behavior has more frequently appeared in OM and lean research (e.g., Arellano et al., 2021; van Dun & Wilderom, 2021).

Still, many questions related to the human success factors of lean programs remain unanswered. For example, general leadership principles have been discussed in previous lean studies, but the specific role and influence of managers from different hierarchical levels have not received much attention yet (Netland et al., 2019). It has been suspected that one major reason why this field has been understudied is the complexity sociotechnical systems bring along (Holweg, Davies, et al., 2018). Behavioral and cognitive foundations of lean production systems are more difficult to conceptualize and observe than the application of purely technical aspects, such as 5S or Kanban cards. The under-representation of social and behavioral aspects in lean studies is thus probably in large part due to ease of measurement (Cusumano et al., 2021). Additionally, it has been speculated that in the beginning lean practitioners and researchers alike have to some extent underestimated the significance of human factors (cf. Åhlström et al., 2021). Concluding, there is a research gap concerning the social factors surrounding the implementation of lean.

As there is no uniform perspective on the purpose of scientific research, I see it as advancing our understanding of natural and social phenomena. Ideally, this would in turn lead to the solution of problems or enhancement of circumstances for humans and other forms of life on our planet. Both the fact that manufacturing companies continue to struggle with the implementation of lean principles aiming at higher productivity and the lack of research on lean leadership have therefore motivated me to conduct my doctoral study and write this thesis. Throughout this journey, it has been my goal to add a building block of knowledge on how managers can best support the implementation of lean programs and help their organizations sustainably increase their performance. To achieve this goal, I suggested and sought to answer the following main research questions:

1. What is the current state of knowledge in the field of lean research?
2. How do managerial practices moderate the effectiveness of lean programs?
3. How do managers from different hierarchical levels influence lean implementation?

The first research question requires a review of the overall lean literature, which allows showing which research streams have evolved in 30 years of lean research and where future lean research could be headed. The second research question aims to investigate the effects of different mechanisms that managers can employ to support the effectiveness of lean programs. The third research question distinguishes between managers from different hierarchical levels and studies their roles and influence on lean implementation. All in all, this doctoral thesis aims to give answers to all three research and, in doing so, add a building block of knowledge to both, lean practitioners and the corresponding scientific community.

With regards to definitions and terminology, it must be noted that there exists no widely accepted definition of lean and that many terms have been used to describe the same or related concepts (e.g., TPS, TQM, JIT). In this thesis, *lean* is being viewed as a socio-technical system comprised of principles (e.g., respect for people) and practices (e.g., 5S) (cf. Lyons et al., 2013; Shah & Ward, 2007), which originate from the TPS and have evolved as industrial practice and standards have kept changing (for more details, see Ch. 1.2.2) (cf. Cusumano et al., 2021). The *implementation of lean* is hence regarded as all organizational efforts aiming to adopt these lean principles or practices. Accordingly, I view *lean programs* as sets of lean principles and practices that organizations define and decide to implement.

This thesis is structured as follows. Chapter 1 serves as an introductory chapter to the overall thesis and provides the motivation and research objectives of this thesis (Ch. 1.1), the conceptual background (Ch. 1.2), the methodological procedure of the single studies presented in this thesis (Ch. 1.3), an overview of the results (Ch. 1.4), and a discussion of the results (Ch. 1.5). The subsequent chapters, Chapters 2, 3, and 4, each contain the single studies conducted to answer the research questions of this thesis. The following table presents an overview of the individual characteristics of each study:

Table 1 – Overview of the Individual Studies Presented in this Dissertation

	Chapter 2	**Chapter 3**	**Chapter 4**
Title of the included study	"An Evolutionary Perspective on Lean: A Bibliometric Review"	"The Role of Management in Lean Implementation: Evidence from the Pharmaceutical Industry"	"The Role of Managerial Perceptions and Behaviors in Lean Programs"
Short title	"Bibliometric Review"	"Management Practices"	"Perceptions and Behaviors"
Authors	Sven Januszek (ETH Zurich), Torbjørn Netland (ETH Zurich), Rachna Shah (Univ. of Minnesota), Alan Pilkington (Univ. of Westminster)	Sven Januszek (ETH Zurich), Julian Macuvele (Univ. of St. Gallen), Thomas Friedli (Univ. of St. Gallen), and Torbjørn Netland (ETH Zurich)	Sven Januszek (ETH Zurich), Torbjørn Netland (ETH Zurich), and Andrea Furlan (Univ. of Padova)
Research question(s)	What is the current state of knowledge in the field of lean research?	How do managerial practices moderate the effectiveness of lean programs?	How do managers from different hierarchical levels influence lean implementation?
Methodology	Citation and co-citation analysis, citation and keyword burst analysis	CFA, PCA, correlation analysis, and multiple linear regression	CFA, Structural equation modeling
Data	Bibliometric data from WoS	Survey data from a global manufacturer operating in the process industry	Survey data from the ITEM-HSG OPEX Benchmarking study (www.tectem.ch)
Sample size	5,638 articles, 131,967 references	37 manufacturing sites (n=280)	351 manufacturing sites (n=351)
Publication Progress	"Reject and Resubmit" decision at *JOM*, as of 19. March 2021	"Revise and Resubmit" decision at *IJOPM*, as of 4. May 2022; resubmission to IJOPM on 2. July 2022	Submission to *IJOPM* on 3. July 2022
Contribution of Sven Januszek	Lead author, research design, literature review, data collection, data analysis, major contribution to writing of the manuscript	Lead author, research design, major contribution to literature review and data analysis, writing of the manuscript	Lead author, research design, literature review, data analysis, writing of the manuscript

1.2. Conceptual Background

The purpose of this chapter is to lay a theoretical and conceptual foundation for the overall work of this thesis and to provide the reader with a general understanding of the studied and discussed concepts. It begins with a brief outline of the history of process improvements, then introduces the concept of lean programs, shows a behavioral perspective on lean implementation, and closes with an explanation of the role of lean leadership.

1.2.1. History of Process Improvements

The way how humans manufacture goods today is the result of hundreds of years of thinking about how to best organize work. Long before the first significant improvements have been made in this regard, humans were mostly operating individually. They did the research, development, production, sales, and distribution of their business mostly on their own. It was only until Adam Smith, a Scottish economist, introduced his ideas of 'Division of Labor' that work has widely started to be separated and assigned to individual workers. Smith saw potential in specializing workers on single subtasks and that it could lead to greater skill and productivity than having the same number of workers work on the overall original task from start to end. The reason for these productivity gains was mainly due to increased quality and, even more importantly, higher efficiency of production (Smith, 1776).

Smith illustrated his ideas with an example of metal pin production: A group of ten workers, in which each one was to perform two or three distinct operations, could produce 48,000 metal pins per day, resulting in 4,800 pins per man. However, if a single worker had to suddenly produce the whole pin by themselves, they would certainly not reach 20 pins per day (Smith, 1776). As businesses have become more and more specialized and complex, this way of developing and matching skills with individual tasks has resulted in new organizational structures. Individual functions, such as purchasing, engineering, production planning, sales, HR, or accounting, are expressions of today's division of labor.

The next milestone in improving the quality and efficiency of work can be attributed to Frederick Winslow Taylor. By establishing a scientific approach to the management of work, he created the first modern management system (Hopp & Spearman, 2011). His vision was to find the 'one best way' to perform a process by scientifically measuring and analyzing it. To achieve this goal, he separated the management of work from the actual work, which allowed workers to concentrate on the execution of their tasks and, at the same time, led to a new way of management (Roser, 2017). Experimentation, development, and testing of new tools, and the detailed study of motions with a stopwatch, which later became the field of *time and motion study*, were examples of the methods Taylor applied to spot potentials for efficiency gains and significantly improve production processes (Taylor, 1911).

In addition, Taylor viewed workers as an essential part of the process and thus tried to also understand their motivation and interests. Consequently, he developed new wage systems and organizational structures, which significantly contributed to balancing the interests of employers and employees (Westkämper & Zahn, 2009). Later, his work was partly criticized for still being dehumanizing and exploitative (e.g., Braverman, 1998; Mintzberg, 1989). Also, his picture of the worker intentionally working slowly, shirking, and not being creative is by now considered outdated (Dombrowski & Mielke, 2015; Taylor, 1911). Nevertheless, many of the themes that have emerged from scientific management are still relevant today and can be found in the profession of industrial engineering, such as empiricism, elimination of waste, and standardization.

Henry Ford counts as another important figure in the evolution of production technology and is today viewed as the father of mass production. On the face of it, Ford and Taylor seemed to share similar ideas. For example, Ford also experimented with different forms of manufacturing organizations in vehicle assembly, changing the number of workers at the assembly station or testing different ways of moving workers and material to and from the station for instance (Womack et al., 1990). However, significant differences remained between these two pioneers. As Taylor was more concerned with the efficiency of the worker, Ford was more interested in mechanizing processes and simplifying work, making the worker almost redundant (Roser, 2017).

By taking inspiration from assembly lines in a slaughterhouse and mastering production-oriented product design with interchangeable parts (Pearson, 1992), Ford developed the first automotive assembly line. Overall, this led to enormous productivity gains reaching up to 1000% for some processes (Pursell, 1995). Assembly operations have become very simple and repetitive, which allowed the hiring of unskilled, cheap workers. At the same time, working conditions were bad and led to a high turnover. To increase worker satisfaction and motivation, Ford later increased the salaries and reduced working hours. Still, Ford’s company remained a highly profitable business. The Ford Model T was being produced at an astonishing takt time of 40 seconds and became the first widely affordable car in the United States (Roser, 2017). In summary, Fordism significantly advanced the concept of the assembly line, which enabled to produce large quantities at a low cost.

Table 2 – Development of Production Numbers and Prices for the Ford Model T Based on Dombrowski and Mielke (2015)

Fiscal year	Price (USD)	Number of units produced
1909/1910	950	18.664
1910/1911	780	34.528
1911/1912	690	78.440
1912/1913	600	168.220
1913/1914	550	248.317
1914/1915	490	308.213
1915/1916	360	785.432

Once manufacturing companies were able to produce in high numbers, product quality has started to become an increasingly important aspect for them. One of the first people who raised significant awareness of the relevance of quality was Joseph Juran (Anderson et al., 1994). After World War II, Juran's work caught the attention of Japanese manufacturers. Juran accepted their invitations and spent much time in Japan to further develop his theories. There, he was able to add a human dimension to quality management by educating and training managers – something US manufacturers had been more resistant to. At the same time, Juran's contributions helped Japanese companies to become world leaders in quality and outperform their global competition (Juran & De Feo, 2010). After his return to the US, he in turn managed to spread many Japanese ideas there, for example, *quality circles*, which are meetings for identifying, analyzing, and solving work-related problems (Juran, 1967). Juran established the field of *managing for quality* and is today considered an important figure in transferring quality knowledge between the East and West.

Another important figure in the development of quality management was William Edwards Deming. Like Juran, he was an expert in this field and moved to Japan after World War II to teach managers various quality-oriented methods. Among his most significant contributions was the *Deming chain reaction*, which was a demonstration that quality is a critical factor for achieving business success. He argued that improved quality would lead to fewer costs due to less rework and fewer delays, higher productivity, gains in market share due to lower prices, and ultimately secure jobs (Deming, 1982). In addition to that, Deming further developed *Shewhart's* (1931) *cycle*, which he labeled the *Plan-Do-Study-Act (PDSA) cycle* and today is mostly known as the *Plan-Do-Check-Act (PDCA) cycle*, to engage employees in learning and knowledge generation and to promote proactive innovation and improvement (Anderson et al., 1994). Deming received many honors and awards and was, together with Juran, seen as a major contributor to the ascend of post-war Japanese industry (Schonberger, 2007).

As a statistician, Deming also focused on statistical quality control (Deming, 1982), but it was only until Motorola developed the *six sigma* approach that it gained widespread attention in the industry (Anderson et al., 1994). The term six sigma stems from the statistics behind it: The goal was to reduce variation to such an extent that process outputs within a range of six standard deviations (σ) away from the mean (μ) would still meet the levels of tolerance. In other words, this required a very high proportion of products to meet its specifications. Assuming a normal distribution, this was in fact an ambitious goal, meaning a defect rate of 3.4 ppm (Harry, 1998). However, the mathematics served a rather academic purpose but the actual purpose of six sigma was organizational change and improvement. Companies like Motorola or later GM effectively followed this approach by applying various methods, such as the *DMAIC* cycle, to significantly increase their quality and save billions of USD (De Feo & Barnard, 2003).

Necessity begets ingenuity. Not many examples illustrate this proverb as well as Toyota. Suffering from the post-war effects, the automotive manufacturer had to manage with very little resources and save costs. To illustrate, while Ford had multiple metal stamping machines per part, Toyota had to produce many different parts with one machine. As a consequence thereof, Toyota developed many different methods to still remain productive, such as the quick changeover method (Roser, 2017), nowadays better known as *SMED*. Many western ideas, such as stopping the production line at Ford in case of defects, the replenishment of American supermarkets, or takt time production at the German Junkers aircraft plants served as an inspiration for Toyota (Holweg, 2007; Ohno, 1988; Roser, 2017). However, Toyota did not just copy these ideas but managed to successfully integrate them into their quite different domestic environment, which is why the TPS is neither considered purely original nor fully imitative (Fujimoto, 1999). Prominent elements of the TPS were the two principles of *Just-in-time* (JIT) and *Jidoka*, continuous improvement (*kaizen* in Japanese), the focus on value creation, and the elimination of waste, inconsistency, and unreasonableness (Monden, 1993; Ohno, 1988; Womack & Jones, 1996). By the 1980s, Taiichi Ohno, the mastermind behind the development of the TPS, had created a global benchmark in manufacturing efficiency, which has until today been copied by many manufacturing companies and other industries under the label 'lean management'.

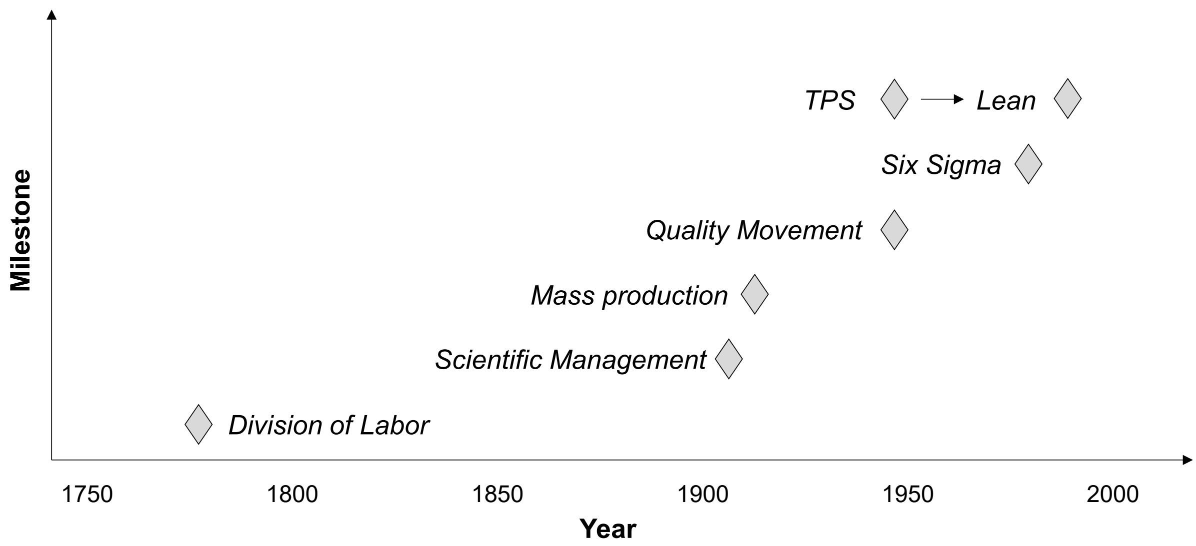

Figure 1 – Timeline of Historic Milestones in Manufacturing Productivity Advancement

This historic overview of manufacturing process improvements is certainly not complete, but it outlines several important milestones that contributed to the overall standards in productivity we have today. Most of these contributions are somewhat related to each other and still have their relevance today. For the rest of this thesis, however, the focus will be put on the lastly introduced concept, lean production, by explaining it in more detail and how manufacturing organizations implement it.

1.2.2. The Concept of Lean Programs

A full description of lean production would go beyond the scope of this thesis and has already been provided in the literature in much detail (e.g., Fujimoto, 1999; Monden, 1983; Ohno, 1988; Sugimori et al., 1977; Womack et al., 1990). Nevertheless, this section will introduce its main ideas to create a fundamental understanding of it and show why and how organizations try to adopt them.

In the scientific OM community, there is no uniform definition of lean. Lately, a series of publications in the *Journal of Operations Management (JOM)* has discussed the definition of lean but did not reach a consensus. Hopp & Spearman (2020) presented four lenses of lean and emphasized lean's focus on efficiency and removing waste. In a follow-up commentary, many authors disagreed with that perspective claiming that effectiveness, i.e., creation of value, would be even more important, and showed alternative interpretations of lean (Cusumano et al., 2021). In their JOM editorial, Browning & Treville (2021) argued in favor of another, more simplified definition of lean consisting of a list of thirteen practices (Cusumano, 1994), but concluded that scholars still would not agree on what lean actually is and encouraged to do more research on the understanding of the TPS and lean concept.

Considering the corresponding numbers of scientific publications and citations, researchers at least seem to broadly agree on lean's conceptualization as a complex system comprised of both social and technical practices that are interdependent and highly integrated (Bortolotti et al., 2015; Shah & Ward, 2003, 2007). There is even more consensus related to lean's origination from the TPS, as researchers from the IMVP, who studied the TPS, first labeled it this way in 1988 (Krafcik, 1988), and shortly after started to promote the concept under this term in the Western world (Womack et al., 1990).

The Lean Enterprise Institute (LEI), a well-established research and teaching institution founded by lean expert James P. Womack, depicts the TPS as a house consisting of two main pillars, JIT and Jidoka, standing on the fundamental principles *heijunka*, *standardized work*, *kaizen*, and *stability* (Lean Enterprise Institute, 2022). The goals followed by the TPS are highest quality, lowest cost, and shortest lead times (see Figure 2).

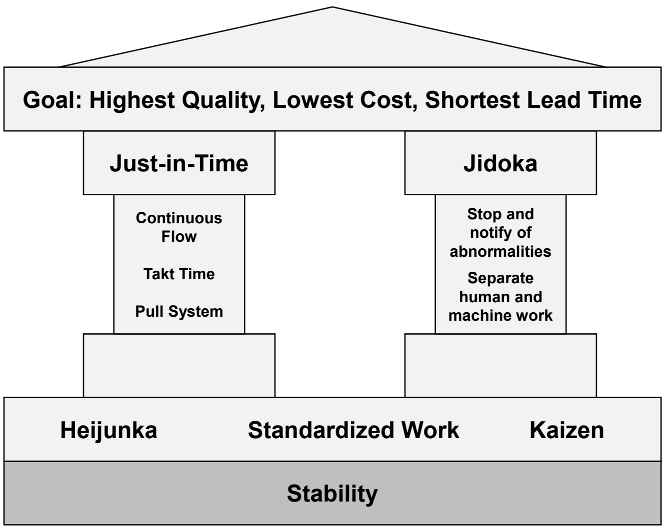

Figure 2 – Toyota House of Production according to the LEI

A continuous one-piece flow at consistent quality with yet enough flexibility to adapt to changing demands both in quantity and variety can be achieved by implementing the two main pillars of the TPS: JIT and Jidoka (Monden, 1993). In its essence, JIT means to produce and procure the *right parts* at the *right time* and in the *right amounts*. Different tools and practices exist to implement JIT. *Kanban* cards are, for example, a popular method to set up a pull production as part of a JIT system. As a signaling instrument, they are attached to materials or containers and appear visible to the worker once a certain amount of material is consumed and notifies them about the need for replenishing new material.

The second pillar, Jidoka, is about stopping the production in case of problems, such as equipment malfunctioning or quality issues, fixing the problems, and solving their root cause (Liker, 2004; Monden, 1993). It was originally realized by separating human work from machines, gradually reducing the work done by people, and building machine intelligence into the process, for example by automatically stopping a machine in case of defects (Baudin, 2007). Additional tools, such as *poka-yoke* – a mistake-proofing mechanism that can be integrated into the process or product, helped Toyota to realize the idea of Jidoka and follow their zero-defect strategy (Ohno, 1988).

The consistent use of the two pillars would not have been so effective without following additional principles and guidelines. One of the most important principles that Toyota followed was kaizen – continuous improvement. Toyota worked diligently to instill a mindset into their employees to always seek further improvements in their production systems and strive for perfection (Womack & Jones, 1996). Central to this notion was the elimination of overburden (*muri* in Japanese), unevenness (*mura* in Japanese), and waste (*muda* in Japanese) (Ohno, 1988; Shingo & Dillon, 1989).

Once improvements have been made, the next step would be to maintain these improvements and prevent errors from reoccurrence. This was achieved by establishing standard work procedures (Ohno, 1988). Heijunka, also known as production leveling or smoothing, was the third principle and aimed for minimizing the variation in the quantity of each produced part – in other words, to produce the same number of products each day. This required a reduction of production lead times, as various parts needed to be produced quickly each day, which Toyota solved by small lot size production or even one-piece-flow. In turn, smoothing of production helped to avoid fluctuations in demand, which would otherwise cause large amounts of inventory (Monden, 1993).

The NUMMI plant, a joint venture between GM and Toyota, demonstrated that the TPS worked not only in Japan but also in American plants (Shook, 2010). This fact and the popularization of the concept by researchers from the IMVP have caught Western manufacturers' interest. Soon, many manufacturing companies have also started to adopt the principles and practices of lean production by changing their organizational structures and implementing new practices (Karlsson & Ahlstrom, 1996).

According to Hines et al. (2004) and Netland in (Cusumano et al., 2021), lean is a fluid concept. As an evolving business phenomenon, it is in constant change, and due to its modular structure able to be adapted to external circumstances.

This has allowed companies to define their own configurations of production systems based on the ideas of lean production, which, in some cases, they complemented with ideas from other concepts like Six Sigma (Netland & Aspelund, 2014). Depending on their individual needs, each manufacturer has been able to select individual sets of principles and practices and formalize them as an organizational change program that the whole company would set out to implement. However, the main elements of lean production remained central to manufacturing organizations when they defined their own new production systems (Netland, 2013), which is why these company-specific production systems are labeled ‘lean programs’ in this thesis.

As practitioners have started to define and implement their lean programs and set out to improve the efficiency of their processes and save costs, researchers simultaneously tried to operationalize lean production as a concept and develop measurement instruments to examine its relationship with firm performance (Shah & Ward, 2003). By now, the association of lean production with enhanced operational performance is well established (Bloom et al., 2019; Negrão et al., 2017; Netland et al., 2015; Pil & Macduffie, 1996; Shah & Ward, 2003). A study conducted by Netland & Ferdows (2016) even managed to establish a more precise picture of lean’s effect on performance over time, indicating an S-curved shape, which implies initial inertia during implementation followed by more significant performance improvements that then again diminish after some time (see Figure 3). Still, there are reports of cases where organizations failed to implement lean or sustain its positive effect on performance (Negrão et al., 2017; Pay, 2008; Sadun et al., 2017). It has been speculated that a common reason for disappointing results is a lack of understanding of the social factors surrounding lean implementation (Losonci et al., 2017; Wiengarten et al., 2015), which is going to be addressed in the following sections.

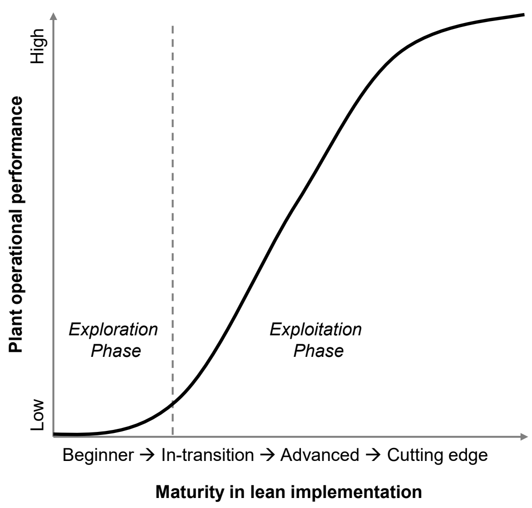

Figure 3 – Netland & Ferdows' (2016) S-curve Theory on the Relationship Between Maturity in Lean Implementation and Operational Performance in Manufacturing Plants

1.2.3. A Behavioral Perspective on Lean Implementation

The gradual dissemination of lean ideas led to its association with Toyota's tools and practices in the first place (Netland, 2013; Pilkington, 1998), and only later with its cultural and behavioral elements (Cusumano et al., 2021; Danese et al., 2018). Accordingly, whereas the previous chapter focused on the technical aspects of lean and its performance effects, the next chapter describes the social factors surrounding the implementation of lean programs. Considering the long lifetime of lean research, researchers have only recently started to study human-related questions in the context of lean implementation. Table 3 summarizes these efforts by briefly reviewing the latest studies on the relationship between social factors and successful lean implementation.

Lean programs are generally defined as systematic initiatives that require the adaptation of existing practices and the adoption of new practices. To illustrate, the change from push to pull production by introducing Kanban cards will require employees to change the way they are being informed to replenish material, the frequency of doing so, and probably also the amount of material to be replenished. Thus, it comes as no surprise that many of the reviewed studies in Table 3 address behavioral issues. For example, Netland et al. (2015) studied the effects of five management control practices on the degree of lean implementation. In a more recent study, van Dun and Wilderom (2021) identified various behavior-value patterns that characterize high-performing lean teams.

Table 3 – Selection of Recent Articles Studying Human-related Aspects surrounding Lean Implementation

#	Reference	Region	Sector	Methodology	Human-related aspects	Key results
1	Dombrowski and Mielke (2014)	Unknown	Unknown	Literature review, study results, and practical experiences of lean implementation	5 principles and 15 rules of lean leadership deduced from several theories and practical reports as well as from study results	Description of a continuous improvement process; explanation of five basic lean leadership principles and identification of 15 practice-oriented requirements for lean implementation framed as rules
2	Kull et al. (2014)	Global	Various	Survey data (n=1453), factor analysis, linear regression analysis	8 national culture dimensions based on the GLOBE model (House et al., 2014)	Identification of national culture dimensions that positively moderate the relationship between lean management and operational performance (high uncertainty avoidance, low assertiveness, low future orientation, and low performance orientation)
3	Fullerton et al. (2014)	USA	Manufacturing	Survey data (n=244), factor analysis, structural equation modeling	3 lean management accounting practices based on lean (accounting) literature	Empirical evidence for the positive relationship between lean manufacturing practices and the use of management accounting practices as well as between lean manufacturing practices and operational performance, the interrelation between management accounting practices, and that lean manufacturing practices indirectly affect operations performance through management accounting practices.
4	Netland et al. (2015)	Global	Automotive	Survey data (n=226), two-stage least squares regression, factory visits, and 140 semi-structured interviews with factory managers, lean managers, and shop-floor personnel	5 management control practices based on management control literature	Empirical evidence for the positive relationship between three management control practices and lean implementation; no evidence for the effects of two other management control practices; the positive relationship between lean implementation and operational performance
5	Bortolotti et al. (2015)	Global (8 countries)	Mechanical, electronics, and transportation industry	Survey data (n=317), confirmatory factor analysis, goodness of fit measures	8 organizational culture dimensions based on the GLOBE model (House et al., 2014) and 6 soft lean practices based on lean literature	Characterization of a specific organizational culture profile for successful lean plants: higher institutional collectivism, future orientation, and, notably, a lower level of assertiveness when compared to unsuccessful plants. Successful lean plants use soft lean practices (i.e., employee training, small group problem solving, customer involvement, supplier partnership, and continuous improvement)
6	Marodin and Saurin (2015)	USA	Aerospace, industrial vehicles	7 interviews with managers, one engineer, and one front-line worker, observations, and document analysis	34 contextual factors and 14 barriers to lean production implementation based on lean literature	Framework for managing barriers to lean production implementation, which consists of normative theory which serves as guidance about what actions will and will not lead to the desired result, and an overview of influential relationships between contextual factors (e.g., dedicated employees, regular meetings, audits) and barriers (e.g., lack of resources, responsibility or communication)

7	Wiengarten et al. (2015)	Global	Various	Survey data (n=932), confirmatory factor analysis, and linear regression analysis	1 cultural dimension on an organizational and national level	Empirical evidence for the significant impact of cultural collectivism at the national and organizational level on the efficacy of lean practices; impossibility of full compensation for an individualistic country through collectivistic organizational culture
8	Dora et al. (2016)	Belgium	Food	Multiple-case study using 45 interviews with operators, OMs, and general managers, review of documents, and on-site observations before and after lean implementation	9 determinants to lean implementation based on lean literature and 3 additional industry-characteristic factors	Identification of determining factors that were considered critical to lean implementation success in the food processing industry: Among various very important factors such as commitment of top management, training, resources, organizational culture, structure, or the nature of the process and product the most important determinant was having a change agent who is motivated and drives change
9	Laureani and Antony (2016)	Global	Various (e.g., industrial goods and services, finance, automotive, computer and services)	Survey data (n=123), exploratory factor analysis	19 critical success factors based on lean literature	Identification of the most important factors for the effective implementation of Lean Six Sigma: project management, leadership, selection of top talented people, and financial accountability
10	Netland (2016)	Global	Automotive, chemicals	Survey data (n=432), chi-square goodness of fit tests	24 critical success factors based on lean literature and empirical analysis	A generic list of critical success factors whose effectiveness can vary depending on the stage of lean implementation and which includes among others active lead, personal participation, employee education, manager education, and communication as supposedly most important factors
11	Galeazzo et al.(2017)	Global (8 countries)	Mechanical, electronics, and transportation industry	Survey data (n=266), structural equation modeling	3 dimensions of an organizational learning infrastructure based on single prior studies	Identification of variables that underlie organizational infrastructure and their links to continuous improvement capability: strategic alignment and teamwork for problem-solving affect continuous improvement capability positively, whereas goals management systems did not show any significant effect
12	Losonci et al. (2017)	Hungary	Carbon-based parts	Survey data (n=57), factor analysis, and linear regression analysis	4 organizational culture dimensions based on the Competing Values Framework and 3 shop floor subculture dimensions based on single prior studies (Detert & Mauriel, 2000; Prajogo & McDermott, 2005)	Theoretical insights and empirical evidence for the multidimensional influence of organizational culture, originating from three different shop-floor subcultures, on lean production practices: Lean production practices are impacted only by two culture types, clan, and adhocracy because the market culture type was omitted from the Competing Values Framework model and the hierarchy culture type does not affect lean production practices

13	van Dun et al. (2017)	Netherlands	Automotive, food, and energy	Two-stage research design: 1. Delphi study among 19 expert lean practitioners 2. 18 interviews with lean middle managers, video analyses, t-tests, and correlation analysis of survey data (n=43)	24 managerial values and 19 managerial behaviors based on lean literature	Identification of values of effective lean managers: honesty, candor, participation and teamwork, and continuous improvement as values -which all are considered indicative of self-transcendence and openness to change; Identification of behaviors of effective lean managers: relations-oriented active listening and agreeing, and significantly less task monitoring and counterproductive work behaviors including negative feedback and the defense of one's own position
14	Tortorella et al. (2018)	Brazil	Various	Survey data (n=225), confirmatory factor analysis, linear regression analysis	2 Leadership style dimensions, leader's age, and team size	Identification of direct effects of leadership styles on lean implementation and moderation effects of contextual variables on the relationship: Task-orientation makes leaders more likely to successfully implement lean than relation-oriented leaders, whereas larger teams and more senior managers were negatively associated with lean implementation
15	DeSanctis et al. (2018)	Global (27 countries)	Manufacturing	Survey data (n=150), association rule analysis, network analysis	9 national culture dimensions based on the GLOBE model (House et al., 2004) and 5 barriers to lean implementation	Positive influence of national culture dimensions, such as performance orientation and gender egalitarianism, on lean management success; maintenance of a lean culture is more difficult than its development; SMEs could have more difficulties developing a lean culture than large organizations; cultural factors such as uncertainty avoidance, future orientation and institutional collectivism help to support a lean culture and overcome human and cultural barriers
16	van Assen (2018)	Netherlands	Various (manufacturing and services)	Survey data (n=178), confirmatory factor analysis, regression analysis	3 management behaviors based on lean literature	Positive effects of three lean-related management actions on lean and the level of process improvement: i) envisioning and communicating the meaning of Lean, ii) setting goals and active steering on improvement performance metrics, and ii) encouraging continuous improvement. Active steering on improvement performance metrics reinforced the effect of lean on process improvement
17	Camuffo and Gerli (2018)	Italy	Various	Factory visits in 26 companies, interviews with senior operations managers on-site assessments, regression analysis	14 management behaviors based on lean literature	Identification and operationalization of a repertoire of management behaviors that supports the adoption of lean practices; empirical validation and identification of a subset of management behaviors that are positively related to lean implementation (standards development, managerial versatility, organizational focus, supportiveness, capability development, and performance evaluation) suggesting a situational approach to lean leadership
18	Beraldin et al. (2019)	Italy	Home appliance manufacturing	Survey data (n=135), moderated hierarchical linear regression	Employee well-being based on the job demands-resources model	Soft lean practices increase the engagement of employees and decrease their exhaustion; JIT-related job demands reduce the engagement of employees and increase their exhaustion; soft lean practices can reduce the effect of JIT-related job demands and exhaustion while JIT-related job demands can increase the effect of soft lean practices on engagement
19	Knol et al. (2019)	Netherlands	Various (e.g., automotive, electronics,	Survey data (n=241), asymmetrical and symmetrical between-case	8 improvement routines based on continuous improvement literature	Improvement activities based on measurements, tools, and techniques support lean practice implementation; lean practices can be implemented to some extent without the development of specific improvement routines; improvement routines, however, become increasingly important for more advanced lean

		machinery, plastics, construction, etc.)	comparison analysis, necessary condition analysis		implementation; initial implementation of lean practices is enabled through i) employee-initiated improvements, ii) implementation across levels and departments, iii) use of a proper improvement system and iv) alignment with the strategy; advanced lean implementation of lean practices is enabled through i) employee-initiated improvements, ii) employee understanding, iii) management involvement and support and iv) adjustment of the improvement system
20	Cadden et al. (2020)	United Kingdom	Various (e.g., electronics, automotive, pharmaceutical, mechanical, etc.)	Survey data (n=295), structural equation modeling	6 organizational culture dimensions based on Hofstede et al. (1990) and Verbeke (2000)	Cultural dimensions fully mediate the impact of lean management practices on operational performance; lean practices are positively associated with organizational cultures that are procedurally focused, employee-oriented, structurally open, socially loose, rule-driven and market-oriented; lean practices are negatively associated with results-oriented and pragmatic cultures, which carried over their negative impact on operational performance; only external market orientation is associated with improved operating performance
21	Tortorella et al. (2020)	Brazil	Various	Survey data (n=135), partial correlation analysis	7 dimensions of a learning organization based on Marsick and Watkins (2003)	In contexts with a low degree of lean production implementation, some learning organization dimensions were found to be negatively correlated with lean production practices, and some others were found to be positively correlated, indicating the need for changing certain management habits before moving on to implement lean; in contexts with a high degree of lean production implementation, learning organization dimensions and lean production practices were generally highly correlated, indicating mutual development and reinforcement of organizational learning and lean implementation
22	Galeazzo et al. (2021)	Global (15 countries)	Various (Electronics, Industry Machinery, Transportation)	Survey data (n=330), regression analyses, response surface graphs	4 Leadership involvement measures, 5 employee participation measures, and 5 measures of centralization of authority	The fit between CI implementation and employee participation is positively associated with operational performance, which suggests that with increasing implementation of CI, the participation of employees becomes more important; the fit between CI implementation and centralization of authority is negatively associated with operational performance, which suggests a shift from top-down management to bottom-up management with increasing implementation of CI
23	Hardcopf et al. (2021)	Global (9 countries)	Various (Electronics, Industry Machinery, Transportation)	Survey data (n=266),	4 organizational culture types based on the Competing Values Framework (Quinn & Rohrbaugh, 1983)	Lean implementation can lead to a cost reduction independently of the organizational culture, but to achieve maximum quality, flexibility, and delivery performance, it requires a supportive organizational culture; a developmental organizational culture is most supportive of implementing lean
24	van Dun & Wilderom (2021)	Netherlands	Service and manufacturing sector	Micro-behavioral coding of film footage, survey data, interviews, participant observation, archival data	Different configurations of managerial behaviors, team behaviors, leader values, and member values	The improvement of lean team performance is associated with various team behaviors (peer support, process improvements, information sharing, and frequent performance monitoring), management behaviors (balancing task- and relations-oriented leadership, face-to-face support), values (e.g., self-transcendence, openness to change), and learning-by-doing as a collective activity

From a theoretical perspective, organizational behavior can be separated into routines that are repetitive but necessary to keep the firm's daily business running (*operational routines*) (Peng et al., 2008; Salvato & Rerup, 2011; Teece et al., 1997), and routines that evaluate, modify, or replace existing routines (*search routines*) (Nelson & Winter, 1982; Zollo & Winter, 2002; Zott, 2003). Lean programs hold a range of search routines. For example, working to standardize processes reduces routine diversity and makes improvements easier to spot and implement (Bicheno & Holweg, 2009; Morgan & Liker, 2006; Ohno, 1988); conducting flow analysis helps identify unnecessary resources ("waste") that can be obstacles for introducing change to existing routines due to interdependencies between routines (Rother & Shook, 2003; Womack & Jones, 1996); and, training shop-floor workers in improvement work can provide the necessary motivation and skills to improve existing routines (Anand et al., 2009; Rother, 2010; Spear & Bowen, 1999).

After reaching a certain degree of maturity, both operational routines and search routines qualify as organizational capabilities. *Dynamic capabilities* result from search routines and describe the way an organization can build, integrate, or reconfigure its resource configuration and routines (Eisenhardt & Martin, 2000; Helfat & Peteraf, 2003). According to Anand et al. (2009), organizations develop dynamic capabilities through patterned activities that change existing operational routines. Hence, the repeated execution of search routines—prescribed by lean programs—can create dynamic capabilities (Anand et al., 2009).

Manufacturing firms can generally be described as complex systems with many different interdependent elements (Teece et al., 1997), involving human, technological, and organizational resources. In such settings, only slight alterations of the resource configuration, which forms the basis of a unique value-creating strategy, can have a significant impact on a firm's competitiveness (Eisenhardt & Martin, 2000; Teece et al., 1997). To this aim, lean programs are used by global manufacturers to build dynamic capabilities throughout the organization (Eisenhardt & Martin, 2000; Teece et al., 1997; Teece & Pisano, 1994).

In the past, researchers have found many terms to describe what constitutes a dynamic capability, e.g., "routines for variation, selection, and retention" (Zott, 2003), "routines to learn routines" (Eisenhardt & Martin, 2000), or "search routines" (Nelson & Winter, 1982; Zollo & Winter, 2002). However, all these terms describe more or less similar concepts and consider organizational learning to be the main driver of dynamic capabilities (Easterby-Smith & Prieto, 2008; Helfat et al., 2009; Manville et al., 2012; Senge, 1999). Importantly, organizational learning has to be conceived not only as a passive process but also as an active one in which humans search for new knowledge and understanding to improve existing routines (Collis, 1994; Fiol & Lyles, 1985; A. P. Nielsen, 2006).

For a lean program to be successful, companies, therefore, need to recognize the value of organizational learning, which is one of the main factors that distinguished Toyota from its competitors (Spear & Bowen, 1999). Organizational learning includes the (co-)creation and sharing of knowledge, which needs to be supported by a respective organizational infrastructure that facilitates relentless reflection (*hansei* in Japanese), improvement suggestions, collaboration, seeking consensus (*nemawashi* in Japanese), group decisions and continuous improvement, which in turn drives organizational learning again (Anand et al., 2009; Furlan et al., 2019; Liker, 2004). As it is generally, the managers of the firm who are responsible for setting up the organizational infrastructure and guiding their employees' behavior, *lean leadership* plays a central role in the success of lean programs and will be therefore discussed in the following chapter.

1.2.4. The Role of Lean Leadership

Leadership and managerial commitment are frequently found terms in studies searching for critical success factors of lean programs (Achanga et al., 2006; Laureani & Antony, 2012; Netland, 2016; Spear, 2004). This is not surprising considering the influence managers can have on organizational behavior (Lowe et al., 1996; Podsakoff et al., 1996; Robbins & Judge, 2012). Yet, the difficulty of putting leadership effectively into practice already begins with a lack of its definition (Northouse, 2021).

An attempt to demarcate leadership from management was done by Nahavandi (2015), who compared *managers*, focusing on the present, maintaining the status quo, and using position power to *leaders*, who, on the other hand, focus on the future, create change, and use personal power. However, what managers ultimately need to do to achieve the desired behavior from their employees and the corresponding firm results is much more difficult to uncover due to the complexity of leadership and its effect on organizations.

The first step towards a better understanding of leadership was done by scientists who advanced leadership theories and characterized different leadership styles. Hersey and Blanchard (1969) proposed a leadership characterization model, which includes two different leadership style dimensions: task-relevant and relationship-relevant leadership. Whereas the first relates to establishing a structure or direction for task behavior, i.e. assigning tasks to individuals or groups and supervising the progress, the latter relates to two-way communication with employees including listening, facilitating, and providing support. Hersey and Blanchard's

(1969) model suggests a situational approach to leadership, in which leaders should adjust their behavior depending on the followers' characteristics.

Another famous leadership model was provided by Bass and Avolio (1997). Their Full Range Leadership Model includes three fundamental leadership styles, *laissez-faire*, *transactional*, and *transformational leadership*, which can be distinguished according to the leader's degree of engagement. Laissez-faire leadership is the least active way of leading people. It leaves the decision-making to the employees and does not include any rules. Transactional leaders promote compliance with rules and the performance of tasks, for example employing rewards or punishments. In contrast, transformational leaders serve as role models, share a future vision, offer individual support, promote group goals, provide intellectual stimulation, and expect high performance (Bass, 1990; Podsakoff et al., 1996).

One way to express certain leadership styles is by means of managerial behaviors. Numerous studies and books discuss the different practices that managers have successfully employed at Toyota, which, according to Netland et al. (2019) can be summarized as six generic lean leadership practices:

- Go and see
- Daily layered accountability
- Structured problem solving
- Continuous improvement
- Coaching
- Strategic alignment

To go and see (*genchi genbutsu* in Japanese) is frequently considered one of the most important lean leadership practices (Liker, 2004; Ohno, 1988; Spear, 2004). It allows leaders to make direct observations on the shop-floor (*gemba* in Japanese), which on the one hand increases their understanding of operational processes and value-creation, and, on the other hand, can improve the relationship with their employees (Goodridge et al., 2015).

Daily layered accountability is usually organized as a cascade of subsequent, daily meetings throughout various hierarchical levels. It serves as a platform to identify and discuss current operational issues and communicate them quickly to higher management levels so that every manager remains updated on the latest condition of the operations (Mann, 2014; Netland et al., 2015).

Structured problem solving is an approach that requires managers and their employees to work methodically and analytically. One typical approach is, for example, Deming's (1982) PDSA cycle, which can help to structure improvement activities. Within the PDSA cycle, further methods, such as scientific thinking or experimentation can be integrated to support the process of understanding the process, identifying improvement potentials, and defining new standards (Netland et al., 2019; Spear, 2004).

The idea of continuous improvement is fundamental to lean and should be lived by all employees on a daily basis, but it applies particularly to leaders (Dombrowski & Mielke, 2013). On the one hand, they are responsible for motivating their employees to stay alert, challenge the status quo, and make improvements (Rother, 2010). On the other hand, they should be present on the shop floor themselves to identify improvement potentials as well (Liker & Convis, 2012).

Another central aspect of lean leadership is the continuous development and coaching of others (Dombrowski & Mielke, 2013). Lean leaders are expected to see the strengths and weaknesses of their employees and create situations for them in which they can grow and develop themselves (Liker & Convis, 2012). Against this backdrop, leaders must create a fail-safe environment where mistakes are not punished but viewed as a learning experience and can be openly discussed (Goodridge et al., 2015).

The final lean leadership practice is *hoshin kanri*, also known as strategic alignment or policy deployment. It essentially is a process of seeking agreement and aligning every person in the organization toward the same overall strategy (Liker & Convis, 2012). To achieve this goal, the company objectives are broken down into smaller objectives and translated into tasks for lower levels of the organization (Netland et al., 2019). Managers are then supposed to make the overall strategy and these goals visible to their teams so that every worker becomes aware of their contribution to the overall goal and vision of the organization (Dombrowski & Mielke, 2013).

Some of the presented leadership styles and practices have been studied empirically lately. Tortorella and Fogliatto (2017) tested Hersey and Blanchard's (1969) model in the context of lean implementation and confirmed the original theory that there is no single best leadership style but that it rather depends on various factors, such as the degree of lean implementation and hierarchical level of the leader. Bass and Avolio's (1997) model was as well studied in the lean context and, again, did not yield a single most effective leadership style but rather advocated the coexistence of leadership styles (Nogueira et al., 2018). Similarly, Camuffo &

Gerli (2018) studied different management behaviors and found a certain set to be effective but concluded that in a different setting a different set of behaviors might be effective.

The results show that whether or not a certain leadership style or practice works well depends on various contingencies. The introduced lean leadership practices count as best practices, but they do not necessarily apply to all organizations in all situations. Organizations differ, among others, in their culture, how they create value and the extent to which they follow the ideas of lean. In addition to that, managers differ in their personality and hierarchical level, among others. All these factors can influence the effectiveness of a leader's behavior. Concluding, many open questions remain with regards to how and under which conditions leaders' behaviors influence the effectiveness of lean programs. It has therefore been the main part of this dissertation to study such questions.

1.3. Research Methodology

Within the scope of this dissertation, two distinct research methodologies have been employed. Since the first research question has set out to review the lean literature – a field that has been reviewed more than one hundred times – bibliometric methods as a less conventional literature review approach were chosen. Thanks to their power of processing large quantities of data, a review of the full lean literature from 1988 until 2021 has been conducted to draw a picture of the lean research landscape and make predictions about its future.

Besides the lean literature as a unit of analysis, this dissertation also focused on manufacturing organizations that implement lean. As one goal of this doctoral study was to conduct relevant research and produce insights that would be helpful to companies, an empirical approach was selected for the two other studies of this dissertation (Meredith et al., 1989). Choosing an 'empirical' approach meant that the studies were based on real-world observations. Specifically, a systematic, multi-step methodology for empirical research based on Flynn (1990) was followed (see Figure 4).

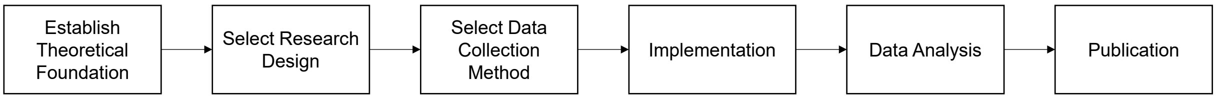

Figure 4 – Research Methodology for Empirical Research Based on Flynn (1990)

According to Edmondson and Mcmanus' (2007) model of methodological fit in management research, more nascent research fields require qualitative methods while more mature fields ask for quantitative methods. Mature research tends to elaborate, clarify, or challenge existing theories and therefore relies on existing concepts and measurements. Similarly, lean research has existed already for more than 30 years now, during which a wide range of concepts, models, and propositions have been already developed. Put simply, research questions have also moved from understanding what lean is to where and under which contingencies it is effective, which is why it can be classified as mature research.

Consequently, confirmatory survey research, a quantitative approach, has been selected as the research design (Forza, 2002). Survey research collects structured and standardized information from a sample by asking people who, as a sample, need to be able to generalize the findings. Confirmatory research, also known as explanatory research, seeks to find causal relationships between variables that are based on expectations from existing theory (Malhotra & Grover, 1998). As concerns the method of data collection, questionnaires were used in both studies to collect cross-sectional data in the process industries. However, each study used a different sample, thus a different dataset. To test hypotheses and convert these data into knowledge that might support organizations in their decision-making, each study uses a certain set of statistical analysis techniques (Hair et al., 2006).

In the following subchapters, the single methods that were applied in the three studies will be explained briefly. Subchapter 1.3.4 discusses the methodological limitations of each study. A full account of the followed methodology is presented in the respective methods sections of each article in the following main chapters.

1.3.1. Research Approach in "Bibliometric Review" (Chapter 2)

The first study was a literature review and since the lean literature is already oversaturated with systematic literature reviews, another one would have made only a small contribution to the field. Further, one major drawback of classic systematic literature reviews is that they are limited in their ability to process large quantities of data. Instead, a bibliometric study was conducted, which allowed following the ambitious goal of conducting the most comprehensive lean literature ever. This study was done in collaboration with my supervisor, Torbjørn Netland, and two additional co-authors, Rachna Shah (University of Minnesota) and Alan Pilkington (University of Westminster).

Bibliometric studies analyze bibliometric data of the literature, such as author names, publication years, or references. Therefore, a bibliometric dataset had to be created first. This was done by defining a set of the 40 most popular keyword combinations related to lean (e.g., lean production, lean practice, lean start-up) and searching the Web of Science for relevant articles. In the end, the main dataset of 5,638 lean articles, covering almost all lean articles published in academic journals from 1988 until 2021, and a second dataset of 131,967 unique references within the main dataset were compiled.

Next, the bibliometric datasets were analyzed using citation and co-citation analysis, on document level. The former is based on the premise that highly cited literature is likely to have had more influence on the subject than literature less frequently referenced (Culnan, 1986; Sharplin & Mabry, 1985), and is hence representative of the activity or importance to the field. Bearing in mind that it represents "the field's view of itself" (White & Griffith, 1981, p. 163), citation analysis can provide useful insights into which contributions in the field of lean are considered influential.

Since citation analyses do not capture the structure of influence within a field (Leong, 1989), we also employ a document co-citation analysis. Co-citation analysis is based on the distribution frequencies obtained from counting the number of articles or books that list the same pair of documents in their references. Due to this, it allows to identify the relationships among documents, evaluate their strengths, and illustrate structural groupings within the co-citation network (White, 1990).

We supplemented the citation and co-citation analyses with two further methods. Citation analysis only measures the absolute influence of documents on the field but does not gauge their relative impact. A citation burst analysis was therefore conducted to identify changes in citations of a certain article relative to the rest of the articles within a specific period of time (Cobo et al., 2011), which allowed the detection of trends and the density of impact over time.

Finally, we searched the dataset for certain keywords (e.g., leadership, sustainability, SCM) and domains, i.e. manufacturing, construction, and healthcare, and plotted them on two growth-share matrices, similar to the "BCG-Matrix" (Henderson, 1970). This overview allowed a more precise classification of certain literature streams into their maturity stages and further predictions about their future growth.

1.3.2. Research Approach in "Management Practices" (Chapter 3)

The second study was concerned with the influence managerial practices have on the effectiveness of lean programs. There have already been several studies that analyzed the impact of managerial behavior on the success of lean (see Ch. 1.2.3), but so far, no empirical study has quantitatively studied managerial practices as moderators of the relationship between hard lean practices and operational performance. Most studies analyzed the direct effects of managerial behavior. A moderation effect exists when the effect of a certain independent variable on another dependent variable depends upon the level of a moderating variable. Much of the lean literature stated that the application of hard lean practices alone would not guarantee success (Emiliani & Stec, 2005; Sadun et al., 2017), but it also depends on managerial support and commitment (Achanga et al., 2006; Netland, 2016). That has motivated us to conduct this study. It was done in collaboration with my supervisor, Torbjørn Netland, and with Julian Macuvele (University of St. Gallen) and Thomas Friedli (University of St. Gallen).

The data collection was part of the OPEX benchmarking study done by the Institute of Technology Management at the University of St.Gallen (ITEM-HSG), the institute in collaboration with which the study was conducted, and the Transfer Center for Technology Management at the University of St Gallen (TECTEM) (www.tectem.ch). Their continuous benchmarking project studies the implementation of lean principles in the pharmaceutical industry and provides the participating companies an opportunity to position themselves against a wide range of other pharmaceutical manufacturing companies and identify the potential for further improvement. At the same time, the dataset, consisting of detailed survey data from more than 350 manufacturing sites, provides a unique research opportunity. The questionnaire consists of three sections. Whereas the first covers descriptive data of the manufacturing site, the second asks for operational performance. The third section collects data on different managerial practices including lean implementation levels.

Since the study aimed at testing the relationships between several well-defined variables, an explanatory research design was followed. The data were analyzed using factor analysis, correlation analysis, and regression analysis. To create scales for our latent variables and ensure their one-dimensionality, we conducted a PCA and a CFA. Then, we conducted a correlation analysis to better understand the interrelations between individual social lean constructs. Finally, a linear hierarchical regression analysis was conducted to establish the relationships between the independent variables, moderating variables, and the dependent variable. Additionally, we controlled for plant size and plant type.

1.3.3. Research Approach in "Perceptions and Behaviors" (Chapter 4)

The third study aimed at understanding how managerial levels differ in their influence on the success of lean programs. Specifically, this study set out to analyze the perceptions and behaviors of top and middle managers and how they affect lean implementation. To achieve this aim, a research collaboration with a global manufacturer in the process industry has been established. Before the collaboration, the industrial partner has already been implementing a global lean program in its nearly 40 globally dispersed factories over a few years. This study was co-authored with my supervisor, Torbjørn Netland, and Andrea Furlan (University of Padova).

As regards the collection of data, we administered a survey in the firm asking about the current level of implementation of lean program practices, in 2017, and two years ago, in 2015, as well as about the use of specific management practices to support the implementation and the perceived effectiveness of the lean program on various operational performance dimensions. We used close-ended questions on a 5-point Likert scale to operationalize the use of managerial practices (from *1 = never*, to *5 = very frequently*), the implementation level of operational practices, and the perceived effectiveness of the program (from *1 = low*, to *5 = high*). We obtained 280 responses (an average of 8 respondents per plant), whereby the respondents were represented, among others, by production supervisors, quality managers, warehouse managers, as well as top management, such as plant managers.

Based on the nature of our research question, an explanatory approach was chosen to determine the relationships between the variables of interest. Therefore, we first ran a hierarchical linear model to determine whether managers from different hierarchical levels perceive the effectiveness differently. We then developed a theoretical model that explained how the perception of different managers relates to their behavior, and how their behavior, in turn, affects the degree of lean implementation. We tested the model by running a structural equation model (SEM) with maximum likelihood estimation. To ensure item reliability, internal consistency, and convergent validity of our measurement model as well as good model fit of our SEM, we calculated commonly used measures of fit and compared them to the accepted thresholds within the field of social sciences and operations management literature.

1.3.4. Methodological Limitations

Despite their suitability and advantages, the methodologies and methods employed in the studies presented in this dissertation also come along with certain limitations. The most important ones are addressed in the table below. In addition to that, the chapters of each study address their respective limitations in further detail.

Table 4 – Overview of Methodological Limitations

Limitation	Explanation	Applies to Ch. 2	3	4
1. Depth vs. breadth	The strength of bibliometric methods to process large quantities of data comes at the cost of limited possibilities to analyze the data qualitatively. While classic systematic literature reviews study only a few articles in depth, our bibliometric review analyzes high numbers of lean articles on a more superficial level, which makes it more difficult to produce in-depth insights. Similarly, the two other, empirical studies use quantitative methods to make statistical inferences from a sampled population. The high number of observations in each study, which supported the generalizability of the results, had to be traded off against the possibility of studying each case in depth though.	X	X	X
2. Subjective interpretation	The interpretation of bibliometric data and their results are to some extent dependent on the subjectivity of the investigator (Ramos-Rodríguez & Ruíz-Navarro, 2004). For example, an increase in the numbers of publications is despite wide acceptance not an objective measure for scientific growth. On the one hand, it is unclear whether an "increase in numbers" actually relates to an increase in actionable knowledge (Bornmann & Mutz, 2015). On the other hand, publication numbers, as well as publication and citation styles, have changed throughout history (De Bellis, 2009).	X	-	-
3. Correlation vs. causation	The demonstration of causality is not a statistical problem but should be rather built on qualitative research and logical reasoning. Regression analyses allow identifying relationships between variables while controlling for effects of other variables but the possibility of a third, unmeasured variable (confounding variable) affecting the two seemingly related variables will always remain. Thus, one limitation of the two empirical studies is that they are correlational and make no causal inferences	-	X	X
4. External validity	Sampling from a single firm or the same industry, as is the case in two studies in this dissertation, has certain advantages like implicitly controlling for organizational culture or industry effects but they come at the expense of limited external validity, which makes generalization of the results more difficult.	-	X	X
5. Cross-sectional data	Cross-sectional research designs, in which information is collected at a given point in time, lack a temporal dimension. Therefore, they are less appropriate to study phenomena that change over time, such as the implementation of lean programs (Malhotra & Grover, 1998). However, longitudinal studies remain difficult to establish due to the significantly higher research efforts, so cross-sectional studies remain a standard to study phenomena like lean programs.	-	X	X
6. Perceptual measures	Perceptual measures, like the perceived performance effect of lean programs, rely on the subjectivity of the respondent. As opposed to objective performance measures, like on-time delivery, RFT, or the productivity of manufacturing equipment, they are much more prone to inaccuracy. As a countermeasure, we ran a hierarchical linear model to at least group answers from the same plants and control for regional aspects.	-	-	X

1.4. Overview of Results

This chapter aims at summarizing the main findings presented in the individual studies of this dissertation. For the sake of brevity, the results are presented in a condensed manner and can be found in more detail in the respective chapters of each study.

1.4.1. Results of "Bibliometric Review" (Chapter 2)

The study in Chapter 2 aims to review the full body of academic lean literature. Conventional, qualitative review methods are limited in their scope, which is why a bibliometric approach was chosen for this study. Accordingly, a bibliometric dataset was compiled from the WoS database consisting of 5,638 unique lean articles and 131,967 unique references. The data were analyzed employing various frequency, citation, and co-citation analyses (see Figure 5 for an overview of the general growth of the lean literature). The results included an overview of the most influential lean articles, a co-citation map drawing a comprehensive picture of the lean research landscape, a list of keyword bursts indicating current trends in the lean literature, and a 2x2 matrix that also identifies conceptual trends in the lean literature.

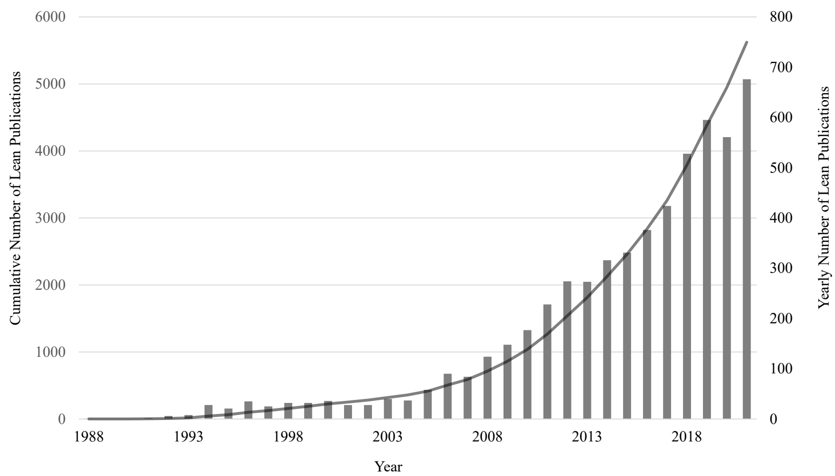

Figure 5 – Publication Numbers of Lean Articles, as Presented in Chapter 2

The co-citation map is the result of a network analysis that identifies the most significant co-citation relationships among lean researchers and plots them as clusters onto a map. Depending on the size of the network and the number of clusters (i.e., knowledge groups), the network analysis calculates a multi-dimensional system of factors, which then usually needs to be scaled down onto a two-dimensional Euclidean space. Therefore, some clusters might overlap slightly but, for the sake of better visibility, are highlighted with circles on the map (see Figure 6). We identified four knowledge groups that represent individual domains of lean research: lean production, lean healthcare, lean start-up, and lean construction. In addition to that, supplementary knowledge groups can be identified in the lean literature, related to the management of quality, performance, supply chains, and sustainability.

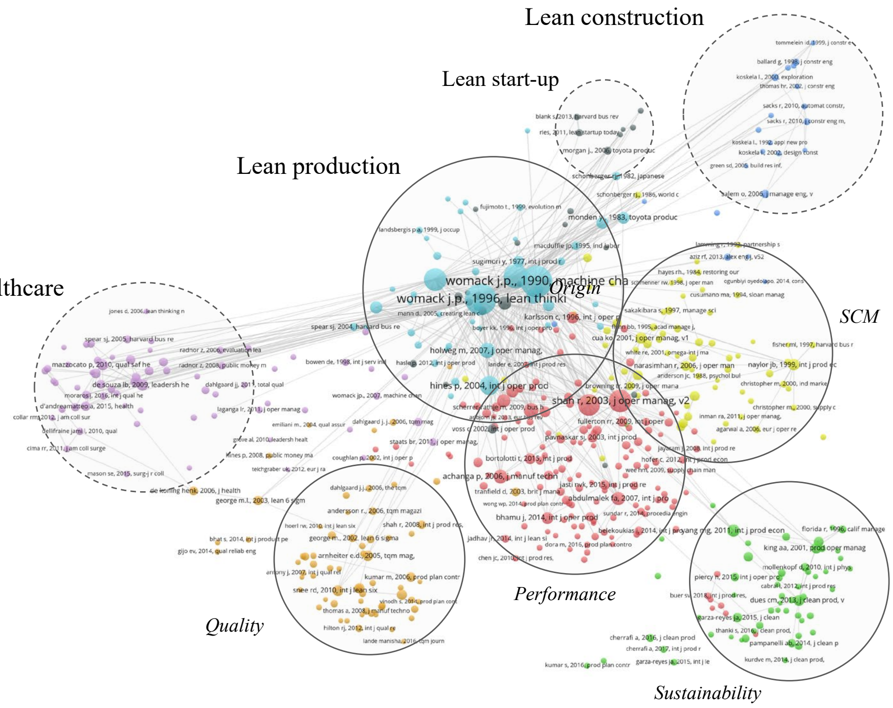

Figure 6 – Bibliometric Map of Lean Literature, as Presented in Chapter 2

Then, we used Kleinberg's (2002) burst detection algorithm to identify the most active areas of past and present lean research. Put simply, the algorithm detects citations, or in our case keywords, that received an extraordinary degree of attention from their scientific community. The results indicate that several keywords have emerged as "hot topics" in the lean literature: sustainability/green, critical success factors/barrier, operational performance, and industry 4.0.

Table 5 – Keyword Burst Results, as Presented in Chapter 2

Keyword	Burst Strength	First appear.	Burst Begin	Burst End	1988-2020
lean production	27.47	1988	1994	2010	
just in time	4.03	1991	1998	2009	
supply chain management	3.95	1993	2004	2007	
agile	3.78	1997	2005	2012	
six sigma	3.74	1995	2016	2017	
sustainability	3.9	1994	2016	2020	
critical success factor	5.47	2012	2015	2020	
operational performance	4.57	2001	2015	2020	
green	5.99	1994	2017	2020	
barrier	4.33	2006	2018	2020	
industry 4.0	3.91	2015	2018	2020	

Lastly, we analyzed the three main research contexts, lean manufacturing, lean construction, and lean healthcare as well as 21 keywords by plotting them on two separate growth-share matrices. The research contexts were mapped by separating each one of them into four periods and tracing how they developed in terms of growth and share. Notably, all three contexts showed a similar clockwise pattern, indicating a natural maturing behavior of single streams of literature. While lean manufacturing seems to have reached a saturated state of research with declining share, lean construction and lean healthcare seem to be reaching a highly mature level soon as well, as they have stopped growing in terms of literature share as well. By plotting the keywords, we were also able to detect current and potential future trends. Among the fast-growing parts of the lean literature, we found *sustainability* and *industry 4.0* to have already accumulated large numbers of articles, whereas *leadership* and *start-up* were still considered small, indicating the potential for more research in the future.

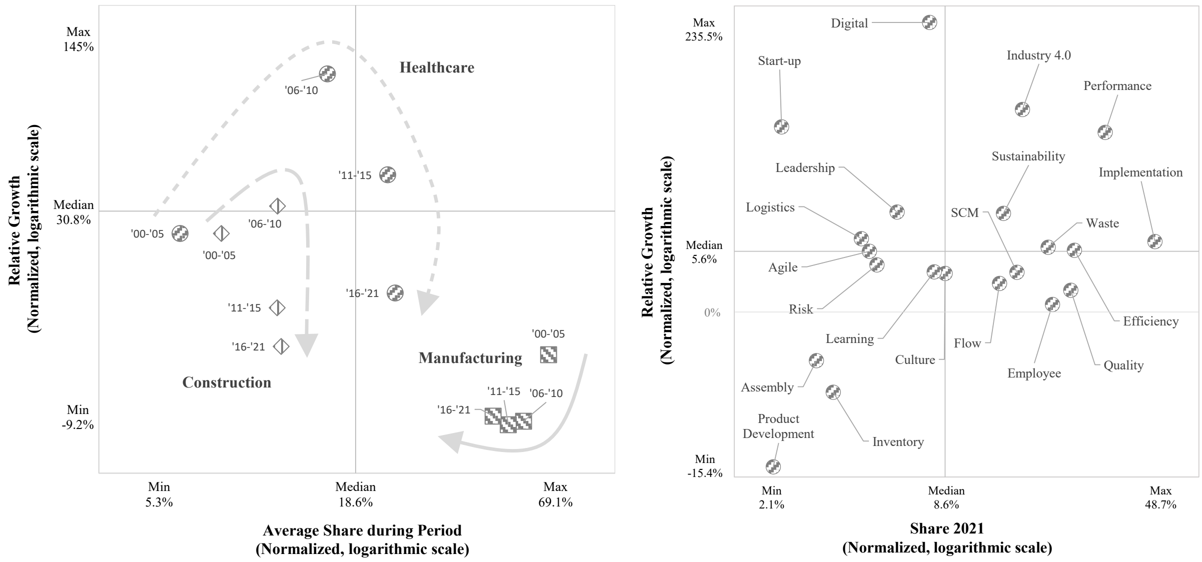

Figure 7 – Growth-Share Matrices, as Presented in Chapter 2

1.4.2. Results of "Management Practices" (Chapter 3)

The study presented in Chapter 3 studied the moderation effects that soft lean practices (e.g., training or employee empowerment) have on the relationship between hard lean practices (e.g., 5S or pull production) and the operational performance of manufacturing firms. A moderation effect, also known as interaction effect, exists when the relationship between two variables depends on another, third variable (Hair et al., 2006).

Several studies have shown that the implementation of lean practices positively affects firm performance (Bloom et al., 2019; Netland et al., 2015; Pil & Macduffie, 1996; Shah & Ward, 2003), but there are also reports of no effects on performance or even negative ones (Negrão et al., 2017; Pay, 2008; Sadun et al., 2017). It, therefore, seems that the lean-performance relationship depends on other variables. Regarding the literature on critical success factors of lean implementation, the involvement and commitment of managers take on a central role (Achanga et al., 2006; Netland, 2016). Thus, it was surprising to us to find no empirical study investigating managerial behaviors or so-called soft lean practices as moderators of the lean-performance link.

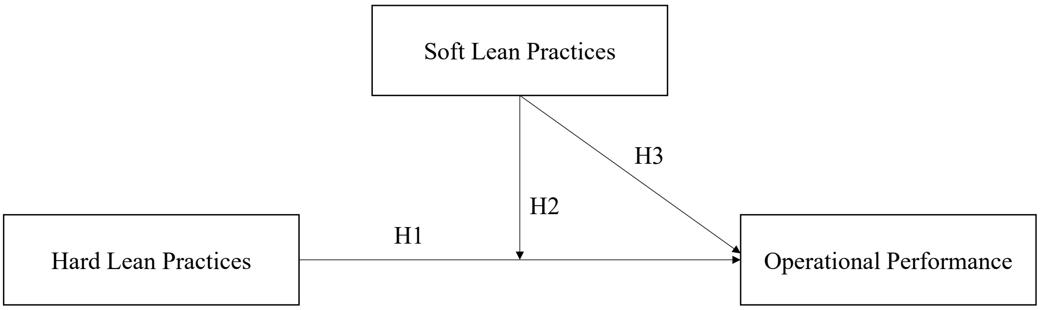

Figure 8 – Conceptual Framework, as Presented in Chapter 3

To fill this research gap, we used survey data collected from 351 manufacturing sites in the pharmaceutical industry (see Table 6). To ensure one-dimensionality of the six individual soft lean practices, which consisted of different items, we performed CFA and obtained factor loadings well above 0.5 with just one exception at 0.42. Results of the $\chi 2$ test, CFI, and RMSEA indicated a good model fit as well. For the hard lean practice construct, we performed PCA and formed a one-factor variable using 11 single items based on TPM, TQM, and JIT concepts.

Table 6 – Sample Composition of Responses (n=351), as Presented in Chapter 3

Region	Europe	274	78%	Plant type	Brand manufacturer	152	43%
	North America	39	11%		Generics manufacturer	92	26%
	South/Mid America	10	3%		Contract manufacturer	107	31%
	Asia	7	2%	Plant size	Small (<100 Employees)	69	20%
	Africa	21	6%		Medium (100-500 Employees)	216	64%
					Large (>500 Employees)	54	16%

The results of our correlation analysis showed that soft lean practices were significantly correlated ($p < 0.01$), which is similar to the findings of Nielsen et al. (2018). The positive correlation coefficients indicated that the implementation of one construct goes hand-in-hand with the implementation of the other ones.

Next, we calculated a hierarchical set of ordinary least square linear regression models to test our hypotheses. In these models, we tested the direct effects of a few control variables as well as soft and hard lean practices on operational performance. In addition, we included interaction terms between each soft lean practice and the hard practice construct in the model. The contextual factors plant size and plant type accounted for a significant but small amount of variance (adjusted $R^2 = 0.038$, $P < 0.001$). The inclusion of hard and soft lean practices increased the R^2 to 0.162. The subsequent addition of interaction terms further increased the explained variance to 23.1%.

The results of our regression analysis confirm our first hypotheses by showing a positive, significant effect of hard lean practices on operational performance. Notably, soft lean practices did not show any statistically significant direct effects on performance. The second hypothesis could only be partially confirmed since only half of the interaction terms showed a statistically significant relationship to operational performance. *Visualization*, *performance measurement*, and *employee empowerment* were found to positively moderate the relationship between technical-lean practice implementation and operational performance. In contrast, the interaction effects of *work standardization* and *goal setting* had a statistically significant negative effect. *Training* did not show a significant interaction with the hard lean practices. The third hypothesis was rejected, as soft lean practices did not affect performance directly.

1.4.3. Results of "Perceptions and Behaviors" (Chapter 4)

After the second study has established the effects certain management practices can have on lean implementation, the third study distinguishes between the influence of managers from different hierarchical levels and takes their perception into consideration. Specifically, it questions whether top managers perceive the effectiveness of lean programs differently compared to middle managers. Further, the study analyzes how the perceptions of top and middle managers are reflected in individual and organizational behavior, and how that in turn affects the implementation of lean (see Figure 9).

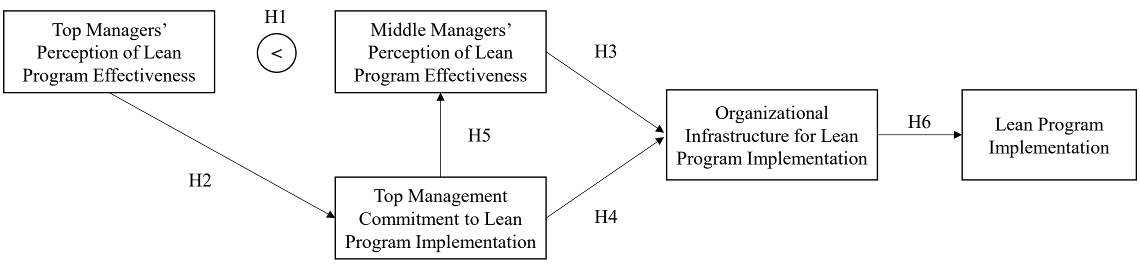

Figure 9 – Theoretical Model, as Presented in Chapter 4

First, a survey was conducted in the global production network of a manufacturing company from the process industries to collect empirical data from managers involved in the implementation of a lean program. Based on our observed items, we defined the five latent constructs of our theoretical model and tested them with a CFA, finding that all measurement items had statistically significant factor loadings ($p<0.001$) indicating good item reliability. The tests of internal consistency and convergent validity also passed the expected criteria. Then, we conducted a hierarchical linear regression model to test whether there are differences between top managers and middle managers in their perception of lean program effectiveness on operational performance and found that middle managers perceived lean programs to be more effective than top managers did, at a statistically significant level ($p<0.01$).

Table 7 – Hierarchical Linear Model, as Presented in Chapter 4

	Model 1		Model 2	
	coefficients	**std. error**	**coefficients**	**std.**
(Constant)	-0.475***	0.269	-0.913***	0.321
Plant age	0.0839	0.057	0.08	0.057
Experience	0.0158*	0.008	0.0192**	0.008
Unionization	-0.04	0.133	-0.067	0.132
Top management			reference	
Middle management			0.489**	0.199

Dependent variable: Perceived effect of program implementation on operational performance
** p < 0.05, *** p < 0.01

In the next step, we ran an SEM to test our remaining hypotheses. Considering several fit indices, such as CFI and TLI as well as RMSEA and χ^2, the SEM had a good model fit. Based on the results of the model, we did not find any support for the second hypothesis, top managers' perception influencing top managers' commitment. However, we found support for all other remaining hypotheses. Accordingly, top managers' commitment supports middle managers' perceptions of the program's effectiveness. Together with middle managers' perceptions, it also supports the buildup of organizational infrastructure for lean implementation. Organizational infrastructure, in turn, positively affects the implementation of the lean program. We completed the analysis with a Sobel test and bootstrapping to confirm a mediating effect, namely middle managers' perception mediating top managers' commitment's effect on organizational infrastructure.

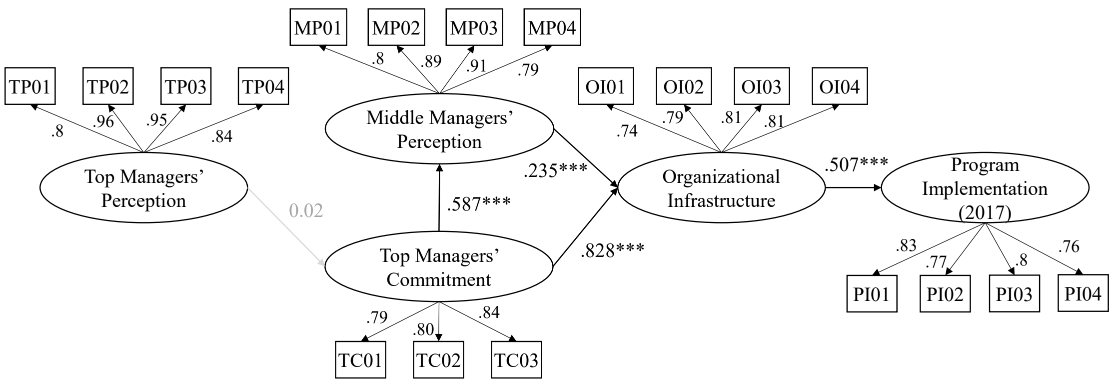

Figure 10 – Structural Equation Model with Parameter Estimates, as Presented in Chapter 4

1.5. Discussion

The purpose of this chapter is to critically reflect and interpret the main findings of this dissertation. As a first step, in Section 1.5.1, the contributions of the three single studies will therefore be discussed from a scientific perspective. To demonstrate their significance and put them into greater context, the implications of this dissertation for scholars and practitioners will be then discussed in Section 1.5.2 and in Section 1.5.3 respectively. For the sake of brevity, the discussion in this chapter is kept concise. Extensive discussions of the findings can instead be found in the respective chapters of the single studies.

1.5.1. Scientific Contributions

The following table provides an overview of the key scientific contributions made by this dissertation. Due to its different nature in research design and scope, the contributions made by the bibliometric review contrast with the contributions from the two empirical studies.

Table 8 – Overview of the Key Scientific Contributions

Contribution	Chapter		
	2	3	4
1. Proposition of possible future research avenues for lean researchers	X	X	X
2. Extensive review of more than 30 years of lean literature	X	-	-
3. Maturity assessment of different research contexts and concepts in the lean literature	X	-	-
4. Identification of current trends in the lean literature	X	-	-
5. Conceptualization of new research measurements of managerial behavior	-	X	X
6. Enhancement of the understanding of how managerial behaviors influence lean programs	-	X	X
7. Analysis of managerial behaviors' moderation effect in the lean-performance relationship	-	X	-
8. Conceptualization of a new measurement of a lean-supportive org. infrastructure	-	-	X
9. Analysis of perception and behavior of managers from different hierarchical levels	-	-	X

Discussion of the first study ("Bibliometric Review")

A few indicators sparked the idea of a possible existential crisis of the lean concept. Technological advancements within the fourth industrial revolution fueled the discussion around lean's *raison d'être* in an increasingly digital era (Mrugalska & Wyrwicka, 2017). In addition, publication numbers declined in 2020 for the first time after a long period of consistent increases (see Chapter 2.5.1). In the same year, a series of publications in the *Journal of Operations Management* has started to question the definition and future of lean (Browning &

Treville, 2021; Cusumano et al., 2021; Hopp & Spearman, 2020), without finding any consensus.

Considering the above, a review of the full body of lean literature and the search for future research opportunities were found to be worthwhile endeavors. While the bibliometric review was being carried out, lean publication numbers reached a record-breaking 676 articles in 2021, and, on top of that, the results of the study highlighted several promising perspectives for future lean research, including the study of human behaviors, lean's potential to support sustainability, and lean's role in digital production systems.

Concluding, it is fairly safe to say that the lean literature has not reached saturation yet and is likely to continue thriving as a field of research. The main reason for that is lean's multi-layered structure as a concept (see Figure 11). It includes specific, adjustable organizational practices (e.g., 5S), which are built on more rigid principles (e.g., pull production) and fundamental philosophies (e.g., continuous improvements). Whereas certain practices might become obsolete over time, new practices will evolve based on the fundamental ideas of lean management. Lean's resulting ability to adjust to changing environmental conditions is also why it has been characterized as an evolving business phenomenon (see Chapter 2.3.1).

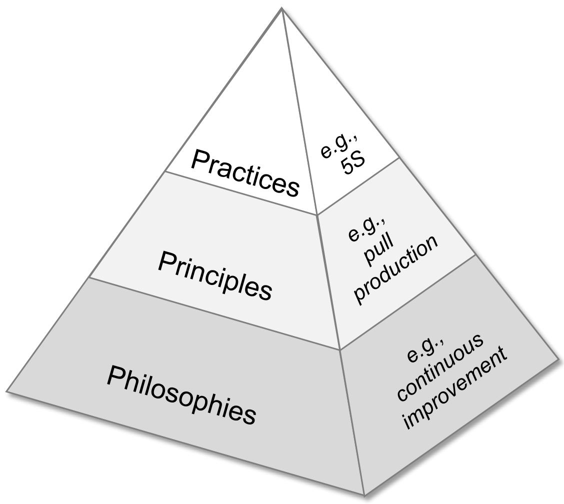

Figure 11 – Multi-layered Structure of the Lean Concept

From a methodological perspective, bibliometric data were considered a rich source of information with great potential for analysis using modern computational tools. Today's databases offer a wide range of variables for each bibliometric entry, which can be exported relatively easily and analyzed in many ways. After just a few steps, researchers are able to generate a comprehensive overview of a certain field of research and learn more about its structure and ongoing trends. Especially, young researchers who aspire to delve into new topics are encouraged to use bibliometric methods as a starting point for their research. This bibliometric study can serve as an example, which young scholars can follow in a modular way.

Discussion of the second study ("Managerial Behaviors")

The second study analyzed the influence of managers on the success of lean programs. One major contribution to the lean literature was the novelty of conceptualizing soft lean practices as a moderator of the relationship between hard lean practices and operational performance, which, to the best of the authors' knowledge, has not been done in any empirical study before. True to the study's title, this conceptualization created a new perspective on the role of managers in lean implementation, which is well-captured by the word 'moderator'. As moderators, managers need to control the behavior of the organization and steer the development of the lean program in the right direction.

The results of the analysis were another significant contribution. Notably, the soft lean practices did not show any direct effect on the operational performance. Only in combination with the hard lean practices, they unleashed significant effects as moderators of the relationship between hard lean practices and operational performance. Given lean's definition as a socio-technical system (Shah & Ward, 2007), this is an interesting finding, which shows that both, the social and technical systems depend on each other.

In addition, the finding that certain managerial practices negatively moderated the lean-performance relationship, namely goal setting, and work standardization, enhanced the understanding of managerial behaviors' influence on lean programs. Managerial involvement in lean programs has usually been presented as a critical success factor (Achanga et al., 2006; Netland, 2016), but this study points to potential negative effects of managerial practices, which signals the need for further investigation. Future researchers are encouraged to continue the study of managerial behaviors as moderators of the lean-performance relationship and explore under which circumstances they could even negatively impact lean program implementation.

Discussion of the third study ("Managerial Perceptions")

Despite their different roles, tasks, and responsibilities (Netland et al., 2019), most empirical studies that investigated managerial behaviors have, so far, not distinguished between different types of managers (see Chapter 1.2.3 for more information). The separation of top management behaviors from other organizational behaviors is therefore an important contribution made by the third study, as it sharpens the understanding of how different groups of people in an organization should behave to effectively implement a lean program. It is a common phenomenon that research topics become increasingly specific as they mature (Edmondson & Mcmanus, 2007), which is why future lean studies are encouraged to follow this line.

As cognitive aspects are increasingly finding their way into the OM literature (e.g., Arellano et al., 2021; van Dun & Wilderom, 2021), another contribution of the third study is the linkage of perceptual and behavioral data. The results showed: To what extent the organization supports the lean program depends on what middle managers think about it, and what middle managers think about the lean program depends on the behavior of top managers. The finding of such interrelationships demonstrates the prevalent complexity in organizations aspiring to implement lean.

Somewhat counterintuitive was the finding that top managers' perception of the lean program did not affect their commitment to it. The decoupling of their behavior from their perceptions might stem from the fact that top managers are exposed to political forces within and outside the organization. Their actions might be more strongly influenced by what other stakeholders expect than by their own opinions. To better understand top managers' motivations and how they relate to their behavior, more in-depth studies would be needed.

1.5.2. Implications for Scholars

Several practical implications can be derived from this dissertation. Due to the different nature of the conducted studies, the implications from the bibliometric review (Chapter 2), which are predominantly relevant for lean scholars, will be presented in this subchapter and the implications from the two other studies (Chapters 3 and 4), which are predominantly relevant for lean practitioners, will be presented in the following subchapter.

Table 9 – Overview of Implications for Scholars

Implication	**Chapter**		
	2	**3**	**4**
1. Lean researchers should be aware of lean's evolutionary character	X	-	-
2. Lean researchers should specify what they mean by the term 'lean'	X	-	-
3. Lean researchers should operationalize lean depending on their setting	X	-	-
4. *Digitization*, *sustainability*, and *human behaviors* are promising avenues for future lean studies	X	-	-

One of the main implications of the bibliometric review is the awareness lean researchers should have about lean's evolutionary character. As we demonstrate and theoretically explain, lean can be viewed as an evolving business phenomenon that has not remained the same since its inception. As environmental conditions have changed over time, the way how manufacturing companies and other organizations have applied lean has also changed. Referring to the multi-layered structure of the lean concept visualized in Figure 11, the more fundamental, philosophical ideas of lean remained stable and did not change much while more practical elements were rather prone to adjustments, for example, the development of digital Kanban cards as part of increased use of digital technologies. This awareness of lean's evolutionary character shall encourage researchers to take on a more flexible perspective on what characterizes the lean concept and leads to two more specific implications.

One of them is that the lean concept is not set in stone. Researchers should accept the fact that there exists no single, correct definition of lean. This becomes visible in Bhamu and Singh Sangwan's (2014) list of 33 identified lean definitions or the recent series of publications from lean experts in the *Journal of Operations Management* that could not settle on a universal lean definition (Browning & Treville, 2021; Cusumano et al., 2021; Hopp & Spearman, 2020). Over time and across so many different fields of application, the interpretations of lean have varied a lot. The existence of so many different perspectives on lean makes it difficult to grasp research articles that do not present any definition of lean. Therefore, lean researchers are advised to clarify how they understand the lean concept.

Having acknowledged that lean is an evolving phenomenon without a universal definition, lean researchers should also recognize lean's individuality when it comes to operationalizing it. Not only lean scholars but also organizations differ in their ways of interpreting lean. Studying lean should thus come along with individual measurements of lean, depending on the research setting. Netland's (2013) study on company-specific production systems has shown that companies choose individual approaches to improve operations but, overall, they build on similar ideas from the lean concept. Our bibliometric study reinforces this finding, as it demonstrates how lean has entered many different industrial contexts, such as healthcare, construction, or start-ups, in each of which lean is interpreted differently. Despite studying lean in different settings, researchers still tend to use identical ways of measuring lean. Therefore, lean researchers are advised to develop individual operationalizations for measuring lean depending on the studied research context.

As a fourth practical implication for lean scholars, this dissertation presents three topics that lean researchers are suggested to delve into: *Digitization*, *sustainability*, and *human behaviors*. These three fields of lean research appeared as currently active research areas in our keyword burst analysis, which means that they currently attract particular attention from the academic lean community. First, in face of increasingly digital environments, the question arises whether lean will become redundant or gain even more potential for improving manufacturing processes. Lean researchers are particularly encouraged to study the interactions between specific technologies and lean.

Second, due to its power of eliminating waste and saving resources, lean has also gained traction in the research field of sustainability, often also referred to as *lean and green*. Extending research beyond just environmental-friendly production to the so-called triple-bottom-line (economic, environmental, and social aspects), there are plenty of opportunities for lean researchers to contribute to sustainability research. These could be the study of how lean can help sustain labor standards, promote worker satisfaction, or reduce employee turnover.

Third, the study of human behaviors stood out as a lately relevant lean research topic. Given the advent of behavioral operations, the study of individual and organizational behavior, as well as their cognitive underpinnings, are currently trending topics bearing potential for future research. For example, lean scholars could try to answer how managerial or organizational support can foster learning the ideas of lean at the individual or collective level.

1.5.3. Implications for Practitioners

Thanks to the empirical character of this dissertation, it also includes several important practical implications for managers, which, among others, can help implement lean programs. The following table lists the most important ones:

Table 10 – Overview of Implications for Practitioners

Implication	**Chapter**		
	2	**3**	**4**
1. To improve the effectiveness of their lean programs, managers are encouraged to employ supportive management practices (e.g., employee empowerment or visualization)	-	X	-
2. Managers should be aware that employing supposedly supportive management practices, such as work standardization and goal setting, can also harm the effectiveness of lean	-	X	-
3. Top managers alone are not able to implement lean, but they can motivate the support of middle managers and the overall workforce by being committed themselves	-	-	X
4. Top managers tend to underrate the effectiveness of lean programs and should therefore listen more actively to subordinate managers who have a better understanding of the operations on the shop floor	-	-	X
5. Top managers’ skepticism about the effectiveness of lean programs could be overcome by being more frequently present on the shop floor and developing an own understanding of lean’s effect on operational performance	-	-	X

Many lean studies point to the necessity of managers being involved and committed to the implementation of their lean programs. This is also a central statement of this dissertation, as the second study finds supportive management practices, such as visualization or employee empowerment to enhance the effectiveness of lean programs. However, the second study also shows that managers need to be careful when employing certain managerial practices. Our results indicated that managers might misinterpret the purpose of certain lean practices and apply them incorrectly.

For example, standardization was found to negatively influence the effectiveness of lean programs, despite being a commonly applied method in the TPS. How is that possible? Standards usually serve as a platform for improvement. Processes that are not standardized quickly lead to variance and quality deficiencies. By formalizing them and prescribing how they should be done, processes become stable and the number of errors will usually be reduced. Moreover, once processes are standardized, they are easier to understand and can be improved upon more quickly. In order for standards to function this way, employees should be involved in the definition of standards and be allowed a certain degree of flexibility with regard to modifying the standards and organizing their daily work (Liker, 2004). However, if work standardization is applied incorrectly, for example by imposing standards on employees as 'set in stone' and making work highly repetitive, they can limit the room for improvement and quickly become ineffective or even counterproductive.

Another supposedly supportive management practice that we found to be negatively associated with lean's effect on operational performance was goal setting. Similarly to work standardization, this can have positive but also negative effects depending on how it is employed. When applied correctly, goal setting can provide employees with better focus and motivation, as they find a purpose in what they are doing. On the other hand, if goals do not find congruence with employees' skills or vision, they can quickly become demotivating and ineffective (Appelbaum & Hare, 1996). Therefore, managers should be aware of the potential negative effects of supposedly supportive management practices. They are advised to not only copy lean practices but also seek an understanding of the purpose behind each practice.

The third study raises awareness of the socio-technical dynamics in organizations aspiring to implement lean. Top managers alone are not able to implement lean and are depending on the collective support of middle managers and the overall workforce. One way for top managers to activate such organizational efforts is to be committed themselves, as their commitment proved to be an influencing factor on the perceptions of middle managers and the organizational efforts spent on lean implementation. Since the perceptions of middle managers also turned out to be an influencing factor on organizational efforts spent on lean implementation, it is recommended to foster communication, and in doing so, also awareness about employees' thoughts in order to counteract if necessary.

Another relevant finding was that top managers tend to underestimate the effectiveness of lean programs compared to middle managers. One reason for that could be the different nature of top managers' tasks and responsibilities, which usually imply more distance to the Gemba. Middle managers are more frequently exposed to operations on the shop floor and develop a better understanding of how lean influences operational performance. Top managers are therefore advised to listen more actively to subordinate managers in order to avoid misconceptions about their lean programs and develop more confidence in their effectiveness. Another way for top managers to avoid potential skepticism about lean would be to increase their presence on the shop floor, which, among many other benefits, would allow them to develop their own understanding of the relationship between lean implementation and performance improvements.

1.6. References (Chapter 1)

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Chapter 2

2. An Evolutionary Perspective on Lean: A Bibliometric Review

This chapter is based on a revised version of a manuscript submitted to the *Journal of Operations Management* which received the decision “Reject & Resubmit” on 19. March 2021.

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2.1. Abstract

Lean is one of the most pervasive phenomena in operations management practice and literature. It still engages vivid interest and debates more than three decades after its inception. According to business fashion theory, this staying power is surprising. Taking an evolutionary perspective, we study the emergence and growth of lean at the level of the phenomenon. We compile two datasets consisting of 5,638 unique lean articles published since the term's inception (our Primary Lean Dataset) and 131,967 unique references cited in the articles in the Primary Lean Dataset (our Cited Dataset). Using bibliometric techniques, we quantitatively analyze where and how lean spreads across application areas, distill its dominant knowledge groups and derive the current trends in the literature. To the lean literature, our extensive review contributes a data-driven overview of the evolution and state of lean as a phenomenon and its current trends. Theoretically, we contribute an understanding of lean as an evolving business phenomenon, opposing studies that seek to ultimately define lean. We use the insights to discuss challenges and opportunities for future lean research. Importantly, our study at the phenomenological level does not imply that "anything goes" when it comes to operationalizing lean at the level of business implementation in individual studies.

Keywords: Lean; Process Improvement; Literature Review; Bibliometric Analysis; Citation Analysis

2.2. Introduction

Process improvement has been central to operations management since the conception of the discipline. Frederick Winslow Taylor, one of the intellectual founders of operations management, laid the foundation in his book The Principles of Scientific Management (1911). Taylor described a scientific approach to improving processes in a steel manufacturing plant. Since then, many different process improvement concepts have emerged. Among them, one particular concept has acquired a dominant status and is considered the most important process improvement method of the 21st century (Holweg, 2007): "Lean."

Given lean's prominence as a prevailing operations management phenomenon and the sheer number of publications related to it, we were surprised to find that a large-scale and rigorous review of research related to lean is missing from top-tier operations management journals. Therefore, more than three decades after its inception, we believe that it is an appropriate time to assess the lean literature broadly and systematically. Our structured approach results in the most comprehensive and extensive review of the lean literature and provides the most up-to-date knowledge of its current state. We used Web of Science (WoS) to construct two comprehensive datasets: A Primary Lean Dataset (consisting of 5,638 unique lean articles) and a Cited Dataset (composed of 131,967 references that are cited in the Primary Lean Dataset). By choice of method, we necessarily take a helicopter view of lean and study it as a higher-level empirical construct: a phenomenon (cf. Netland's commentaries in Cusumano et al., 2021 and Åhlström et al., 2021).

In describing the current state of lean literature and understanding its influential structural relationships, we use citation analysis and co-citation analysis. These bibliometric techniques refer to statistically analyzing patterns that appear in published documents (Diodato, 1994). Because authors generally cite papers they consider relevant and important, the more frequently cited documents exert greater influence on the development of the topic in a field of study than less often cited ones (Culnan, 1987; Tahai & Meyer, 1999). Citation analysis assesses this relative influence. Co-citation analysis takes a structural approach, as it analyzes which references have been cited by the same article. This way it is possible to identify so-called knowledge groups (i.e., subsets within a certain field of research).

Our first contribution is to retrospectively determine how lean literature has evolved since the term was introduced. While many authors have attempted to summarize the academic literature associated with lean, these studies are relatively narrow in scope and time duration. Even the most extensive literature reviews published in acknowledged academic journals are limited to a few hundred articles (cf. Jasti & Kodali, 2015; Danese et al., 2018; Antony et al., 2020). Armed with the insights of management fashion theory (Abrahamson, 1996), we use our results to understand lean's staying power and evolutionary pattern as a business phenomenon. Based on our large sample, we confirm that lean research has grown exponentially and diversified greatly into other disciplines from its manufacturing roots in Toyota Motor Company. The results provide compelling evidence that lean's popularity has not only endured but also grown significantly—also when compared to the growth of the overall field of operations management. We use rigorous bibliometric techniques and network mapping methods to uncover structural clusters of research topics within the lean literature.

Our second contribution is to identify emerging areas and trends quantitatively, which helps us provide an outlook of where lean research should (re)focus in the future. For this, we use burst detection algorithms that identify articles with sudden surges in citations, thus signaling extraordinary scholarly interest at certain periods. We focus our attention on the most recent bursts, as these most likely represent current and near-future interest areas. We complement the burst analyses with quantitative growth-share matrixes that help identify relative trajectories of trending topics. We use the results to derive a research agenda. Other reviews have also derived research agendas, with some overlap on themes, but none have been able to back it up with data the way we do in this paper.

Our third contribution is to revisit the debate of lean's definitional problem from a phenomenological perspective. Two recent Forum articles (Hopp & Spearman, 2020; Cusumano et al., 2021) and an editorial (Browning & de Treville, 2021) in the *Journal of Operations Management* (JOM) have sparked a revived discussion around the understanding of lean. There is consensus that lean is evolving and spreading, but an unsolved problem is how to meaningfully study phenomena with such elastic characteristics. On the one side, Hopp and Spearman (2020), Browning and de Treville (2021), and Cusumano (in Cusumano et al., 2021) suggest that the lean researchers should agree on common definitions and scales that help clarify the conditions under which lean is a (more or less) appropriate approach. On the other side, the commentaries by Shah and Holweg, the Lean Enterprise Institute (represented by Ward, Shook, Womack, and Howell), and Netland (all in Cusumano et al., 2021) suggest a progressive understanding of lean, where lean has some fundamental and universal characteristics that help it evolve but are continuously adapted to fit a variety of contexts.

We show that lean has outgrown its original definition and cannot be reduced to a set of specific and universally valid practices. Users continuously adapt lean to their specific work-based conditions. In particular, we argue that the lean concept is fluid enough to travel across discipline boundaries, and yet it has retained sufficient preciseness that allows researchers to use it in a specific manner (Osigweh, 1989). Juxtaposing definitions from the most dominant articles in top journals, we propose a hierarchical understanding of lean that spans its philosophy, principles, and practices. As a phenomenon, lean is evolving faster at the level of practices than at the level of philosophy. At the philosophical level, lean is concerned with creating an organizational learning culture that continuously seeks to improve processes and increase customer value. At the principle level, lean's preciseness stems from common grounds in waste reduction, variability reduction, cost reduction, and time compression. At the practice level, lean contains numerous behaviors, methods, and tools that are shape-shifting and continually emerging across contexts, some of which have more staying power than others. We discuss strategies authors can use to increase external validity by accurately defining lean in their studies without compromising construct validity.

The paper is organized as follows. In section 2.3, we provide a brief introduction to the literature concerning lean and the use of literature reviews to inform management debates. Section 2.4 presents a detailed description of the steps we followed in compiling and analyzing the database, as well as the bibliometric tools and the graphing methods. We present our analyses in Section 2.5 and discuss implications for future lean research in Section 2.6. We end with a conclusion in Section 2.7.

2.3. Background

2.3.1. A Neo-Schumpeterian View on the Phenomenon Lean

To ground our study of the progression of lean as a phenomenon we draw on Bodrožić and Adler's (2018) neo-Schumpeterian theory of management model evolution. This theory suggests that management concepts develop into management models and eventually paradigms through four stages: (1) The incubation period, (2) the installation period, (3) the deployment period, and (4) the exhaustion period.

The incubation period for lean goes back to Taylor (1911), at least. However, there is a broad consensus that the most significant episode was the development of the Toyota Production System (TPS)—the manufacturing approach of Toyota Motor Company in Japan—over several decades beginning in the 1940s (Ohno, 1988). Cusumano (1985), Ohno (1988), and Fujimoto (1999), among others, describe in detail the origins of Toyota Motor Company and the numerous tools and practices included under the TPS umbrella. Early academic researchers focused primarily on understanding narrow aspects of TPS, such as just-in-time, kanban, inventory reduction, and quick machine set-ups (for comprehensive reviews of this early academic literature, see Sohal et al., 1989; Waters-Fuller, 1995).

The installation period can be pinned to the publication of Krafcik's (1988) article *Triumph of the Lean Production System*, which coined the term lean. Holweg (2007) summarized this historical lineage and carefully chronicled the critical role MIT's International Motor Vehicle Program and its most famous publication, *The Machine That Changed the World* (hereinafter, *The Machine),* played in conceptualizing and promoting the lean production concept, as well as in disseminating it all across the world (Womack et al., 1990). Although *The Machine* described TPS, it used "lean production" to refer to it. Additionally, because TPS spread outside Japan gradually and in a piecemeal manner, the nuanced differences between its constituent elements and the overarching organizational and manufacturing system were slow to discern and disentangle (Holweg, 2007; Shah & Ward, 2003). Thus, lean first became associated primarily with the tools and practices used by Toyota Motor Company (Pilkington, 1998) and only later with the behavioral and cultural elements supporting TPS (Cusumano et al., 2021; Danese et al., 2018).

In the deployment period, the phenomenon "diffuses beyond the lead industries into older industries" (Bodrožić and Adler, 2018, p. 90). Lean expanded from its origins in automotive manufacturing (Ohno, 1988) to diverse industry settings such as construction (Mostafa et al., 2016), software development (Poppendieck & Poppendieck, 2003), and healthcare (Ranjan et al., 2017), among others. Netland and Powell (2016) provide a detailed account of lean's spread across many industries. And not only across but also within industries, the way how organizations operate has changed significantly during the last few decades while lean has remained a relevant concept for them (Cusumano et al., 2021). Such broad adoption across diverse settings suggests that lean as a phenomenon has *traveled* well. Concept traveling is a desirable property and implies that the concept is precise enough to mean roughly the same thing regardless of the level of abstraction, and yet flexible enough to allow researchers to use it in a wide range of settings (Abbott, 1988; Osigweh, 1989). This preciseness and flexibility may explain lean's universal appeal.

During the deployment phase, researchers moved toward examining the lean phenomenon more broadly while also acknowledging the overlapping use of terms. Numerous articles focused on defining what constitutes lean production, developing measurement instruments to operationalize it, examining its relationship with performance, and identifying contingencies that impact the relationship (Shah & Ward, 2007). Lean's association with superior performance and its ability to provide a competitive advantage is well established (Bloom et al., 2019; Netland & Ferdows, 2016; Pil & Macduffie, 1996; Shah & Ward, 2003). Recently, researchers have in particular sought to identify contingencies both external and internal to the firm that impacts lean implementation and its relationship with performance.

It is too early to say ex-ante whether the lean phenomenon has entered the exhaustion period. According to Bodrožić and Adler (2018, p. 90), phenomena get exhausted when they "can no longer drive productivity or stimulate innovation and growth because the developmental potential of the new technologies [lean] is largely fulfilled, and innovations are increasingly incremental." There are plenty anecdotal predictions that the lean "paradigm" may be coming to an end, and will be replaced by a new technology-driven paradigm—also called the fourth industrial revolution (Schwab, 2016). However, lean has been predicted as outdated before (Cusumano, 1994; Kochan et al., 2018; Moody, 2001), and yet the number of industries, companies, and researchers starting to engage in lean seems only to grow. To understand the current trends, we present the largest review of the lean literature to date.

2.3.2. Role of Literature Reviews in Operations Management Research

Literature reviews allow scholars to assess the state of the art once a research topic or a research discipline has reached a certain degree of maturity (Ramos-Rodríguez & Ruíz-Navarro, 2004). They may also help identify gaps in the current literature because they synthesize existing research and integrate substantive findings of previous research studies (Cooper, 1998). Literature reviews are especially useful at present when scientific output is estimated to be increasing at a rate of 8-9% per year (Bornmann & Mutz, 2015). In recent years, numerous literature reviews have appeared in leading management journals, suggesting that they have gained recognition as making research contributions in their own right. For example, to celebrate its completion of 20 years of publication, *Manufacturing & Service Operations Management* dedicated an entire issue to literature reviews with the expressed objective of reflecting on the past and looking to the future to identify emerging trends (Dai et al., 2020). The reviews ranged from focusing on a specific topic (e.g., inventory and capacity management), a particular industry setting (e.g., healthcare operations), or a specific research method (e.g., business analytics and behavioral operations).

Several authors have summarized the academic literature related to lean. However, almost all of these studies have been limited in scope and narrow in domain coverage. One of the most extensive reviews of lean research is by Danese et al. (2018), who examined 240 articles published from 2003 to 2015 in 25 peer-reviewed journals to identify research gaps and derive several suggestions for future research. Another extensive review has been done by Jasti and Kodali (2015), who included 546 articles published between 1988 to 2011 and provided a comprehensive but rather descriptive overview of lean literature. Other researchers have focused on specific aspects (e.g., implementation) or contexts (healthcare, workplace ergonomics) in their reviews of lean literature (Arezes et al., 2015; Marodin & Saurin, 2013; Poksinska, 2010). It is noteworthy that the most comprehensive reviews we identified cover articles only until 2015. Since then, the lean literature has more than doubled in volume. Furthermore, despite many recent attempts, we could not identify any high-quality review of the lean literature using bibliometric methods. Table 11 compares our review against the most relevant lean literature reviews.

Table 11 – Overview of Comparable and Recent Lean Literature Reviews

	Martinez-Jurado and Moyano-Fuentes (2014)	**Bhamu and Sangwan (2014)**	**Jasti and Kodali (2015)**	**Danese et al. (2018)**	***This Review***
Years covered	1990-2013 24 years	1988-2012 25 years	1988-2011 24 years	2003-2015 12 years	1988-2021 34 years
#Journals covered	N/A	75	24	25	>500
#Articles	58	209	546	240	5638
Review type	Narrative	Narrative	Descriptive	Narrative	Bibliometric
Main contributions	• Identification of critical success factors for economic sustainability and basic principles for lean supply chains • Summary of key contributions in the field of lean and sustainability • Summary of potentials for future research	• Overview of 33 different lean definitions • Characterization of lean studies as confirmatory rather than exploratory • Description of lean studies across various contexts (location, industry, company size, etc.)	• Descriptive representation of the lean literature in terms of studied contexts, lean tools, waste types, and frameworks	• Grouping of lean literature into 4 content clusters • Identification of four main research gaps • Suggestion for future research directions	• The most extensive overview of the lean literature • Identification of lean knowledge clusters • Track evolution of the clusters over time • Identification of trending research topics • A phenomenological analysis of lean • Proposes a solution to the definitional problem of lean • Provision of an up-to-date research agenda
Journal	*Journal of Cleaner Production*	*International Journal of Operations & Production Management*	*International Journal of Production Research*	*International Journal of Management Reviews*	
Citations on Google scholar (02/02/2022)	526	947	528	178	

2.4. Data Collection

Our review focuses on understanding the development, current state, and future direction of lean as a phenomenon. To accomplish our objectives and develop a comprehensive dataset of the lean literature, we adopted the multi-step approach shown in Figure 12.

Step 1. Define Scope

1. Study research on the phenomenon *lean*.
2. Selected academic research articles in *peer reviewed journals*.
3. Selected *all* academic journals (in our analyses differentiating UTD 24, FT 50, and others).
4. Select the *full time horizon* starting 1988 (term "lean" was coined) and ending 2021: 34 years.

Output: Inclusion and exclusion criteria for literature search.

Step 2. Compile the Primary Lean Dataset

1. Generated an extensive list of keywords used in conjunction with "lean" on Google and cross-checked the list with existing literature. Compiled a list of 40 keywords.
2. Searched Web of Science for articles that include any of the 40 keywords in the title, abstract, or the article's listed keywords. Collect bibliometric data for these articles.

Output: 5,638 lean academic articles used to assess *the past, current, and future state of lean*

Step 3. Compile the Cited Dataset

1. Compile the citations from the 5,638 articles in the Primary Lean Dataset.

Output: 131,967 cited articles used to assess *what has influenced the lean literature.*

Step 4. Bibliometric Analysis

1. *Citation analysis*: Identification of influential work
2. *Co-citation analysis*: Identification of knowledge groups through structural relationships
3. *Burst detection:* Identification of prior and currently most active areas of research

Figure 12 – Schematic Representation of the Methodological Steps

2.4.1. Step 1: Define Scope

Over time, publications concerning lean have grown exponentially and appeared in numerous academic and practitioner outlets in various formats. The main outlets include peer-reviewed academic journals (e.g., *JOM, IJOPM*), non-peer-reviewed practitioner outlets (e.g., *Industry Week*, *Planet Lean*), business publications (e.g., *The Economist*), and more recently blogs (e.g., *allaboutlean.com*). Numerous lean publications have also appeared as books directed to academic and industry audiences. Given the variety of outlets, the diversity of formats, and our need for robustness, we restricted our search to published articles in peer-reviewed academic journals because these are tracked in many citation indices (such as Social Science Citation Index), making it possible to access the bibliometric data and assess the articles' influence. We followed established practice and used the Social Science Citations Index through WoS (Meredith & Pilkington, 2018; Nerur et al., 2008; White & McCain, 1998) to access the required information. We also restrict our search to publications in the English language. Thus, our main unit of analysis is a peer-reviewed English-language article on lean, published in an academic journal indexed by WoS.

In considering which journals to select, we faced a significant tradeoff: selecting a broad set of journals might include spurious articles, whereas restricting our list to a narrow set of journals may result in incomplete coverage. We decided to choose a broad set of journals indexed in WoS because it aligns better with our research objective of assessing how lean has dispersed beyond its foundations over time.

To accurately represent the evolution since its inception, our data spans from January 1988 term's origin in Krafcik (1988) to December 2021. Thus, our dataset consists of peer-reviewed journal articles published over 32 years, from 1988 to 2021. To the best of our knowledge, it constitutes the longest time duration for a literature review on the topic.

2.4.2. Step 2: Compile the Primary Lean Dataset

To construct a dataset capable of comprehensively capturing lean, we adopted a keywords approach. Similar to other researchers, we used a Google search to identify the most common lean suffixes. We refined this list using existing research on lean evolution (e.g., Samuel et al., 2015; Netland & Powell, 2016) and our knowledge of the field. This procedure resulted in a list of 40 keywords (see Appendix 1, Table 19), which included many familiar ones such as "lean production" and "lean manufacturing," and other lesser-known ones such as "lean accounting" and "lean journey."We searched WoS for articles containing at least one of these 40 keywords in either the title, abstract, or article keywords. In particular, our results were split across the different citation indices: Science Citation Index Expanded (SCI-E) (39.2%), Social Science Citation Index (SSCI) (32.7%), and Emerging Sources Citation Index (ESCI) (28.1%). We captured bibliometric variables related to the journal (journal name and publication year), article (title and abstract), authors (names, primary affiliation, and country), and all the references cited in an article. Each record was manually examined for correctness and completeness. We removed duplicate records and completed missing information.[1] This process resulted in a dataset of 5,638 unique articles, all in one standard format. We label the collected data the "Primary Lean Dataset" and use it in the rest of this article.

[1] The compilation of our first dataset also provided interesting insights into the relative occurrence of the keywords. The first three keywords (lean+ manufacturing, production, and six sigma) together account for over 50% of the total unique articles, and the first 17 keywords account for over 90% of the total unique articles. In contrast, the last ten keywords account for not even 2%, suggesting a long tail in the distribution.

2.4.3. Step 3: Compile the Cited Dataset

To understand which literature has served as the source of influence to lean literature, we also downloaded all the references included in the 5,638 articles. The references primarily comprise journal publications, but they also contain books, practitioner articles, and other types of publications. Using WoS as our source ensured that the records were correct, complete, and followed a standard format. This dataset consists of 131,967 unique documents cited by the 5,638 articles in the Primary Lean Dataset. We refer to this second set of publications as the "Cited Dataset." It represents literature that has influenced lean research.

2.4.4. Step 4: Bibliometric Analysis

Bibliometrics, sometimes called scientometrics, is the quantitative analysis of books, articles, and other publications. It is an established way to uncover "invisible colleges" or "schools of research" that do not necessarily share organizational links but relate to each other contextually (Garfield, 1979; H. G. Small, 1978) and show the inherent structure of a research domain and its evolution over time (H. Small, 1980). Bibliometrics falls into two categories depending on whether the output is activity indicators such as counts or relationship indicators such as networks (Ramos-Rodríguez & Ruíz-Navarro, 2004). We employ both approaches in this study.

Citation and Co-Citation Analysis

Citation analysis is based on the premise that highly cited documents have more influence than those referenced less frequently (Culnan, 1986; Sharplin & Mabry, 1985). It is a way to identify the "field's view of itself" (White & Griffith, 1981, p. 163). In our context, citation analysis helps identify the most influential lean publications. However, because citation analysis does not capture the inter-relational structure within a field (Leong, 1989), it is often used in conjunction with other approaches, such as co-citation and co-occurrence analysis. We employ co-citation analysis and map the set of the most cited articles into a network by using the VOS mapping technique, described in more detail below.

There are many ways to analyze bibliometric networks. Two of the most popular among them are *graph-based* and *distance-based* approaches. In the graph-based approach, edges indicate the relatedness between nodes, but the distance between the nodes does not explicitly indicate closeness. The graph-based approach is frequently used for smaller networks. In the distance-based approach, the distance between nodes is a measure of closeness between nodes (van Eck & Waltman, 2010). We use the distance-based approach in this paper because it provides a more accurate representation of the inter-relational structure and can accommodate more extensive networks.

Two frequently used distance-based methods are multidimensional scaling (MDS) and visualization of similarities (VOS). MDS has been used in many previous bibliometric studies (Hoffman & Holbrook, 1993; Ramos-Rodríguez & Ruíz-Navarro, 2004; White & McCain, 1998). However, recent researchers have noted that MDS does not distinguish the absolute distances between nodes. Moreover, it tends to create circular maps by locating essential items in the middle of the maps. VOS overcomes these limitations (van Eck & Waltman, 2010). In VOS, nodes are positioned in a low-dimensional space so that the distances between them reflect their total relatedness resulting in a more accurate representation of the whole network compared to MDS where spacing is only relative to the immediate neighbors (van Eck & Waltman, 2010). VOS generates better results than MDS and has been used by many researchers to conduct bibliometric analysis to map publications and identify research gaps (Ikeziri et al., 2018; Leydesdorff et al., 2017; Xu et al., 2019). For instance, Ikeziri et al. (2018) used it to conduct a historical review of the Theory of Constraints and propose a future research agenda. In this paper, we use VOS to conduct network analysis with the open-source program VOSviewer (van Eck & Waltman, 2010).

Steps followed during VOS

The first step of the VOS approach is the transformation of a co-occurrence matrix into a similarity matrix. The similarity of two documents i and j is calculated as

$$s_{ij} = \frac{c_{ij}}{c_i c_j}, \qquad (1)$$

where c_{ij} denotes the number of co-occurrences of the documents i and j and where c_i and c_j denote the total number of occurrences of documents i and j. The VOS mapping technique then uses the calculated similarities as weights for the squared distances between the nodes of the network and minimizes their sum. This way, documents with high similarities are located close to each other, whereas documents with low similarities are located far from each other. Mathematically, the function to be minimized is defined as

$$V(x_1, \dots, x_n) = \sum_{i<j} s_{ij} \left\| x_i - x_j \right\|^2, \qquad (2)$$

where the vector $x_i = (x_{i1}, x_{i2})$ denotes the location of reference i in two-dimensional space and $\| \bullet \|$ denotes the Euclidean norm. Another constraint is added to avoid that all documents are located at one point by

$$\frac{2}{n(n-1)} \sum_{i<j} \|x_i - x_j\| = 1. \quad (3)$$

To solve the constrained optimization problem of minimizing (2) subject to (3), it is first converted into an unconstrained optimization problem, which is solved by applying a variant of the SMACOF algorithm (Borg & Groenen, 2005). Next, three transformation steps are performed to obtain a unique globally optimal solution. The initial solution is first translated so that it becomes centered at the origin. Second, it is rotated so that the variance is maximal on the horizontal dimension. Third, the solution is reflected on the vertical axis if the median of $x_{11}, \ldots, x_{n1}$ is larger than 0. If the median of $x_{12}, \ldots, x_{n2}$ is larger than 0, then it is reflected on the horizontal axis. Finally, each document is assigned to one cluster by using a modularity-based clustering technique proposed by Waltman et al. (2010). A resolution parameter defines the number of clusters, which we use to perform hierarchical, divisive clustering (van Eck & Waltman, 2010).

Burst Detection

Regular citation or keyword counts measure absolute influence in the scientific community but do not gauge relative impact and thus might overlook rising trends or the density of impact within a specific period. Burst detection algorithms address this shortcoming, as they identify changes in a variable relative to the rest of the population within a specific period (Cobo et al., 2011). This way, they are able to detect citations or keywords in the literature that have experienced a sharp increase in frequency, which equals an extraordinary degree of attention from the scientific community.

Therefore, we complement our citation and co-citation analysis by employing Kleinberg's (2002) burst detection algorithm to identify the most active areas of lean research, both in the past and present. The way how this algorithm works is that it models bursts as state transitions in a multiple-state automaton. In our analysis, we use a two-state model and distinguish between the baseline state and the “bursty” state. Put simply, first a bursty state probability is calculated based on the overall citation or keyword frequency. Transitioning from one state to another comes at a cost, which is dependent on the goodness of fit between a citation’s or keyword’s frequency at a given point in time and the bursty state probability. The algorithm then minimizes this cost function and identifies bursts, which can last for multiple years as well as only a single year.

2.5. Results

2.5.1. The Lean Literature up to Today

We use the Primary Lean Dataset consisting of 5,638 published articles to understand the current state of lean research by tracing its evolution since its origin in 1988.

General Trends

We find that lean research has grown exponentially over the last 30 years. Not surprisingly, it had a slow start, and the journals in our sample published fewer than 200 articles in the first decade of their existence from 1988 to 1998. This amounts to less than five percent of the total 5,638 articles. However, as Figure 13 shows, lean research began to gain momentum around the millennium turn, and the rate of publications has continued to increase ever since.

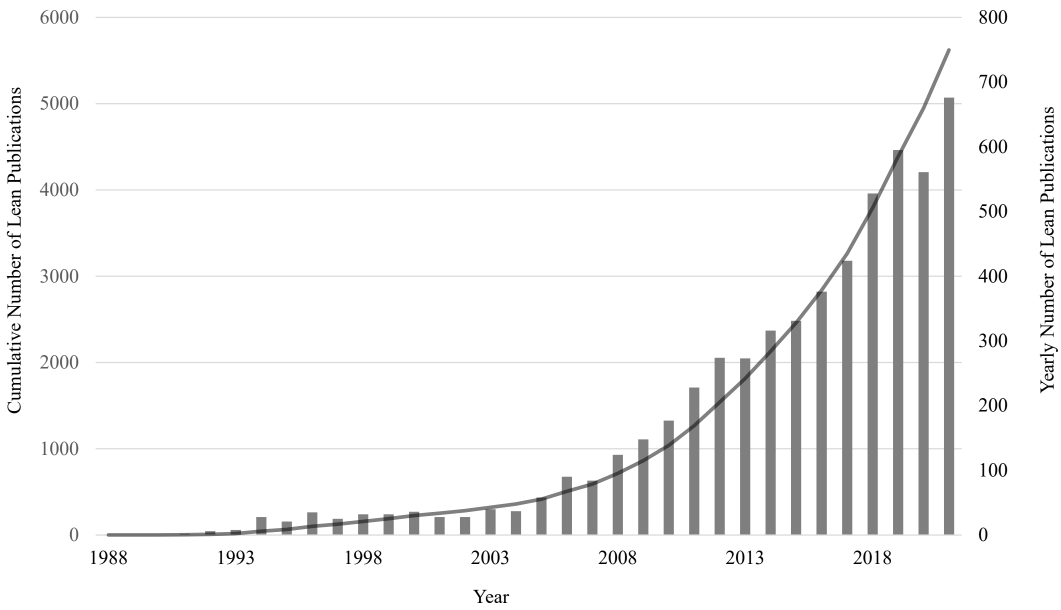


Figure 13 – Growth of Lean Literature

However, because journal publications have generally increased over the last decades, we also compute the relative growth rate of lean articles. We divide the number of lean articles by the total number of articles published in the 100 management journals that contain the most publications on lean. We calculate the normalized growth rate for each year and regressed it on an index of the year of publication. The regression model is significant ($F_{1,30}$ = 186.92, p = 0.000) and indicates that 84.9% of the variance in the relative number of lean articles is explained by the linear effect of time. We find that the lean literature has exceeded average publication growth in these top 100 management journals by 4% within the last 20 years (16% vs. 12%). This result suggests that lean research has not only grown in absolute terms but has also consistently grown as a proportion of overall management research over the last three decades. It indicates that thirty years after *The Machine*, lean remains an increasingly popular research topic in academia.

The most influential lean literature

The following tables show the results of our analysis of influence using the Cited Dataset. Table 12 shows the 30 most cited lean articles overall. Table 13 shows the citation bursts of the 30 most cited lean articles. Table 14 lists the five most cited lean articles per five-year periods. Table 15 lists the ten most-cited books. Table 16 shows the most frequently cited journals, sorted into UTD 24 journals and non-UTD 24 journals.

Table 12 – Top 30 Most Influential Journal Articles

#	Authors (year)	Primary Lean dataset		Google Scholar database	
		Frequency	Rank	Frequency	Rank
1	Shah and Ward (2003)	699	(1)	3643	(1)
2	Shah and Ward (2007)	629	(2)	3014	(2)
3	Hines et al. (2004)	500	(3)	2601	(3)
4	Holweg (2007)	323	(4)	2117	(7)
5	Krafcik (1988)	272	(5)	2490	(4)
6	Achanga et al. (2006)	256	(6)	1423	(11)
7	Abdulmalek and Rajgopal (2007)	244	(7)	1603	(10)
8	Bhasin and Burcher (2006)	237	(8)	1420	(12)
9	Spear & Bowen (1999)	202	(9)	2321	(6)
10	Bhamu & Sangwan (2014)	201	(10)	943	(18)
11	Yang et al. (2011)	199	(11)	1013	(14)
12	Karlsson and Åhlström (1996)	196	(12)	1010	(15)
13	Pettersen (2009)	191	(13)	956	(17)
14	Bortolotti et al. (2015)	187	(14)	640	(26)
15	Radnor et al. (2012)	183	(15)	933	(19)
16	de Souza (2009)	181	(16)	856	(20)
17	Cua et al. (2001)	179	(17)	1645	(9)
18	Sugimori et al. (1977)	173	(18)	2030	(8)
19	Naylor et al. (1999)	172	(19)	2443	(5)
20	de Treville and Antonakis (2006)	170	(20)	675	(24)
21	Mazzocato et al. (2010)	167	(21)	738	(23)
22	Dües et al. (2013)	164	(22)	661	(25)
23	Snee (2010)	163	(23)	784	(21)
24	Hines & Rich (1997)	157	(24)	426	(29)
25	King & Lenox (2001)	155	(25)	1114	(13)
26	Radnor & Walley (2008)	155	(26)	475	(27)
27	Vinodh & Balaji (2011)	150	(27)	226	(30)
28	Pepper & Spedding (2010)	146	(28)	761	(22)
29	Arnheiter & Maleyeff (2005)	143	(29)	988	(16)
30	Albliwi et al. (2014)	141	(30)	442	(28)

Note: Citation data were retrieved on 01/20/2022. Methodology-focused publications are excluded from this table.

Table 13 – Citation Bursts of the Top 30 Most Cited Lean Articles

#	Article	Burst Strength	Burst Begin	Burst End	1988-2020
1	Shah and Ward (2003)	28.88	2005	2012	
2	Shah and Ward (2007)	17.75	2011	2016	
3	Hines et al. (2004)	23.14	2006	2013	
4	Holweg (2007)	8.71	2009	2015	
5	Krafcik (1988)	-	-	-	
6	Achanga et al. (2006)	10.13	2013	2015	
7	Abdulmalek and Rajgopal (2007)	4.16	2011	2013	
8	Bhasin and Burcher (2006)	10	2013	2015	
9	Spear & Bowen (1999)	7.45	2006	2008	
10	Bhamu & Sangwan (2014)	9.37	2016	2020	
11	Yang et al. (2011)	2.09	2018	2020	
12	Karlsson and Åhlström (1996)	-	-	-	
13	Pettersen (2009)	7.19	2013	2015	
14	Bortolotti et al. (2015)	10.12	2016	2020	
15	Radnor et al. (2012)	5.19	2014	2015	
16	de Souza (2009)	4.07	2013	2014	
17	Cua et al. (2001)	5.26	2006	2009	
18	Sugimori et al. (1977)	-	-	-	
19	Naylor et al. (1999)	7.73	2004	2008	
20	de Treville and Antonakis (2006)	25.12	2007	2015	
21	Mazzocato et al. (2010)	4.69	2016	2017	
22	Dües et al. (2013)	-	-	-	
23	Snee (2010)	6.6	2014	2018	
24	Hines & Rich (1997)	3.2	2004	2006	
25	King & Lenox (2001)	3.84	2004	2006	
26	Radnor & Walley (2008)	3.27	2012	2013	
27	Vinodh & Balaji (2011)	8.91	2016	2020	
28	Pepper & Spedding (2010)	3.79	2014	2020	
29	Arnheiter & Maleyeff (2005)	6.16	2010	2014	
30	Albliwi et al. (2014)	7.49	2016	2020	

Table 14 – Top 5 Most Influential Journal Articles per Single Period

	#	Authors (year)	Web of Science database Frequency	Google Scholar database Frequency
2016-2021	1	Sanders et al. (2016)	235	688
	2	Tortorella & Fettermann (2018)	206	414
	3	Buer et al. (2018)	204	460
	4	Yin et al. (2018)	196	436
	5	Cherrafi et al. (2016)	174	362
2011-2015	1	Yang et al. (2011)	495	1013
	2	Blank (2013)	462	2342
	3	Radnor et al. (2012)	340	933
	4	Bhamu & Sangwan (2014)	323	943
	5	Dües et al. (2013)	304	663
2006-2010	1	Shah and Ward (2007)	1012	3014
	2	Holweg (2007)	568	2117
	3	Abdulmalek and Rajgopal (2007)	456	1603
	4	Achanga et al. (2006)	431	1423
	5	Bozarth et al. (2009)	372	851
2001-2005	1	Shah and Ward (2003)	1305	3643
	2	Zhu & Sarkis (2004)	1288	2890
	3	Kleindorfer et al. (2005)	884	2097
	4	Hines et al. (2004)	763	2600
	5	King & Lenox (2001)	495	1113
1996-2000	1	Brucker et al. (1999)	871	5490
	2	Naylor et al. (1999)	752	2442
	3	Florida (1996)	410	1996
	4	MacDuffie et al. (1996)	306	827
	5	Mason-Jones et al. (2000)	249	878
1988-1995	1	Krafcik (1988)	528	2492
	2	Hayes & Pisano (1994)	263	1337
	3	Womack & Jones (1994)	231	1375
	4	Adler & Cole (1993)	171	867
	5	Cusumano (1994)	105	515

Table 15 – Top 10 Most Influential Books

#	Text	Primary Lean Dataset		Google Scholar Database	
		Frequency	Rank	Frequency	Rank
1	Womack et al. (1990)	1456	(1)	21749	(1)
2	Womack and Jones (1996)	1405	(2)	14888	(2)
3	Ohno (1988)	813	(3)	9891	(3)
4	Liker (2004)	755	(4)	8864	(4)
5	Rother and Shook (2003)	419	(5)	4144	(5)
6	Monden (1983)	363	(6)	2806	(8)
7	Shingo and Dillon (1989)	199	(7)	2921	(7)
8	George (2003)	129	(8)	1383	(10)
9	Schonberger (1982)	97	(9)	3150	(6)
10	Morgan and Liker (2006)	89	(10)	1442	(9)

Note: This table provides the list of the top ten books that were most frequently cited in the Primary Lean Dataset. It also includes the number of times each book has been cited in the Primary Lean Dataset and Google Scholar. Methodology-focused texts (e.g., Yin (2003), Hair et al. (2006)) are excluded.

Table 16 – Most Influential Journals in Lean Literature

Journal Name	Influence of a Journal's Lean Articles			Journal's Total Influence		
	# Lean Articles (A)	# Lean Article Cites (B)	Impact Factor (all years) (C=B/A)	# Overall Articles (D)	# Overall Cites (E)	Impact Factor (all years) (F=E/D)
Panel 1: UTD 24 or FT 50						
JOM	28	2563	91.54	650	6727	10.35
HBR	13	478	36.77	585	2703	4.62
MS	4	45	11.25	542	1412	2.61
AMR	0	-	-	377	1308	3.47
SMR	13	543	41.77	212	1137	5.36
AMJ	1	-	-	459	1201	2.62
POM	11	411	37.36	259	1037	4.00
SMJ	1	-	-	379	1047	2.76
ASQ	2	9	4.50	245	755	3.08
HR	12	161	13.42	226	575	2.54
OS	-	-	-	253	629	2.49
Panel 2: Non-UTD 24 or FT 50						
IJOPM	115	3886	33.79	1050	7654	7.29
IJPR	185	3779	20.43	1612	7160	4.44
IJPE	105	2423	23.08	1354	5789	4.28
JCP	111	2374	21.39	1338	4767	3.56
JMTM	141	2655	18.83	395	3343	8.46
PPC	151	2197	14.55	599	3281	5.48
IJLSS	250	2637	10.55	285	3060	10.74
TQMBE	95	984	10.36	673	2375	3.53
IJQRM	78	1159	14.86	454	2245	4.94
JCEM	72	654	9.08	671	1960	2.92
JSCM	28	564	20.14	467	1753	3.75
EJOR	12	103	8.58	847	1544	1.82
IJAMT	68	792	11.65	409	1495	3.66
IJPPM	96	1218	12.69	244	1606	6.58
IJPDLM	5	141	28.20	301	793	2.63
AC	29	192	6.62	496	1199	2.42
IMDS	19	229	12.05	269	837	3.11
BPMJ	31	474	15.29	218	892	4.09
JAP	-	-	-	345	1575	4.57
TQMJ**	115	3886	33.79	1050	7654	7.29

Notes: Column A describes how many lean articles of the respective journal are identified in the Primary Lean Dataset. Column B describes how many times lean articles of the respective journal have been cited by the Primary Lean Dataset. Column D describes how many articles of the respective journal, in general, have been cited by the Primary Lean dataset. Column E describes how many citations the articles in column D received in the Primary Lean Dataset.

Publication outlets: AC = *Automation in Construction;* AMJ = *Academy of Management Journal;* AMR = *Academy of Management Review;* ASQ = *Administrative Science Quarterly;* BPMJ = *Business Process Management Journal;* EJOR = *European Journal of Operations Research;* HBR = *Harvard Business Review; HR = Human Relations;* IJLSS = *International Journal of Lean Six Sigma;* IJAMT = *International Journal of Advanced Manufacturing Technology;* IJPE = *International Journal of Production Economics;* IJOPM = *International Journal of Production and Operations Management;* IJPDLM = *International Journal of Physical Distribution & Logistics Management;* IJPPM = *International Journal of Production and Performance Management;* IJPR = *International Journal of Production Research; IJQRM = International Journal of Quality & Reliability Management;* IMDS = *Industrial Management & Data Systems;* JAP = *Journal of Applied Psychology;* JCEM = *Journal of Construction Engineering and Management;* JCP = *Journal of Cleaner Production;* JMTM = *Journal of Manufacturing Technology Management;* JOM = *Journal of Operations Management;* JSCM = *Journal of Supply Chain Management; MS = Management Science;* OS = *Organization Science; POM = Production and Operations Management Journal;* PPC = *Production Planning and Control;* SMJ = *Strategic Management Journal;* SMR = *Sloan Management Review;* TQMBE = *Total Quality Management & Business Excellence;* TQMJ = *Total Quality Management Journal.*

* Journals combined into two groups based on whether they are included in UTD 24 or FT 50 list or not.
** *The TQM Journal* is not listed in WoS. Thus, it is not included in the Primary Lean Dataset.

Lean across Academic Disciplines and Geography

Next, we assess the diversity in lean literature by classifying the Primary Lean Dataset articles into academic disciplines. WoS provides general categories to indicate the underlying discipline to which each article belongs. We use WoS' classification but combine them to obtain seven broad logical categories (Figure 14). The categories include business/management/economics, operations research/management science, and combinations of different engineering disciplines. For instance, we combine "industrial," "manufacturing," and "mechanical engineering" into one category. The results substantiate lean's multi-faceted nature and show that lean research has spanned numerous academic disciplines since its origin. While business, management, and economics were predominant in the early years, the focus has reduced significantly over the years. Of note, the industrial, manufacturing, and mechanical engineering category accounts for the second-largest proportion and has held stable over the last thirty years. Over time, we see a broader dispersion to other engineering (e.g., civil and environmental) and non-engineering (such as public service) fields.

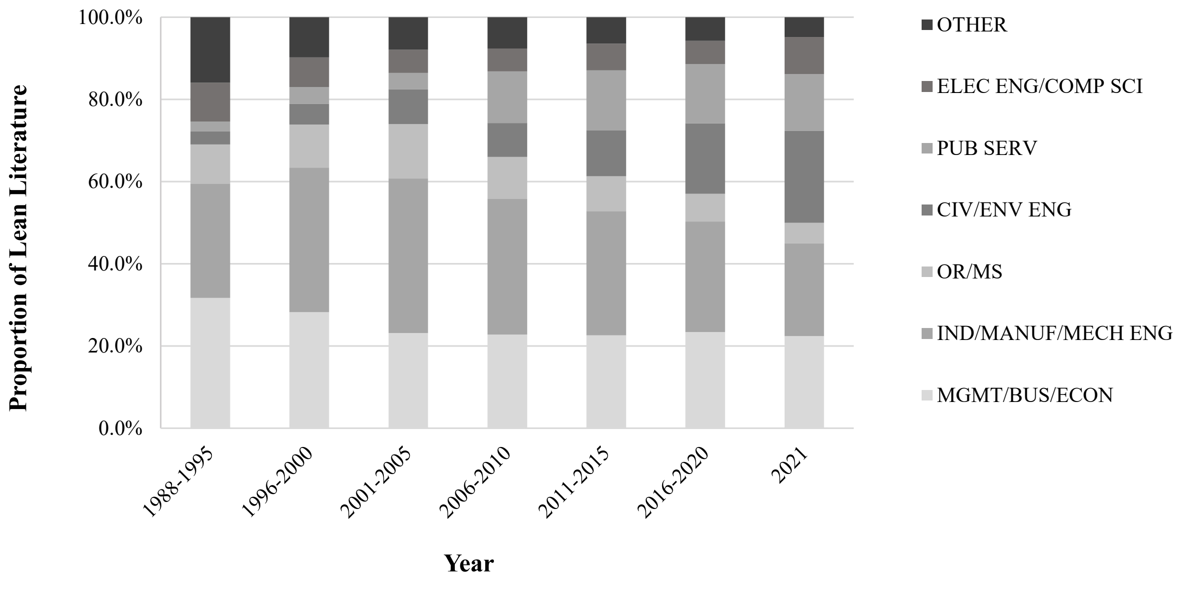


Figure 14 – Lean Article Distribution Grouped by Research Domains

We further analyze the geographic affiliation of authors publishing lean research (see Figure 15). Until 2010, authors from Europe and North America accounted for a vast majority of published lean research. However, since then, there has been a significant decline in the annual publication rate of North American authors. In contrast, there has been an exponential growth of publications from authors in Asia. Authors in Europe have maintained a relatively steady publication rate. Interestingly, authors from Asia and Europe have surpassed North America's research output in published lean articles. Research interest in lean is also on the rise from authors in South America, Oceania, and Africa. While these trends indicate a general geographical shift in authorship, whether it can be attributed to a change in authors' interests or the journal editors' interests remains an open question.

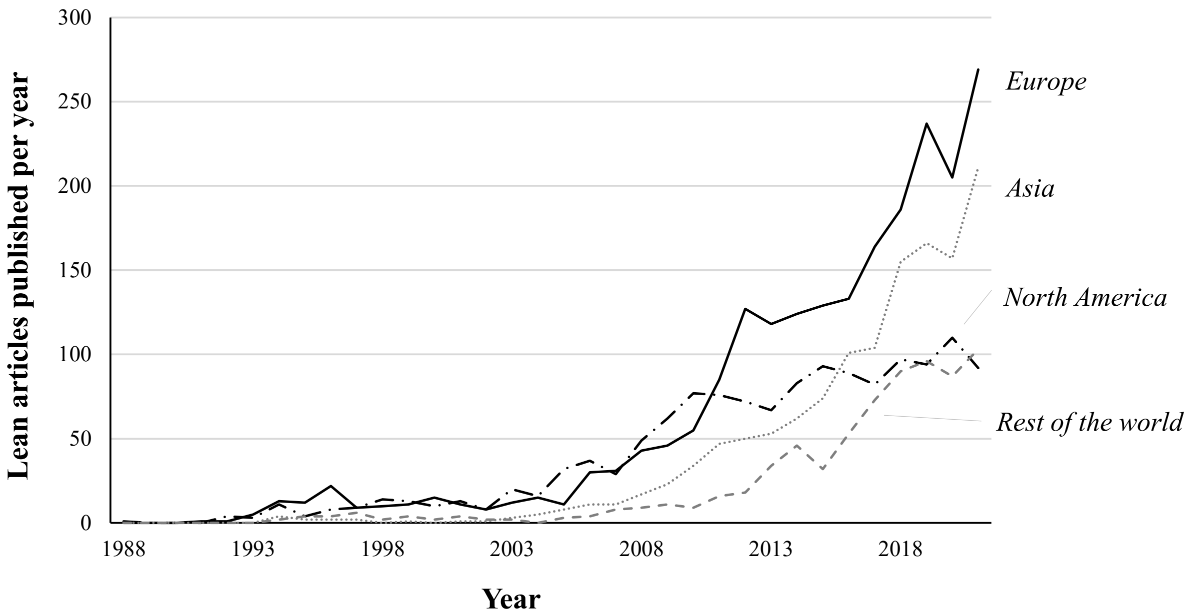


Figure 15 – Lean Articles Grouped by Lead Author's Country Membership

Method Use in the Lean Literature

We also examined the research methods used in lean articles. We identified six broad categories of research methods. These are literature reviews, conceptual research, qualitative methods, quantitative methods, analytical models and simulations, and mixed methods. A research assistant was hired to classify each of the lean research articles based on the primary research method used in the article. One of the authors classified 100 articles independent of the research assistant. There was a 91% inter-rater reliability between the two classifications. Table 17 gives an overview of how the use of research methods has evolved over the years. We find that conceptual research has decreased significantly as the field has matured. Although the popularity of qualitative research methods has also declined in recent years, it continues to account for over 40% of all published lean articles. Qualitative research methods include case studies based on interviews and action research based on personal observations.

Quantitative research, which consists of both primary and secondary data, and psychometric as well as econometric methods for analysis, has experienced significant growth in recent years. The proportion of articles using analytical models and simulation methods and literature reviews has remained relatively constant over the years, while mixed methods have also gained popularity in recent years.

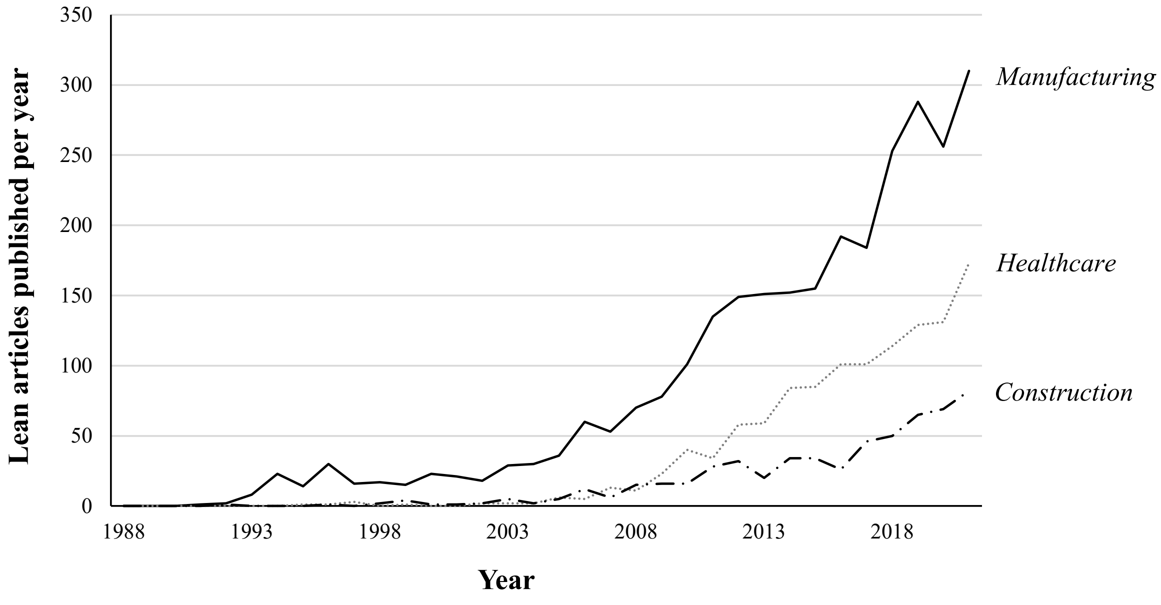
Table 17 – Lean Article Distribution Grouped by Research Method

Year	'88-'94	'95-'99	'00-'04	'05-'09	'10-'14	'15-'19	'88-'19
Literature reviews	0%	5%	1%	2%	5%	7%	6%
Conceptual research	18%	19%	13%	8%	7%	8%	8%
Qualitative methods	55%	53%	53%	56%	49%	38%	44%
Quantitative methods	18%	16%	20%	22%	29%	34%	30%
Analytical and simulations	9%	2%	7%	7%	5%	4%	5%
Mixed methods	0%	5%	6%	6%	5%	9%	7%
Total (in absolute numbers)	22	81	97	337	958	1813	3308

Notes: Lean articles are categorized according to the primary research method using the information provided in the title, keywords, and abstract of the article. Not all research articles could be categorized due to missing data.

Lean across Industries

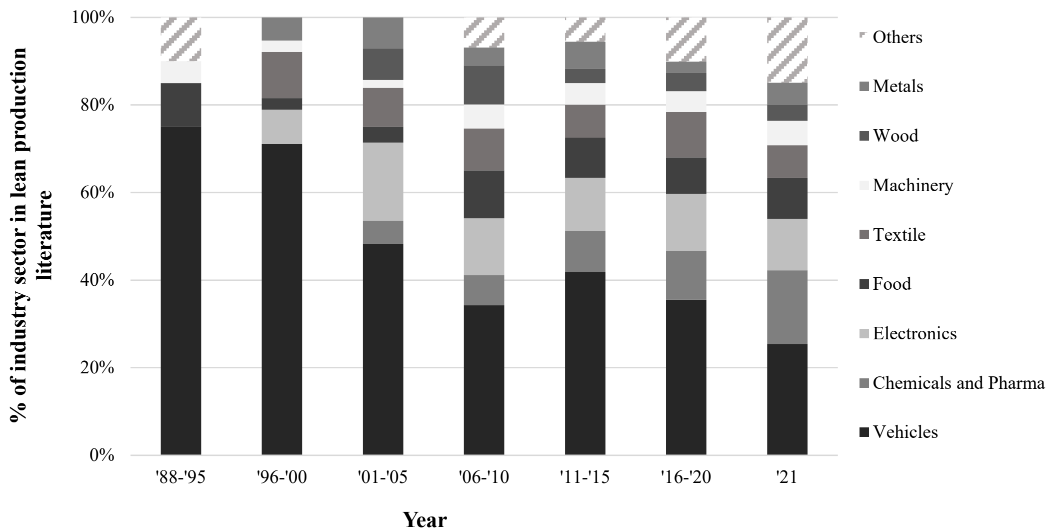
Finally, we analyze the research contexts in terms of industry membership. Figure 16 shows the growth of the three most frequently represented industry sectors: manufacturing, healthcare, and construction.



Note: This figure presents the results of an analysis of lean research contexts. We analyzed the keywords, abstracts, and titles for terms that would indicate industry membership. For example, we used keywords such as "healthcare," "patient," and "hospital" to classify a paper into the *healthcare* domain. Following this method for all the papers, we found three dominant industry sectors–manufacturing, healthcare, and construction—accounting for almost 85% of the Primary Lean Dataset. The remaining articles were in other sectors (e.g., education or public administration) or other parts of the value chain (e.g., product development or after sales) and could not be classified accurately because the industry sector was not easily discernible. The figure illustrates the annual growth of lean articles in the three industry sectors manufacturing, healthcare, and construction.

Figure 16 – Lean Article Distribution Grouped by Major Industry Sectors

The manufacturing sector accounts for most lean research (2870 articles; 50.9% of Primary Lean Dataset) and that the interest in this sector endures. Figure 17 provides a breakdown of the articles covering various manufacturing industries. While the automotive applications accounted for almost 100% of the lean articles in the manufacturing sector in the early years, the proportion of automotive applications has reduced to less than 40% in recent years with a corresponding increase in a diverse set of manufacturing industries, including electronics, chemical, food, textile, metals, machinery, and wood manufacturing. Over the last decade, there has also been a steep growth of lean articles in the healthcare and construction sectors. These two sectors account for about 20% and 10% of the Primary Lean Dataset (1179 and 575 articles), respectively. This expansion is an encouraging development for the lean phenomenon and can be construed as an indicator of a broader recognition of its effectiveness. Whether knowledgeable academics (and practitioners) across many industries would pursue lean if it were ineffective, remains an open question.

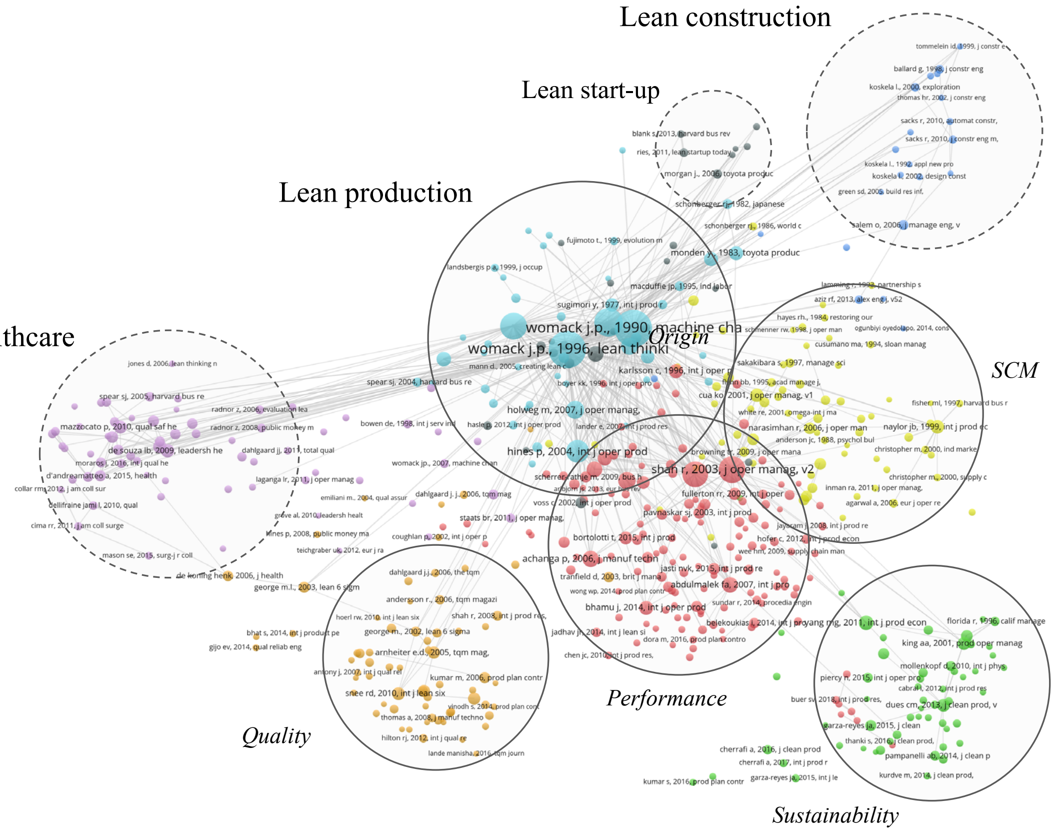


Note: To assess the relative importance of automotive in the manufacturing sector, we examined the manufacturing sector more closely and used industry-related keywords to screen the abstracts in the Primary Lean Dataset. The figure shows that the lean articles in the manufacturing sector mainly represent seven different manufacturing industries, including automotive ("vehicles") as the most represented.

Figure 17 – Lean Article Distribution Grouped by Manufacturing Sub-sectors

Lean Knowledge Groups

To create a deeper understanding of the lean literature's intellectual structure, we run a co-citation analysis of the Cited Dataset (Appendix 1 details our network measurements). In Figure 18, we display the generated network in a bibliometric map that shows how documents within a network relate to each other. We illustrate documents as colored bubbles, whereas the size of the bubbles represents the document's number of citations. The proximity to another node (document) indicates similarity of the documents perceived by their citers. Equally colored bubbles belong to one cluster, indicated by superimposed circles.



Note: This figure shows a co-citation network of documents cited by lean researchers. It allows for a deeper understanding of the literature and provides insights into the knowledge structure of lean research.

Figure 18 – Bibliometric Map Representing Co-citation Analysis of Publications

Overall, we identify eight different clusters representing the different knowledge groups within the lean literature. The *manufacturing* sector represents five knowledge clusters. The center of the network consists of fundamental and original work such as Womack et al. (1990) or Ohno (1988). Work from this cluster is central to the network because it serves as a source of general knowledge and receives many co-citations from any knowledge group. Further knowledge groups are associated with the effect of lean on performance (e.g., Shah & Ward, 2003), its relation to quality management (e.g., Arnheiter & Maleyeff, 2005), the integration of lean into supply chains (e.g., Naylor et al., 1999), and lean's potential for creating more sustainable manufacturing (e.g., Dües et al., 2013).

Most distant and least related to the other clusters, *lean construction* stands out as a knowledge group. It started to form in the early 90s with the doctoral thesis of Lauri Koskela (1992). Next is *lean healthcare*. Despite its later start, lean has become a common improvement method in healthcare today (D'Andreamatteo et al., 2015). Just as for manufacturing, some authors have emphasized the implementation of lean practices, primarily to eliminate waste (de Souza, 2009; Z. J. Radnor et al., 2012), while others have focused more on establishing a culture and developing employees (Dahlgaard et al., 2011). As the most recent knowledge group, *lean start-up* literature has emerged by studying the application of lean to young businesses and entrepreneurial activities (Blank, 2013; Ries, 2011).

2.5.2. Identification of Current Trends

Keyword Burst detection

To look ahead, we use our rich dataset to stratify and identify significant patterns and trends. We do so by applying a keyword burst analysis (see Table 18). As opposed to citation bursts, which contain only single references, keyword bursts are a more robust approach to identifying fast-growing research topics because they generally comprise multiple research articles. Our analysis yields 19 keyword bursts that have occurred over 33 years of lean research. In the beginning, strong bursts were identified among others for keywords like “organization”, “work”, and “manufacturing system”, which shows that relevant research topics were rather general and focused on manufacturing compared to today’s research topics. Regarding the recent and still ongoing keyword bursts, trending topics are “sustainability”, “industry 4.0”, and “barriers” as well as “critical success factors” to lean implementation.

Table 18 – Keyword Bursts from 1988-2020 in the 1,000 Most Cited Lean Articles

Keyword	Burst Strength	First appear.	Burst Begin	Burst End	1988-2020
lean production	27.47	1988	1994	2010	
just in time	4.03	1991	1998	2009	
supply chain management	3.95	1993	2004	2007	
agile	3.78	1997	2005	2012	
six sigma	3.74	1995	2016	2017	
sustainability	3.9	1994	2016	2020	
critical success factor	5.47	2012	2015	2020	
operational performance	4.57	2001	2015	2020	
green	5.99	1994	2017	2020	
barrier	4.33	2006	2018	2020	
industry 4.0	3.91	2015	2018	2020	

Research topic share and growth

We take inspiration from the “BCG Matrix” (e.g., Henderson, 1970) where the share and growth of a portfolio of items are organized into a 2x2 matrix. In our adaptation, the X-axis represents the share of publications, thus the importance of a topic at a point in time, and the Y-axis represents recent relative growth over five years. To trace the development of the identified research domains over the last 20 years, we map the relative growth and share in several periods for each respective knowledge group into one map as shown in Figure 19. We compute the *share* as the percentage of articles mentioning a set of a specific keyword(s), which we assign to each research domain based on the co-occurrence of words (e.g., “hospital,” “patient,” and “care” for lean healthcare). The *relative growth* is computed as the proportional change of the share over a five-year sliding window.

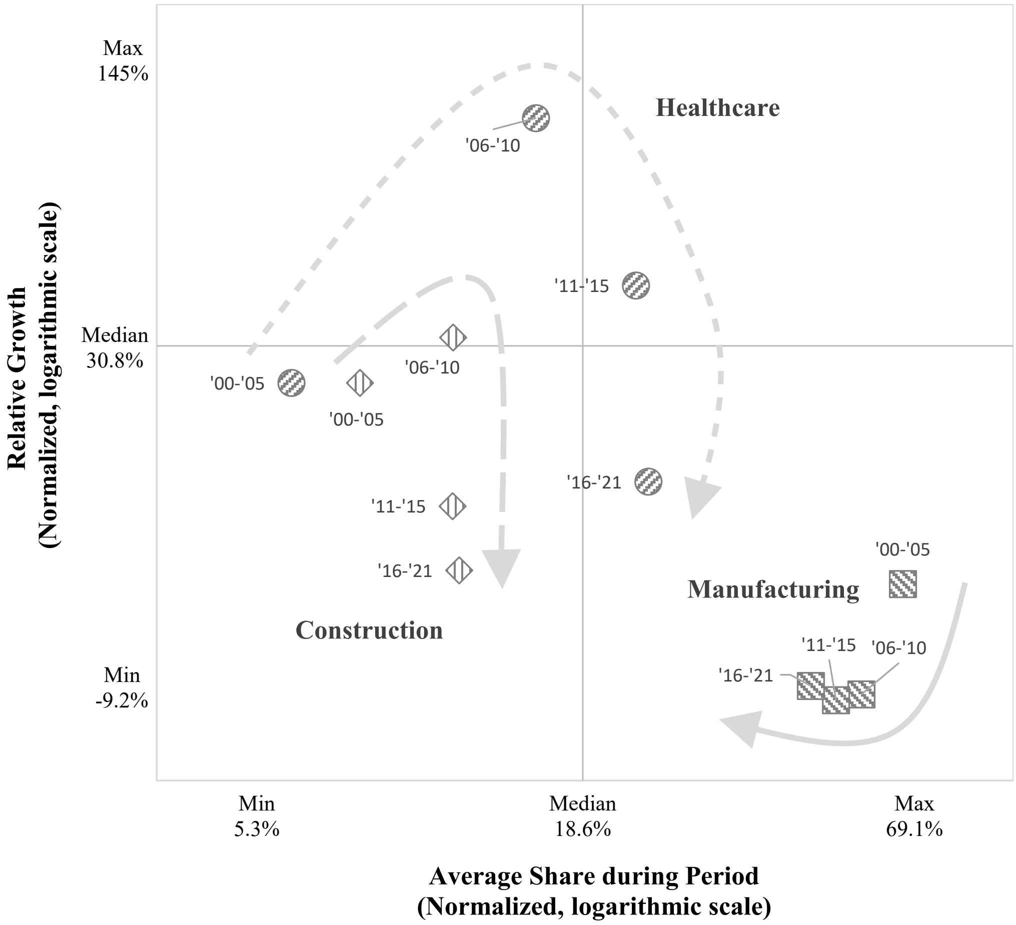


Figure 19 – 2x2 Matrix to Trace Contextual Trends in the Lean Literature

Figure 19 shows the development patterns of the three most important lean domains: manufacturing, healthcare, and construction. Unsurprisingly, manufacturing has always remained the largest knowledge group, but as new lean application areas have emerged, its *relative* share has declined. Regarding its number of publications, lean manufacturing has plateaued. Literature on lean construction, on the other hand, has recently been growing and increased its share to about 14%. Lean healthcare has had the highest relative growth and has a share somewhere in-between manufacturing and construction.

To understand the importance of trends of key concepts in the lean literature, we repeat the analysis for a selection of commonly discussed keywords in lean research (“digitalization,” “leadership,” “waste”, etc.). Due to smaller Ns, we only map the last five years onto the map shown in Figure 20.

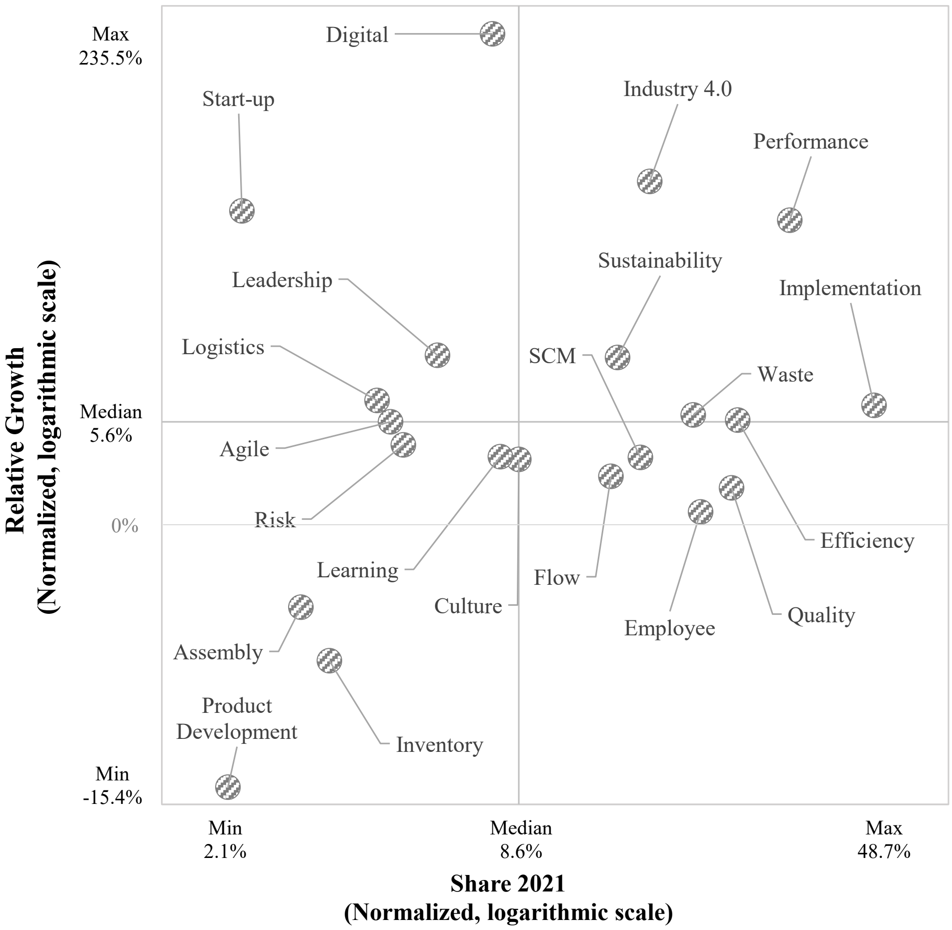


Figure 20 – 2x2 Matrix to Identify Conceptual Trends

Figure 20 reveals some interesting insights. We can use it to identify topics in the lean literature that can be characterized as *trending* (upper left quadrant), *prevailing* (upper right quadrant), and *maturing* (lower right quadrant). Topics in the lower left quadrant have little attention in the lean literature and are shrinking from low numbers. Figure 9 draws particular attention to certain clearly trending topics, including lean and "digital" (in combination with "Industry 4.0"), lean and green applications to support "sustainability," and behavioral aspects represented by "leadership". This can be witnessed by their position far above the horizontal median growth line (recall the logarithmic scales). Interestingly, these results confirm the identified keyword bursts from the previous subchapter as currently active and relevant research topics in the lean literature.

2.6. Discussion

After more than three decades of practice within and across many industries, lean still prevails as a widely accepted management approach. However, lean has not remained the same–at least from an academic standpoint. This study has shown how a growing academic community has changed its perspective on lean, starting with a more technical focus on single concepts like JIT while slowly adopting a more and more socio-technical perspective. Lack of consensus in this regard has sparked a discussion lately (Browning & de Treville, 2021; Cusumano et al., 2021; Hopp & Spearman, 2020): What is lean?

One recent response to that question is: Lean itself is not a theory (Åhlström et al., 2021). However, lean can be seen as a phenomenon that influences how people manage operations. And as a phenomenon, it needs to be described, documented, and conceptualized before theories can be built around it (von Krogh et al., 2012). At the same time, it is being continuously adapted to new social, organizational, and technological changes. As new managerial challenges arise, lean is therefore being applied and studied in new settings while different research questions arise in each of them. Our study has identified three of these settings as currently relevant topics in the field of lean research. Therefore, in our subsequent discussion, we focus on these three topics and discuss their meaning for the future of lean research.

2.6.1. Digitalization

Articles containing the content keyword "digital" have, collectively, a low relative share in 2021 but the highest growth rate (upper left quadrant, Figure 20). Clearly, lean researchers are incorporating the growing trend of "Industry 4.0," "smart manufacturing," and "digitization" (cf. Holmström et al., 2019) into their studies. Further evidence of this is given by the detection of "Industry 4.0" as an ongoing keyword burst in the lean literature. Conventional wisdom suggests that the way firms organize industrial activity is changing radically using digital technology (Schwab, 2016). The implementation of information technology is hardly new but connecting business processes through digital platforms may fracture the traditional linear supply chains and call into question the applicability of lean concepts and tools. While some early work in this domain has been published (e.g., Netland, 2015; Buer et al., 2018; Tortorella et al., 2019), we still have limited knowledge about the role of lean in the "fourth industrial revolution."

Considering the nascence of the fourth industrial revolution, there are plenty of opportunities for lean researchers. For example, if scholars take advantage of what digital technologies can *add* to lean, they can ask some of the following research questions: How will platforms that create demand transparency affect just-in-time policies? How can cognitive technologies empower shop-floor employees in kaizen activities? How can new technologies such as digital boards, smartwatches, and augmented reality enable more efficient shop-floor planning, execution, and control?

Alternatively, scholars can study whether and how lean is *adapting* to the new reality. For example, many lean elements that are dependent on interacting directly with physical work will be challenged when work moves from analog to digital (e.g., shop-floor labeling, die exchange, Kanban cards, Gemba walks, kaizen activities, and manual problem-solving activities). Scholars who discover a path forward for lean in this new environment can facilitate further development of lean research (and possibly also its survival). Rather than broad-brush research, we call for research designs that examine the relationship between lean and specific technologies.

2.6.2. Human Behaviors

Another trending topic in Figure 20 is "leadership," covering the role of leaders and managers in creating a supportive culture and learning environment to help employees during lean implementations. Not surprisingly, related terms such as "learning," "culture," and "employee" are also represented in the center of the figure. Each of these underscores the importance of behavioral aspects in implementing lean. The cognitive and social aspects of problem-solving and learning at the individual level were prominent in early lean research (for early work, see Spear & Bowen, 1999), and these have regained popularity with the advent of behavioral operations. For example, team dynamics and the underlying behavioral aspects related to problem-solving in lean teams have recently garnered attention (e.g., Easton & Rosenzweig, 2015; Morrison, 2015; Furlan et al., 2019). Additionally, while scholars have repeatedly noted that the management's commitment is the most important success factor in lean implementations, researchers have only recently started to investigate which *behaviors* relate to commitment (e.g., Choo et al., 2015; Netland et al., 2015; Dreyfus et al., 2020) and its cognitive underpinnings (e.g., Stevens & van Schaik, 2020). Therefore, it is also no surprise that terms like "barrier" or "critical success factor" pop up as keyword bursts in our analysis, as leadership plays a key role in this regard. This stream of research is being referred to as "lean leadership".

Relatedly, a substantial literature base relates lean to the learning organization literature (Anand et al., 2009; Spear & Bowen, 1999), but the causal links remain elusive and ill-defined. Many seem to agree that "a learning organization" or "a culture of continuous improvement" is a key characteristic of effective lean implementation on one hand, and a critical outcome needed to sustain gains from lean implementation on the other hand. At Toyota, the lean tools and methods implemented on the shop floor (e.g., Kanban, Andon, 5S), in the management (e.g., A3, Gemba walk, VSM), and in the supply chain (e.g., JIT, supplier development programs, market intelligence) can be interpreted as vehicles for individual and organizational learning. However, few researchers have examined lean from a behavioral perspective. Thus, using a behavioral paradigm instead of an efficiency paradigm to examine lean can potentially contribute new knowledge to existing literature.

Researchers can also contribute new knowledge by disentangling the cognitive underpinnings of commitment and action (rather than studying organizational success factors). Thirty years of research have shown that lean is challenging to implement and sustain, but we have little insight into the barriers to *learning* lean? How can managerial or organizational support foster learning at the individual or collective level? Other promising questions relate to organizational dynamics. Given that lean is a "fragile" production system characterized by interdependent processes, how can formal (e.g., position) and informal (e.g., trust) interpersonal relationships affect learning? For all these questions, lean researchers could take advantage of the rich literature in organizational behavior and human psychology.

2.6.3. Sustainability

The global sustainability movement has never been stronger. In recent years, sustainability has gained significant momentum with academics and management decision-makers and risen to become a board room issue (cf. Arora et al., 2020), and the general public has become much more concerned about the environment. Lean has since its inception been linked to a more sustainable way of production (e.g., Florida, 1996; King and Lenox, 2001; Rothenberg et al., 2001; Zhu and Sarkis, 2004; Kleindorfer et al., 2005)—because it focuses on producing what, and only what, the customer wants and reduces all forms of waste in the production process. However, in our analyses, sustainability consistently appeared as a separate knowledge group rather than an integrated part of other knowledge groups. It has become an independent subfield of lean research, often referred to as *lean and green*. We also detect "green" and "sustainability" as ongoing keyword bursts in the lean literature, which testifies the academic interest in this topic.

Sustainability extends beyond environmental-friendly production to the so-called triple-bottom-line (economic, environmental, and social aspects). There are plenty of opportunities for lean researchers to contribute to sustainability research. New research should move beyond studying the differences and synergies between lean concepts and green concepts, as this has already been extensively covered (e.g., Florida, 1996; King and Lenox, 2001; Zhu and Sarkis, 2004). Instead, lean researchers can study the effect of lean practices on the triple bottom line.

A recent example that can serve as inspiration is Distelhorst et al. (2017), who studied how Nike's lean program contributed to improving labor standards in Nike's global supply chain.

2.6.4. Pivoting Lean in the Time of Covid-19

Despite being absent in our literature review due to its recent occurrence, we think that the Covid-19 pandemic deserves some discussion in view of the future of lean research. Undoubtedly, it is the most disruptive event of our times and has challenged every aspect of life. It is different from other disruptions in three ways: it has simultaneously impacted both demand and supply, it is global in nature, but the spread across countries has differed in time and rate. These aspects have significant implications for researchers who are studying lean as well as others who examine general supply chain and operations issues. While our literature review does not capture the impact of the pandemic, we predict some trends that are likely to re-energize lean research in light of the current pandemic-focused debate in the academic literature and business press.

The pandemic has resulted in demand spikes (for at least some items) and supply shortages of others, worldwide. Many have blamed lean, and specifically just-in-time inventory policies for supply shortages and have called business leaders to transfer focus from "efficient" (lean) supply chains to building "resilient" (agile) supply chains (Fisher, 1997). We believe that some realignment is essential, beneficial, and even likely to occur. Whether it will result in a massive restructuring of global supply chains is unclear and beyond the scope of this article. However, we can be certain that it will raise 'matching supply and demand' issues to a higher level of executive decision-making. It is worth noting that in *The Machine*, two of the five systems are related to coordinating the supply chain and dealing with customers. Similarly, at Toyota, the role of customers and suppliers was always an integral part of the production system with great respect for responsive solutions often over efficiency. This immense interest in supply chains and just-in-time suggests a potential change in lean scholars' focus toward examining supply chain issues, from shop floor to broader supply chain issues. Despite the vast challenges associated with observing supply chain dynamics firsthand or collecting data at dyadic and triadic levels, we believe that lean research is underdeveloped in its study of supply chains and risk. The pandemic might serve as a catalyst to spur future research in this area.

2.7. Conclusion and Limitations

This article provides the most extensive review of the lean literature. We used bibliometric techniques with network mapping methods to understand the current state of the lean literature.

We used a dataset consisting of 5,638 unique lean articles to understand the current state of lean research. We also looked at the 131,967 references that had been cited in these articles to identify source literature that facilitated the growth of lean literature. From our analyses, we can confidently conclude that—three decades after its inception—lean has become a widespread business phenomenon that garners significant attention from researchers from many disciplines all over the world. Although it is impossible to predict if its success will continue, we believe that the future of lean research is exciting.

Like most research, our study also has some limitations stemming from our decisions related to study design and analysis. One criticism that can be leveled against our approach is that we neither adopt any existing definition of lean nor offer any new definition. However, in this paper, it was not our goal to settle the ongoing debate about how lean is defined and what constitutes lean. Instead, our primary goal was to document the evolution of lean literature since the term's inception. It is likely that some researchers may apply the term incorrectly, and its operationalization varies among researchers. While we believe that there exists a generally consistent understanding amongst researchers across disciplines, future researchers might want to address the definitional conundrum surrounding lean and its underlying components.

Because our objective was to review lean literature, we limited our data collection to articles that specifically used "lean" and one of the 50 suffixes in the title, abstract, and keywords. In doing so, we may have excluded articles that primarily focus on one of its underlying components, such as just-in-time and total quality management, and if the article did not use "lean" and one of the 50 suffixes in the title, abstract, and keywords. While this may have reduced our total article count, our approach is more conservative and consistent overall. Limiting our search terms to 50 lean-related keywords may have excluded some, albeit a small number, of published articles. Lastly, given our large datasets, we did not delve in-depth into any specific paper to avoid cherry-picking.

Despite these limitations, our review provides valuable and useful information on the current state of lean. We believe similar other opportunities exist and describe two of them. One involves reviewing research related to six sigma. The other involves tracing the journey of the underlying components of TPS, specifically JIT and TQM overtime, and their relationships with lean and six sigma. Tracking the evolution and demonstrating their inter-relationship might help the ongoing and recurring debate on how to view these two critically important process improvement methods.

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2.9. Appendix 1

Table 19 – Selected Keywords and Distribution of Published Lean Research Articles by Keywords

#	Keyword A	# Articles B	# Unique C	Cum Total D	% Articles E=B/5638	% Unique F=C/5638	Cum % Unique G=D/5638
1	Lean Manufactur*	1327	1327	1327	23.54%	23.54%	23.54%
2	Lean Production	1321	1099	2426	23.43%	19.49%	43.03%
3	Lean Six Sigma	677	584	3010	12.01%	10.36%	53.39%
4	Lean Manage*	611	460	3470	10.84%	8.16%	61.55%
5	Lean Think*	489	332	3802	8.67%	5.89%	67.44%
6	Lean Implement*	486	168	3970	8.62%	2.98%	70.42%
7	Lean Principle*	466	222	4192	8.27%	3.94%	74.35%
8	Lean Instruction*	380	271	4463	6.74%	4.81%	79.16%
9	Lean Practice*	350	93	4556	6.21%	1.65%	80.81%
10	Lean Tool*	338	81	4637	6.00%	1.44%	82.25%
11	Lean Method*	299	173	4810	5.30%	3.07%	85.31%
12	Lean Approach*	189	61	4871	3.35%	1.08%	86.40%
13	Lean Concept*	163	34	4905	2.89%	0.60%	87.00%
14	Lean Suppl*	135	66	4971	2.39%	1.17%	88.17%
15	Lean Process*	127	41	5012	2.25%	0.73%	88.90%
16	Lean and Green	123	53	5065	2.18%	0.94%	89.84%
17	Lean System*	123	33	5098	2.18%	0.59%	90.42%
18	Lean Start*	122	112	5210	2.16%	1.99%	92.41%
19	Lean Philosoph*	121	27	5237	2.15%	0.48%	92.89%
20	Lean Operation*	116	74	5311	2.06%	1.31%	94.20%
21	Lean Product	100	41	5352	1.77%	0.73%	94.93%
22	Lean Transform*	93	19	5371	1.65%	0.34%	95.26%
23	Lean Healthcare*	93	29	5400	1.65%	0.51%	95.78%
24	Lean Agile	81	54	5454	1.44%	0.96%	96.74%
25	Lean Strateg*	77	16	5470	1.37%	0.28%	97.02%
26	Lean Enterprise	64	15	5485	1.14%	0.27%	97.29%
27	Lean Project*	62	8	5493	1.10%	0.14%	97.43%
28	Lean Organi*	55	19	5512	0.98%	0.34%	97.77%
29	Lean Service*	49	17	5529	0.87%	0.30%	98.07%
30	Lean Leader*	47	10	5539	0.83%	0.18%	98.24%
31	Lean Cultur*	46	8	5547	0.82%	0.14%	98.39%
32	Lean Perform*	44	6	5553	0.78%	0.11%	98.49%
33	Lean Program*	42	13	5566	0.74%	0.23%	98.72%
34	Lean Journey*	39	3	5569	0.69%	0.05%	98.78%
35	Lean Logistic*	32	16	5585	0.57%	0.28%	99.06%
36	Lean Software*	29	17	5602	0.51%	0.30%	99.36%
37	Lean Waste*	27	5	5607	0.48%	0.09%	99.45%
38	Lean Qualit*	25	8	5615	0.44%	0.14%	99.59%
39	Lean Value*	25	12	5627	0.44%	0.21%	99.80%
40	Lean Innovation*	24	11	5638	0.43%	0.20%	100.00%

Notes: Column A shows the selected lean-related keywords. Column B indicates the number of published research articles corresponding to the keyword. The keywords are organized in decreasing order of occurrence. Column C provides the incremental change in the number of unique articles as each new keyword is added. Column D lists the cumulative number of unique articles. Columns E, F, and G specify the percent contribution corresponding to the numbers of articles in Columns B, C, and D, respectively. *asterisk in search strings represents any following group of characters, including no character

2.10. Appendix 2

Table 20 – Overview of Network Measurements according to Gmür (2003)

Measurement	Symbol	Explanation
Cluster size	*S*	The number of items in a cluster.
In-degree	deg_i	The number of all internal relationships, i.e. the sum of all co-citations/co-occurrences between the items within one cluster
Out-degree	deg_o	The number of all external relationships, i.e. the sum of all co-citations between items within a cluster and items outside of it.
Cluster density	*d*	The quotient between a cluster's in-degree and its maximum possible in-degree. It indicates the certainty that a school of research has formed.
Centralization	*C*	The quotient of the co-citation/co-occurrence sum of the most-connected item within one cluster and the mean co-citation/co-occurrence sum of it. It is an expression for the dominance of a single reference within a cluster.
Differentiation within the network	*D*	The quotient of the sum of all clusters' in-degrees and out-degrees. It indicates how well clusters in one network can be distinguished from one another.

Table 21 – Network Measurements of the Co-citation Network from the Cited Dataset

Cluster	*S*	deg_i	deg_o	*d*	*C*	*D*
Lean Construction	39	427	3,545	57.62%	2.648712	
Lean Healthcare	67	2028	12,956	91.72%	2.180473	
Lean Production – Origin	66	1750	15,997	81.59%	2.451429	
Lean Production – Performance	134	7522	28,788	84.41%	2.369317	16.9%
Lean Production – Quality	61	1716	14,159	93.77%	2.132867	
Lean Production – SCM	88	3236	19,460	84.54%	2.365884	
Lean Production – Sustainability	45	985	9,469	99.49%	2.010152	

Chapter 3

3. The Role of Management in Lean Implementation: Evidence from the Pharmaceutical Industry

This chapter is based on a revised version of a manuscript that was submitted to the *International Journal of Operations and Production Management* and received the decision "Revise & Resubmit" on 4. May 2022.

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3.1. Abstract

Purpose – In contrast to the rich literature on lean shop-floor practices and their performance effects, there is less scientific research about the managerial practices that foster lean implementation. One reason is that "hard" lean practices, such as just-in-time and maintenance schemes are easier to observe, define and quantify than "soft" lean practices such as management routines. We investigate how soft lean practices moderate the performance effects of hard lean practices.

Design/methodology/approach – Based on a review of the literature, we define a set of soft and hard lean practices. We test our hypotheses using factor analysis and moderated hierarchical linear regression on a unique dataset containing survey data and real performance measures of 351 pharmaceutical plants.

Findings – The results show that soft lean practices can be both enabling and constraining. When management engages in performance measurement, visualisation and employee empowerment the relationship between hard lean practices and performance is positively moderated. On the other hand, when managers emphasise goal setting and work standardisation the performance outcomes are reduced.

Practical implications – Effective lean managers build organisational commitment by motivating other employees to implement lean. They use performance measurement, visualisation and employee empowerment to focus on the 'why'. Less effective managers engage in commanding and micro-management. Such managers focus on the 'what' by using practices like goal setting and work standardisation.

Originality/value – This article contributes to the literature on lean management by empirically testing the interaction effects between soft and hard lean practices. In addition, it adds evidence from the important pharmaceutical industry.

Keywords Lean production, soft lean practices, moderating effect, pharmaceutical manufacturing

3.2. Introduction

To remain competitive, firms seek to improve their operations continuously. Inspired by the success of the Toyota Production System (TPS)—popularised as ‘lean production’ by Womack et al. (1990)—manufacturers use holistic and company-specific lean programmes (Netland, 2013). Yet, despite widespread popularity and numerous scientific studies confirming the positive effects of lean on firm performance (Abreu-Ledón et al., 2018; Bloom et al., 2019; Negrão et al., 2017), many companies struggle to succeed with their lean programmes (Holweg et al., 2018; Losonci et al., 2017; Marodin & Saurin, 2015). Despite its industry-specific peculiarities, the pharmaceutical industry is no different in this regard (Friedli et al., 2013, 2018).

Lean programmes can be conceptualised as sets of organisational practices that work synergistically to improve the value creation processes (Shah & Ward, 2003). Prior literature has shown that lean programmes consist of both technical (hard) and human-related (soft) components (Cua et al., 2001; Furlan et al., 2011; Hadid & Mansouri, 2014). Yet, only a few studies methodologically distinguish between these two concepts to investigate their interplay and separate performance effects (for recent exceptions, see Bortolotti et al., 2015; Kristensen & Israelsen, 2014; Nielsen et al., 2018).

To date, the existing lean research provides only a limited understanding of how soft lean practices impact performance in manufacturing organisations. Specifically, lean research studying the lean-performance relationship is highly skewed toward hard lean practices. Despite a few early studies on the social and behavioural aspects of lean systems (e.g., Emiliani, 1998; Emiliani & Stec, 2005; Liker, 2004; Spear, 2004; Spear & Bowen, 1999), it is only recently that these aspects have received significant research interest (e.g., Arellano et al., 2021; Cadden et al., 2020; Camuffo & Gerli, 2018; Galeazzo et al., 2017; Netland et al., 2015; Saabye et al., 2022).

This study addresses this gap by building on prior research that has already indicated interactions between hard and soft lean practices (e.g., Bortolotti et al., 2015; Hadid & Mansouri, 2014). The novelty and contribution of our study lie in the interpretation and empirical testing of soft lean practices as *moderators* of the relationship between hard lean practices and operational performance. We think that this does not only contribute to the understanding of lean in its scientific community but can also help managers adapt their behaviours and chose appropriate methods to support their organisations in the implementation of lean.

Studying lean implementation in the pharmaceutical sector is another contribution of this study as it has received limited attention in extant research. It represents a special setting for studying lean implementation due to its highly regulated and technology-intensive manufacturing environment, which inevitably affects the interaction among humans as well as between humans and the technical system. In this setting, we develop theoretically grounded hypotheses relating to the moderating role of soft lean practices on the link between hard lean practices and operational performance. We test them by performing exploratory factor analysis (PCA), confirmatory factor analysis (CFA) and ordinary linear least squares (OLS) regression on survey data from 351 pharmaceutical plants. We thereby contribute to the ongoing discussion on the role of management in lean programme implementations.

3.3. Theoretical Background and Hypothesis Development

Lean has become a topic of great interest across many industries and academic disciplines (Danese et al., 2018; Jasti & Kodali, 2015; Netland & Powell, 2016). In this section, we first review the conceptualisation of hard versus soft lean practices and then develop our hypotheses.

3.3.1. Hard and Soft Lean Practices

Shah and Ward (2003) provided one of the most often used conceptualisations of lean production when they defined it as a system composed of four bundles of practices: Just-in-Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM) and Human Resource Management (HRM). Each of these bundles again consists of a set of practices. The JIT bundle aims to identify and eliminate all forms of waste in production (Ohno, 1988; Sugimori et al., 1977). Common JIT practices are, for example, *set-up time reduction* or *pull production* with *Kanban* (Cua et al., 2001). The TQM bundle aims at continuous improvement of product and process quality (Shah & Ward, 2003). Typical TQM practices are *process management*, *customer involvement* and *supplier quality management* (Flynn et al., 1995; Pettersen, 2009). The TPM bundle is oriented toward maximizing equipment effectiveness by keeping machines in excellent working conditions to avoid breakdowns or delays. Examples of TPM practices are autonomous as well as *planned maintenance* and *housekeeping* (Cua et al., 2001; Shah & Ward, 2003).

In addition to the technically oriented constructs (JIT, TPM and TQM), Shah and Ward (2003) included HRM as a fourth, more socially oriented bundle of practices. Typical HRM practices include *self-directed teams*, a *cross-functional workforce* and *committed leadership* (Shah & Ward, 2003). In contrast, Cua et al. (2001) did not view HRM as a separate bundle but saw corresponding soft practices as cross-cutting the three hard bundles of practices. Other authors are less concerned about whether these soft practices should be seen as 'lean' and suggest that they are simply good management practices supporting any kind of production system (Höök & Stehn, 2008; Pettersen, 2009). In whatever way these social constructs are included, the majority of the literature agrees on the importance of human-oriented practices for lean success (Bai et al., 2019; Camuffo & Gerli, 2018; Liker, 2004). Furthermore, as Bortolotti et al. (2015) pointed out, separation of hard versus soft lean practices can be worthwhile, as it can potentially enhance the understanding of how to achieve a successful implementation of lean programmes.

As we are interested in understanding the role that management practices play in successful lean implementation, we take on a socio-technical perspective and first separate hard from soft lean practices (Bortolotti et al., 2015). We conceptualise hard lean practices as a bundle of technically oriented JIT, TQM and TPM practices (Cua et al., 2001). As a counterpart to hard lean practices, we consider soft lean practices as organisational practices related to the *management* of the social system. We view *practices* as the organised constellation of activities related to the design or process of the organisation's technical and social system (cf. Schatzki, 2012), respectively. Accordingly, we define lean implementation as the organisational adoption of lean practices.

3.3.2. Hypothesis Development

Most studies identify positive performance effects of lean on firm performance (Bloom et al., 2019; Moyano-Fuentes & Sacristán-Díaz, 2012; Netland et al., 2015), but there are still reports of no effects or even negative ones (cf. Wemmerlöv, 2021). Put simply, many companies struggle to implement lean. As the mere implementation of tools and techniques (e.g., 5S or Kanban cards) will not suffice, it seems that the lean-performance relationship is *contingent* upon other variables.

While lean has often been reduced to a system of technical practices, the literature on critical success factors of lean suggests that human-related aspects play a central role in the success of lean adoption (Achanga et al., 2006; Netland, 2016). Several studies focus on the direct effects of human aspects on performance in lean contexts (e.g., Camuffo & Gerli, 2018; Galeazzo et al., 2017; Netland et al., 2015), but we found no empirical study that takes on a contingent perspective by viewing human-oriented management practices as moderators of the lean-performance relationship.

Our main hypothesis is that soft lean practices strengthen the effect of hard lean practices. Hence, we examine the role of soft lean practices as moderators of the relationship between hard lean practices and performance. We do so by first hypothesising a direct positive relationship between hard lean practices and operational performance. Second, we expect the effectiveness of hard lean practices to depend on the support by soft lean practices. We, therefore, set forward a set of hypotheses relating to the interaction effects of soft lean practices on the relationship between hard lean practices and operational performance.

Specifically, we hypothesize moderator-variable interactions. Contrary to independent-variable interactions where each variable has an effect on the dependent variable, the moderating variable has no direct effect on the dependent variable (Luft & Shields, 2003). Despite being tested identically, the difference matters for the theoretical argumentation and development of hypotheses (MacKinnon, 2011; Tanriverdi & Venkatraman, 2005), which we elaborate on in the following. To confirm the existence of a moderator interaction effect, we also hypothesize a direct effect of soft lean practices on operational performance. Figure 21 provides an overview of the general research model.

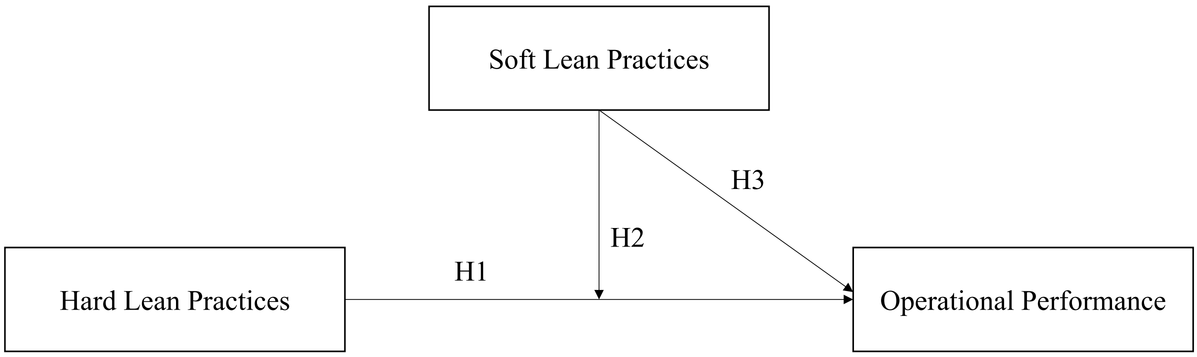

Figure 21 – Conceptual Framework

Prior research has extensively studied the performance effects of lean practices (Cua et al., 2001; Furlan et al., 2011; Galeazzo & Furlan, 2018; Netland et al., 2015; Shah & Ward, 2003). Generally, there is consensus that lean positively relates to operational performance (Bevilacqua et al., 2017; Godinho Filho et al., 2016; Vinodh & Joy, 2012), with some exceptions (Negrão et al., 2017). While a positive relationship should therefore be expected, we include this hypothesis because our research setting—the pharmaceutical industry—differs from other industries in several important ways and has received only limited attention (see Friedli et al., 2013, for a notable exception).

Pharmaceutical manufacturing sorts as process industry. Compared to discrete manufacturing, process industries have in general larger equipment, higher volumes, lower variety, fixed layouts, complex product changeovers, time dependence of the process and limitation of throughput by equipment rather than workforce (Abdulmalek et al., 2006). In addition to the mentioned issues, fixed batch sizes, the complicacy of spontaneously stopping or starting processes and the difficulty of moving manufacturing assets in classical cellular arrangements, which can be, for example, due to specific temperatures or pressures that need to be met, make it difficult to realize JIT principles, such as pull production or continuous flow (Abdulmalek & Rajgopal, 2007; King, 2009). This, however, only means that such circumstances can make the implementation of hard practices more difficult, but if successfully implemented, JIT production could still help pharmaceutical companies reduce inventory.

On the other hand, as the output is largely dependent upon manufacturing equipment, TPM practices can play an even more important role in the pharmaceutical industry compared to discrete manufacturing (King, 2009). As opposed to JIT, certain TPM practices are to some extent implemented in the pharmaceutical industry by nature. For example, pharmaceutical regulations require manufacturing companies to keep their workplace clean and organized according to certain standards, which is a goal that is also followed by lean housekeeping tools, such as 5S. Moreover, being one of the most strictly regulated manufacturing industries, pharmaceutical firms pay a lot of attention to controlling their quality. Hence, TQM is an effective set of tools for them to manage their process stability and consistency. Statistical process control is one of these tools that pharmaceutical manufacturers can employ just as well as in discrete manufacturing, as mathematical models can be developed independently of the environmental circumstances of the production system (cf. Floyd, 2010).

The pharmaceutical industry also has additional constraints in very strict market access regulations that limit or slow down the changes that can be imposed on the processes. Moreover, pharmaceutical products are often subject to large market volatility and unpredictability (consider, for example, Tamiflu or COVID-19 vaccines). These important characteristics assumedly affect the way hard lean practices can be employed and how they affect firm performance (Lyons et al., 2013). Nevertheless, pharmaceutical companies are seeking to implement lean like other industries (Friedli et al., 2013). The empirical evidence, while limited, further indicates a positive effect of lean implementation on firm performance in pharmaceutical companies (Boltic et al., 2016; Friedli et al., 2013). We therefore hypothesise:

Hypothesis 1: The application of hard lean practices is associated with higher operational performance in pharmaceutical manufacturing firms.

Soft lean practices aim at managing the social system of the organisation and involving all organisational members in lean thinking and acting. To define an appropriate set of management practices that serve as soft lean practices, we have reviewed prior literature.

Kennedy and Widener (2008) propose a framework of management practices associated with lean manufacturing that we used to inform our choice of practices. We adopt *employee empowerment*, *training*, *visualisation*, *work standardisation* and *performance measurement* as soft lean practices in our study. Further, we add *goal setting* to our set of practices, as the literature also suggests that it has performance effects (Bortolotti et al., 2015; Earley et al., 1990; Locke & Latham, 1990). Our theoretical argument for its inclusion is that externally imposed goals establish performance standards that can have an effect on the behaviour of employees. As employees are provided challenging but attainable goals matched with strong self-efficacy beliefs, they develop congruency between personal and organizational goals that supports motivation and, as a consequence thereof, higher performance levels (Appelbaum & Hare, 1996). Further, the formulation of common goals makes it easier for employees and teams to establish clarity of targets and reach consensus, which can positively affect teamwork and performance (Hong et al., 2004). Overall, we find that our selected soft lean constructs are commonly applied in manufacturing organisations to manage the implementation of lean (Camuffo & Gerli, 2018; Netland et al., 2015; Nielsen et al., 2018; Shah & Ward, 2003). In the following, we explain the related hypotheses.

Drawing on prior literature, a variety of potentially supportive effects of respective practices can be identified. *Employee empowerment* can help create a sense of responsibility by providing employees with the authority and means necessary to drive improvement activities (Fullerton et al., 2013). For example, empowerment can make employees more attentive and caring when it comes to maintaining equipment as part of a TPM programme. Further, employees are more eager to accept and follow plans when they have been involved in the decision-making process and realise ideas or projects that they have conceptualised themselves (Dombrowski et al., 2012; Poksinska, 2010). In addition, the empowerment of employees can encourage them to carry out experiments with the potential of learning more about the work environment and improving processes according to lean principles (Netland et al., 2021; Nielsen et al., 2018). In this context, the importance of learning has been recently demonstrated by Nielsen et al. (2021), who found that lean's effect on performance increases as employees who implemented lean showed a progressive learning curve. Based on these arguments, we hypothesise that:

Hypothesis 2a: Employee empowerment positively moderates the relationship between the application of hard lean practices and operational performance.

Another main reason for the success of the TPS is the way Toyota has developed its employees (Liker, 2004; Spear & Bowen, 1999). Toyota has invested considerable resources in employee and supplier qualification programmes (Ohno, 1988). Accordingly, *training* of employees has been recognised as a potential success factor by numerous lean studies (e.g., Bortolotti et al., 2015; Hadid & Mansouri, 2014; Kennedy & Widener, 2008; Netland, 2016). By qualifying employees in methods for eliminating waste, they can, for example, be equipped with skills that help them perform set-up time and cleaning time reductions more effectively (Ferradás & Salonitis, 2013). Further, cross-training of the workforce broadens their knowledge such that interdisciplinary tasks can be performed more efficiently (Boyer, 1996; McDonald et al., 2009). We, therefore, hypothesise a positive moderation effect through training of employees:

Hypothesis 2b: Training positively moderates the relationship between the application of hard lean practices and operational performance.

Work standardisation in the form of standard operating procedures (SOPs) represents a third soft lean practice that can support lean programmes. SOPs structure the behaviour of employees by specifying process steps (Langfield-Smith, 1997). Through the formalisation of standards, knowledge can be replicated and the spread of lean principles throughout the organisation can be supported (Netland et al., 2021; Secchi and Camuffo, 2016). Further, SOPs serve as a baseline for continuous improvement, which should be continuously updated to incorporate improvements (Nielsen et al., 2018; Secchi & Camuffo, 2016). They can therefore serve as a platform to capture hard lean practices and apply them more consistently. Additionally, they can, for example, help to structure maintenance, planning, or documentation efforts as part of a lean programme and reduce errors when exercising them, eventually leading to better operational performance. Due to the general applicability of work standardisation, we see potential performance effects with all types of hard lean practices. Activities such as establishing a Kanban system to realize pull production (JIT), using statistical models to control process quality (TQM), as well as doing planned maintenance (TPM) can be all standardized by defining how they should be conducted. Hence, we hypothesise a positive moderation effect:

Hypothesis 2c: Work standardisation positively moderates the relationship between the application of hard lean practices and operational performance.

Another way to guide the behaviour of shop-floor workers in the process is *visualisation*. Visualisation via visual boards, for example, directs the attention of employees to potential improvement areas on the shop floor (Liker, 2004). Further, visualisations can indicate deviations of current work processes or equipment from set standards (Emiliani et al., 2003). This can, for example, help employees detect anomalies in the manufacturing equipment, whereupon they can inspect it and possibly conduct maintenance activities to prevent downtime, fostering the effective use of TPM practices. Visualisation of current performance ensures that employees receive feedback when changing the process and enables them to assess the effectiveness of their changes. Through visualisation, also transparency can be established (Adler & Borys, 1996), which allows employees to not only solve their problems but also help others (Nielsen et al., 2018). This way, organisational learning and continuous improvement are supported, which supports the effects on operational performance (Galeazzo et al., 2017). To conclude, visualisation can lead to more effective use of hard lean practices:

Hypothesis 2d: Visualisation positively moderates the relationship between the application of hard lean practices and operational performance.

Goal setting depicts a fifth critical aspect of lean success that is often emphasised in the lean literature. Malmi and Brown (2008) include the planning of goals and actions as a core element of social lean systems. Galeazzo et al. (2017) confirm this notion and add that a goals-management system can support organisational learning. Bhamu and Singh Sangwan (2014) point out that clear goal setting for everyone in the enterprise can avoid misconceptions about goals and attention being paid to the wrong things. Similarly, Bortolotti et al. (2015) highlight that by clearly communicating goals, team members' efforts are more likely to converge toward a common direction, leading to increased team effectiveness. Hong et al. (2004) carried out a study on the team-level and came to the same conclusion. Due to increased consensus, target clarity and common goals foster teamwork and their performance. This can support hard lean practices that are carried out in teams, such as cross-functional teams developing new products as part of a TQM initiative. Therefore, we hypothesise that:

Hypothesis 2e: Goal setting positively moderates the relationship between the application of hard lean practices and operational performance.

Lastly, *performance measurement* is also known to influence the behaviour in production systems. To make good decisions and respond to situations appropriately, performance information is needed for managers and employees. Examples of performance information can be data on process quality (e.g., defects). Information is thus considered a powerful tool, which can act like a 'cueing device or tool for strategy implementation' (Earley et al., 1990, p. 102). The measurement of operational performance provides such information and reflects outcomes that are important to improve upon. On the one hand, employees have better information about what to target when implementing hard lean practices. To illustrate, knowing that unplanned maintenance has been an issue lately, employees can draw conclusions about when to focus on TPM practices, which could lead to more effective use of maintenance activities and ultimately to better performance. On the other hand, it can motivate employees to engage themselves more purposefully, leading to more effective performance improvement suggestions (Fullerton and Wempe, 2009; Said et al., 2003). Due to the transparency it creates on respective performance metrics and potential motivational aspects, performance measurement is likely to support the performance effect of hard lean practices. In other words, without the support of performance measurement, hard lean practices will not show their full potential. We therefore hypothesise:

Hypothesis 2f: Performance measurement positively moderates the relationship between the application of hard lean practices and operational performance.

By hypothesizing moderation effects, as opposed to independent-variable interactions, we implicitly assume that the moderating variable has no direct effect on the dependent variable (Luft & Shields, 2003). The reason why we think so is that we view an immediate link between hard lean practices and the technical system, which is generating output and directly related to operational performance. Soft lean practices affect the social system, which operates the technical system. Hard lean practices are thus a vehicle to drive operational performance, whereas soft lean practices instruct employees on how to drive that vehicle.

Merely training employees but not changing the technical system from push to pull production will obviously not have a performance effect but having trained employees who understand the actual purpose of pull production will make rather sure that pull practices have a performance impact. Another example is that visualization alone will not help improve performance, as it does not directly affect changes in the technical system. It is rather meant to be a cueing device that helps employees direct their improvement efforts more consciously and thereby increase the effectiveness of hard lean practices like maintenance activities. It will only exert its performance effect in combination with other activities. We can draw similar conclusions for the remaining soft lean practices, which we refrain from for the sake of brevity. Overall, we therefore hypothesize that soft lean practices generally do not affect operational performance directly:

Hypothesis 3: The application of soft lean practices alone is not directly associated with higher operational performance in pharmaceutical manufacturing firms.

3.4. Research Method

3.4.1. Instrument Development and Data Collection

We focus on pharmaceutical manufacturing firms to study the role of soft lean practices during the implementation of hard lean practices. Pharmaceutical firms operate in a highly regulated environment, which offers a unique opportunity to study the impact of soft lean practices across many organisations with homogenous organisational contexts. To test our hypotheses, we conducted one of the world's most comprehensive academic surveys in the field of pharmaceutical manufacturing—considering the number of participating manufacturing facilities and the extent of the questionnaire.

Data were collected from 2004 to 2019 and contain a cross-section of 351 manufacturing facilities located in 37 different countries, with a majority of the sites located in Europe. Our data showed a similar distribution across three distinct types of pharmaceutical manufacturers: brand, generics and contract manufacturers. Thus, the sample allows generalisation about the effect of soft lean practices on lean production across different types of pharmaceutical manufacturing facilities. Table 22 provides an overview of the data distribution for the studied sample.

Table 22 – Sample Composition of Responses (N=351)

Region	Europe	274	78%	**Plant type**	Brand manufacturer	152	43%
	North America	39	11%		Generics manufacturer	92	26%
	South/Mid America	10	3%		Contract manufacturer	107	31%
	Asia	7	2%	**Plant size**	Small (<100 Employees)	69	20%
	Africa	21	6%		Medium (100-500 Employees)	216	64%
					Large (>500 Employees)	54	16%

The questionnaire that was used for data collection consists of three sections. The first section collects contextual data, such as information on plant type, plant size, or the number of products manufactured at the facility. The second section collects data on operational performance. The third section assesses implementation levels of lean practices. The items in our study are primarily drawn from the global world-class manufacturing study (Schroeder & Flynn, 2001), which we structured into TPM, TQM, JIT and human-related management practices, analogously to prior studies (Cua et al., 2001; Flynn et al., 1995; Shah & Ward, 2003). We thereby cover both hard and soft lean practices.

To ensure validity for pharmaceutical manufacturing, the measures were extended and adjusted to the pharmaceutical context. This means that we have reformulated some of the questions and added further questions with particular relevance to the pharma context (e.g., supplier qualification processes, audits, use of latest technology). The measurement instrument was then reviewed by seven pharmaceutical lean production experts to ensure that the measurements were appropriate for the pharmaceutical industry and interpreted correctly by target respondents. The fourth and fifth constructs, namely *Basic Elements* and *Effective Management System,* measure the implementation of soft lean practices, similarly to Cua et al.'s (2001) construct of cross-cutting common practices.

To reduce common-respondent bias, data were collected from multiple respondents per firm. Middle and top managers, such as plant managers, site directors, or lean programme managers, were asked to fill out the first two parts of the survey covering contextual and performance data. To ensure an objective lean maturity self-assessment, teams of company representatives from relevant cross-functions such as quality or maintenance were asked to *jointly* fill out the third part of the survey, thus avoiding bias from single respondents in the self-assessment. It was also highlighted that there were no correct or incorrect answers in the self-assessment. Bias from proximity and single respondent bias was further avoided by splitting the questionnaire into two parts with different respondents for the performance and lean maturity assessments. Since all respondents were either involved in leading or executing lean implementation at a site, it was ensured that all respondents were appropriate informants for data collection.

3.4.2. Measurement

The collected data facilitate an objective assessment of the effects of different hard lean practices on operational performance. In particular, our questionnaire has two benefits that distinguish it from most existing lean research.

First, it separates efforts from outcomes in the lean assessment, as it measures levels of lean practice application rather than asking for outcomes. Many other studies ask for the degree to which different lean principles are evidenced by outcomes (e.g., 'We have low set-up times'). In contrast, our survey instrument explicitly asks for the organisational efforts applied to fulfil these principles (e.g., 'We are continuously working to lower set-up and cleaning times in our plant'). By doing so, our database allows us to separate efforts from outcomes as part of the lean assessment, similarly to a recent study carried out by Nielsen et al. (2021). This has the advantage of creating more instructive insights for managers and allowing us to study moderation effects of soft lean practices, as their presence can be the determining factor for the outcome of hard lean practices.

Second, the survey instrument measures operational performance with actual performance metrics (e.g., the number of rejected batches as a percentage of all batches produced, annual cost of goods sold divided by the average finished goods inventory, etc.), thereby allowing a highly objective assessment of performance, as it does not include any personal feelings, opinions or tastes. Usually, academic lean studies measure operational performance predominantly in one of the following two ways: either by asking for percentages of performance change in a given time frame (such as the last three or five years) and by using rough ordinal scales (e.g., increase by less than 3 %, by 3 to 5 %, or by more than 5 %), or by asking for a self-assessment against the performance of competitors in a similar time frame (e.g., different Likert scales indicating worse, equal, or better).

In contrast to most studies on lean that use performance proxies, our study uses actual, realised performance numbers (see Appendix 2), which is inevitably associated with a significantly higher effort of data collection. As a reward, our study facilitates more accurate and more objective insights into the relation between lean implementation and operational performance than the described alternatives. Yet, due to the high complexity of production systems and the associated high number of influencing factors on the performance of these systems, it could be difficult to establish a statistically significant effect using hard performance numbers. Asking for perceptive data about the changes in performance could be closer to capturing the cause-and-effect relationship. However, not only does it entail the risk of a response bias (i.e., the respondents' opinion influencing the measure), but it will also never be as accurate as realised numbers. Therefore, we perceived the benefits of real performance metrics to outweigh their drawbacks and opted for this approach.

Table 23 provides an overview of the measurements for dependent, independent and moderating variables. The data collected on lean practice implementation comprised both hard and soft lean practices.

Table 23 – Conceptualization of Soft Lean Practices, Hard Lean Practices and Operational Performance

Category	Subcategory	Indicator
Soft Lean Practices	-	Employee Empowerment
		Training
		Work Standardisation
		Visualisation
		Goal Setting
		Performance Measurement
Hard Lean Practices	JIT Basic Techniques	Set-up time reduction
		Pull system production
		Equipment layout
		Schedule adherence
	TQM Basic Techniques	Process management
		Cross-functional product design
		Supplier quality management
		Customer involvement
	TPM Basic Techniques	Autonomous and planned maintenance
		Technology emphasis
		Housekeeping
Operational Performance[a]	Quality – Internal	Rejected batches
	Quality – External	Customer complaint rate
	Dependability – Equipment	Unplanned maintenance
	Dependability – Internal Delivery	Production schedule adherence
	Dependability – External Delivery	On-time delivery
	Speed – Process Time	Deviation closure time
	Cost – Inbound Inventory	Raw material turns
	Cost – Outbound Inventory	Finished good turns

[a] Real performance indicators used for operational performance

To measure the implementation of hard lean practices, we used the constructs *TPM practices, TQM practices and JIT practices.* To construct a scale for hard lean practices, we used principal component analysis (PCA). Since we were interested in studying the effect of soft lean practices on the effectiveness of the entire lean system and given the high interrelation between hard lean practices outlined in lean literature (Shah & Ward, 2007), a one-factor model was considered adequate and confirmed by our extraction using PCA (cf. Table 25).

To develop individual soft lean constructs, we drew on items from the socially-oriented constructs in our survey ('Basic elements' and 'Effective Management System'). For soft lean practices, we combined multiple survey items into six new constructs: *employee involvement (EE)*, *training (Tra), work standardisation (WS)*, *visualisation (Vis)*, *goal setting (GS) and performance measurement (PM)* (see Appendix 1 for further details). For this purpose, we first performed a content-based preselection of potentially suitable soft lean practices for each construct based on available survey items. Then, we verified the content-based preselection using CFA.

Finally, we used eight real performance metrics to measure the actual operational performance of a plant. All performance measures were calculated in such a way that higher values indicated better performance, also variables such as inventory or time. More details about the metrics definitions and operationalisation, such as units, positive direction and normalisation can be found in Appendix 2. To ensure a comprehensive assessment of operational performance, we measured performance in dependability, speed, cost performance and quality (Ferdows & De Meyer, 1990). To identify relevant metrics for measuring performance in the four dimensions, we drew on key objectives of TQM, JIT and TPM as formulated in the literature as guidance because, in conjunction, they facilitate operational effectiveness and efficiency (Cua et al., 2001). TQM aims at eliminating defects and reworking to increase quality (Brown & Mitchell, 1991). For quality performance, we distinguished between an *internal* and *external quality* performance dimension as per Shah et al. (2017) and used the metrics *rejected batches* and *customer complaint rate* as respective internal and external performance indicators. JIT aims at reducing waste in production flow to achieve low inventory levels (Shah & Ward, 2003). We used the metrics *production schedule adherence* and *on-time delivery* as measures of internal and external dependability and further used the metrics *raw material turns* and *finished good turns* as indicators for inventory levels. Finally, as the primary objective of TPM is to maximise equipment effectiveness and stability to avoid breakdowns or delays (Cua et al., 2001), we included equipment as the third dimension of dependability performance and used the metric *unplanned maintenance* as a measure of equipment dependability. Since linear hierarchical regression requires point estimates and thus a single score for the dependent variable, we calculated a single performance score for each plant by averaging the scores of the eight underlying performance metrics.

3.4.3. Common Method Bias

To avoid common method bias, our study follows Podsakoff et al.'s (2003) recommendations. Method bias from proximity was avoided by assessing lean practice implementation and operational performance in physically separated sections. The subjectivity of the performance assessment was avoided by asking for data on actual performance metrics. To also maximise objectivity for lean implementation self-assessment, study participants were asked to form a team of multiple respondents from different relevant functional areas and fill out the self-assessment jointly. Overall, we received responses from three to five respondents per plant.

3.4.4. Control and Moderator Variables

We used site size as a control variable in the quantitative analyses since several lean researchers have pointed out that the size of a company can affect the level of lean implementation (Shah & Ward, 2003; Tortorella et al., 2018). To control for company site size, we followed common classification in operations management research and distinguished between large sites on the one hand (≥500 employees) and small or medium-sized sites on the other hand (<500 employees) (e.g., Lyons et al., 2013; Tortorella et al., 2019; Youn et al., 2012). To allow generalisation across distinct pharmaceutical site types, we further considered the site classifiers *brand manufacturers*, *generics manufacturers and contract manufacturers* as control variables[2]. We also tested the age of machinery equipment, level of automation and the number of manufactured products at the site as control variables but did not find any other significant results. Thus, we included only site size and the three distinct site types in the hierarchical regression models.

Since we are studying the role of soft lean practices on the relationship between hard lean practices and operational performance, we used each of the six soft lean constructs as moderators in our regression. The measurement items for the soft lean constructs provided values on a Likert scale from 1 to 5. We used standardised values for the predictor and moderator variables and tested for multicollinearity to ensure that it was not an issue (Aiken et al., 1991). All variance inflation factors in our regression models did not exceed 1.18 and were thus below the threshold of 4.0, suggesting that multicollinearity was not a concern. We also verified that our data met the normality, linearity and homoscedasticity requirements for regression analysis (Hair et al., 2006). We then calculated one interaction term for each soft lean construct with the hard lean practice construct, summing up to a total of six interaction terms (HLPxEE, HLPxTra, HLPxWS, HLPxVis, HLPxGS, HLPxPM).

3.5. Results

3.5.1. Construct Validity and Reliability

To ensure one-dimensionality of the six individual soft lean practices, we used CFA (see Table 24). All factor loadings ended up well above 0.5 (with one exception at 0.42), which generally meets the suggested threshold by Hair et al. (2006). Following Hu and Bentler (1999), our

[2] Brand manufacturers are pharmaceutical companies that produce regulatorily approved original brand-name drugs, for which they hold patents. Generics manufacturers produce drugs that are made of the same active ingredients as the original brand-name drugs after their patents have expired. Contract manufacturers are pharmaceutical contractors that produce drug products for pharmaceutical clients.

model showed further good fitness indices. Results of the $\chi 2$ test were below the threshold of 3 ($\chi 2$/df = 1.994), the Comparative Fit Index (CFI) was considered high (CFI = 0.95) and the Root Mean Square Error of Approximation (RMSEA) was only slightly above the threshold of 0.05, but still below 0.08 (RMSEA = 0.056), which is considered as good model fit. To test reliability, Cronbach's α was calculated and was greater than 0.7 for each construct, indicating satisfactory construct validity (Hair et al., 2006). Convergent validity and discriminant validity were further tested under consideration of composite reliability (CR) and the average variance extracted (AVE), respectively (Hair et al., 2006; Zait & Bertea, 2011). The recommended values of CR > 0.7 and AVE > 0.5 were exceeded for all six soft lean constructs, thereby indicating good convergent and discriminant validity. Further, we support discriminant validity by showing that the square root of average variance extracted exceeded all other correlation coefficient values (see Table 26).

Table 24 – Control Measurement Items, CFA Factor Loadings and Construct Reliability

Construct	Item	Factor loading CFA	Composite Reliability (CR)
Employee Empowerment	EE1	0.790	0.763
	EE2	0.633	
	EE3	0.732	
Training	Tra1	0.773	0.804
	Tra2	0.922	
	Tra3	0.559	
Work Standardisation	WS1	0.655	0.772
	WS2	0.733	
	WS3	0.792	
Visualisation	Vis1	0.793	0.792
	Vis2	0.842	
	Vis3	0.702	
	Vis4	0.419	
Goal Setting	GS1	0.764	0.799
	GS2	0.779	
	GS3	0.722	
Performance Measurement	PM1	0.666	0.757
	PM2	0.886	

To create a scale for the hard lean practice measure, we used 11 variables measuring TPM, TQM and JIT practices as independent variables in the PCA. Table 25 shows the means and all factor loadings for the extracted component. The means range from 2.78 to 3.92, which is a spread that indicates a preference of certain hard lean practices over others. Set-up time reduction and pull system production, both JIT practices, were applied least intensely. Overall, TQM and TPM practices, such as autonomous and planned maintenance, customer involvement and housekeeping were applied more strongly, which is not surprising in an equipment-heavy and quality-oriented industry like pharmaceuticals.

The factor loadings of the constructs were all above 0.4. The component had an eigenvalue of 4.40 with a Cronbach's α of 0.842. The one-factor model explained 40.01 % of the variation. Consequently, the hard lean practice score was calculated as a one-factor variable including the 11 factor scores underlying the constructs TPM, TQM and JIT practice.

Table 25 – Hard Lean Practice Construct: Means, Standard Deviation and Factor Loadings

			Component
	Mean	**S.D.**	**Hard lean practices**
Set-up time reduction (JIT)	2.91	0.74	0.771
Pull system production (JIT)	2.78	0.64	0.526
Equipment layout (JIT)	3.04	0.81	0.665
Schedule adherence (JIT)	3.50	0.67	0.727
Process management (TQM)	3.20	0.79	0.736
Cross-functional product design (TQM)	3.39	0.93	0.558
Supplier quality management (TQM)	3.35	0.62	0.522
Customer involvement (TQM)	3.60	0.74	0.497
Autonomous and planned maintenance (TPM)	3.55	0.68	0.665
Technology emphasis (TPM)	2.88	0.72	0.639
Housekeeping (TPM)	3.92	0.86	0.578
Eigenvalue (variance explained)			4.40 (40.01%)
Cronbach's α			0.842

Extraction method: Principal component analysis.

3.5.2. Pearson Correlations

To understand the interrelation between individual soft lean constructs, correlations among the six constructs are presented in Table 26. First, the results showed a strong correlation among all control constructs ($p < 0.01$) indicating high interrelation among the constructs. These findings correspond well to the findings of Nielsen et al. (2018) who found similar significant correlations between individual soft management practices. Second, correlations among the six constructs were positive, suggesting that pharmaceutical companies follow a comprehensive approach where the implementation of one construct goes hand-in-hand with the implementation of the others. Third, *training* showed on average the lowest correlation coefficients with other control constructs (on average $r = 0.383$), suggesting that it is coupled more loosely to the other control constructs. Finally, *goal setting* and *employee empowerment* showed on average the highest correlation coefficients (on average $r = 0.638$ and $r = 0.584$), signifying the highest interconnectivity with other soft lean practices.

Table 26 – Correlation, Mean and Standard Deviation of Soft Lean Practices

Construct		Mean	S.D.	AVE	EE	Tra	WS	Vis	GS	PM
Employee Empowerment	EE	3.582	0.858	0.52	**.721**					
Training	Tra	3.381	0.784	0.587	.461	**.766**				
Work Standardisation	WS	3.657	0.800	0.531	.530	.489	**.729**			
Visualisation	Vis	2.894	1.006	0.502	.673	.441	.471	**.708**		
Goal Setting	GS	3.964	0.779	0.571	.687	.544	.646	.650	**.755**	
Performance	PM	3.877	0.933	0.614	.567	.363	.529	.510	.661	**.784**

**Significant at the p < 0.01 level, square root of average variance extracted in the diagonal

3.5.3. Linear Hierarchical Regression

To test our hypotheses, we calculated a hierarchical set of ordinary least square linear regression models. In these models, we considered the effects of hard lean practices and soft lean practices on operational performance. We further calculated interaction terms between each of the soft lean constructs with lean practices (e.g., HLPxVis) and tested their effects on operational performance (aggregation of the performance metrics outlined above). Also, we included control variables in the model, such as *site type* and *firm size*.

Table 27 shows the hierarchical linear regression results with control variables, the two types of lean practices, plus their interaction terms as independent variables and performance as a dependent variable. We reported the unstandardised regression coefficients given the prior standardisation of the moderation variables (Goldsby et al., 2013). The results show that the contextual factors plant size and plant type accounted for a small but significant amount of variance (adjusted $R^2 = 0.038$, $P < 0.001$). The inclusion of hard lean practices and individual soft lean practices resulted in a change of R^2 to 0.162. Subsequent additional inclusion of the interaction terms further improved the model and explained variance of 23.1%. Five out of six interaction terms showed statistically significant effects.

The results confirm our first hypothesis and show a positive effect of hard lean practices on operational performance. For the remaining hypotheses, some soft lean practices showed significant moderating effects on the relationship between hard lean practices and operational performance. The three soft lean practices *visualisation, performance measurement and employee empowerment* showed a significant positive effect, whereas *work standardisation* and *goal setting* had a statistically significant negative effect. Since *training* did not show a significant interaction with hard lean practices, we only find evidence in support of hypotheses

2a, 2d and 2f. Lastly, we confirm our third hypothesis, as we find soft lean practices to have no direct effect on operational performance.

Table 27 – Results of OLS Regression Analysis

	Model 1	Model 2	Model 3
Size	-0.001**	-0.001***	-0.001***
Brand Manufacturer	0.237	0.093	0.206
Generics Manufacturer	-0.015	-0.017	-0.023
Contract Manufacturing Organisation (CMO)	-0.502**	-0.330	-0.319
Hard Lean Practices (HLP)		0.361**	0.387***
Employee Empowerment (EE)		0.075	0.116
Training (Tra)		0.109	0.076
Work Standardisation (WS)		0.071	0.058
Visualisation (Vis)		-0.077	-0.129
Goal Setting (GS)		-0.083	-0.142
Performance Measurement (PM)		0.126	0.179*
HLPxEE			0.290**
HLPxTra			-0.113
HLPxWS			-0.292***
HLPxVis			0.259**
HLPxGS			-0.221*
HLPxPM			0.171*
Adj. R^2	0.038	0.162	0.231
ΔR^2	0.060	0.153	0.091
F-value	2.788	4.674	3.539
P-value of F statistic	0.028	0.000	0.003

*p < 0.1; **p < 0.05; ***p < 0.01.

3.6. Discussion

Our findings indicate that soft lean practices can have complex implications for the implementation of lean programs. First, we show statistically significant correlations between individual soft lean practices, which suggests that they might be commonly applied together in pharmaceutical manufacturing firms. This raises the question of whether companies blindly apply them all together as common practice without considering the individual effects each of them might have on the effectiveness of hard lean practices. Current approaches for lean implementation in these firms are, therefore, potentially not optimised for an effective interplay between both hard and soft lean practices.

Second, the results of our linear hierarchical regression show significant interaction effects between soft lean practices and the technical lean system. More specifically, the regression results reveal two-directional interaction effects on operational performance. Some soft lean practices support the relationship between hard lean practices and operational performance, some do not, and some even undermine it with a negative effect. Interestingly, soft lean practices do not show significant performance effects in isolation, which can be due to not affecting the technical system directly but only the social system. These findings expose a conditionality for the effect of soft lean practices on operational performance that is dependent on the technical lean system (cf. Beraldin et al., 2019; Galeazzo & Furlan, 2018).

Accordingly, pharmaceutical manufacturing companies should implement hard lean practices if they want to improve their operational performance. Further, managers are advised to pay close attention to the behavioural implications of soft lean practices for the effect of hard lean practices, as these interactions can enhance but also weaken operational performance. We discuss these implications in the following sections.

3.6.1. Enhancing the Performance Effect of Lean

We find significant, positive moderation effects for visualisation, *employee empowerment* and *performance measurement* and thus confirm the three corresponding hypotheses. Regarding *visualisation*, our results confirm that the use of real-time performance charts, technical documents and visualised workplace information on the shop floor increases the positive effect of hard lean practices on operational performance. Such measures can help to raise the employees' awareness of potential improvement areas and the understanding of how their work relates to other work activities (Liker, 2004; Nielsen et al., 2018), which ultimately leads to effective use of hard lean practices.

We find similar effects for *employee empowerment*, as shop-floor workers' involvement in writing policies and procedures, decision-making authority and engagement in suggestion programmes supported lean effectiveness. Such empowerment of people can go hand-in-hand with an increased sense of responsibility, which is also what Lincoln and Kalleberg (1990) identified as a characteristic of Japanese workers. Once employees feel responsible for certain tasks, they do not do them just because they are being told to do so but start being concerned about the quality of their output, which reflects their behaviour as well as its potential consequences (Hackman & Oldham, 1976). This in turn reduces the risk of employees only *copying* hard lean practices into already existing organisational habits (corruption of lean practices) instead of *transforming* existing processes for the sake of actual performance improvement (cf. Lozeau et al., 2002).

The third positive moderation effect we identify is related to performance measurement. Continuous, real-time measurement of quality, use of statistical process control and the linkage of process measures to plant objectives create comprehensive awareness of plant performance

(Bunderson & Boumgarden, 2010; van Dun & Wilderom, 2021). Well-informed employees can therefore more easily align their behaviour with lean manufacturing objectives by, for instance, deciding where to lower set-up times or how to reduce batch sizes (Liker, 2004; Nielsen et al., 2018). In addition to that, the awareness caused by performance measurement can create a feeling of responsibility and promote employees' commitment to improvement activities (van Dun & Wilderom, 2021; Fullerton et al., 2014).

3.6.2. Inhibiting the Performance Effect of Lean

The significant negative effects found in this study for the interaction of *work standardisation* and *goal setting* with the technical lean system might be surprising at first. However, we find literature that takes the risk of counterproductive consequences of both constructs similarly into account. Examples include *selective attention* and *illusion of control* (Franco-Santos & Otley, 2018), *inertia* and *disempowerment* (Bititci, 2015), *reduction of intrinsic motivation and employee engagement* (Sitkin et al., 2010), or *lack of learning and innovation capabilities* (Adler & Borys, 1996).

SOPs are often associated with higher product quality and performance (Kennedy & Widener, 2008). However, Adler and Borys (1996) also highlight that these often lead to inefficient workarounds or barriers to improvement because they are often not designed to aid the user or to enable continuous improvement. In the pharmaceutical industry, SOPs primarily serve a regulatory role, ensuring that procedures are carried out correctly (Friedli et al., 2010). This falls short of the broader lean vision of ensuring a company-wide and ongoing effort for improvement (Liker, 2004; Ohno, 1988). Thus, in pharmaceutical manufacturing, procedural regulation could act as a barrier for improvement, particularly given the fact that changes in regulatory procedures can require resource-intensive regulatory validation.

In terms of *goal setting*, lean literature emphasises the importance of clearly communicating goals for lean success. However, recent literature also highlights potential counterproductive consequences of directive performance management, including the selective focus on target metrics to the detriment of other important aspects of performance (Franco-Santos & Otley, 2018). Some of the latest research further suggests that these side effects of directive performance management are more likely to appear in complex and regulated organisations such as pharmaceutical manufacturing firms (Franco-Santos & Otley, 2018; Tan & Rae, 2009). Liker (2004) emphasised the danger of selective attention to strict goal setting and noted that employees 'will work to make the numbers regardless of quality' (p. 141). Thus, our findings are closely related to the question of how goals are set and communicated in pharmaceutical manufacturing firms. It also shows that this may either enable an organisation-wide pursuit of holistic lean goals or hinder it by leading to the pursuit of more selective performance objectives.

3.6.3. Enabling vs. Coercive Effects on the Workforce

The formalization of processes can either have an *enabling* effect or *coercive* effect on the workforce (Adler & Borys, 1996), which could explain the different outcomes we observed with the application of soft lean practices. Enabling forces occur when employees are supported in dealing with contingencies that arise when doing their work. This can be guidelines for solving problems in case of breakdowns, transparency about the progress or quality of processes, global transparency about issues that go beyond an employee's primary scope like information on the strategic orientation, or flexibility in terms of having options to choose from, or even developing new ones, when solving tasks. On the contrary, coercive mechanisms force employee's efforts and compliance by limiting their freedom when executing their tasks and discouraging any deviation from the standard procedure (Adler & Borys, 1996). They can cause feelings of powerlessness, alienation and psychological stress for employees and ultimately lead to negative performance effects (Adler & Borys, 1996; Kakabadse, 1986). In the lean context, enabling mechanisms tend to be favoured and produce better results compared to coercive mechanisms (Kristensen, 2021; Mehta & Shah, 2005).

Among the positive moderators, we identify a notable commonality. All of them support organisational commitment and involvement by facilitating employees to implement lean, which reflects the concept of enabling mechanisms well. By increasing the responsibility and performance awareness of employees as well as the information available on the shop floor, employees are better equipped and potentially more motivated to engage themselves in continuous improvement. This is confirmed by Hirzel et al. (2017) who show that employee empowerment promotes commitment to continuous improvement activities. The importance of this finding is stressed by Angelis et al. (2011) who stated that lean programmes neither inherently support nor impede commitment, but the design of policies and practices does so.

Regarding the negative moderators, we find a commonality in that they reflect a more commandment-oriented management approach rather than one that is commitment-oriented. As opposed to the positive moderators that support facilitation and empowerment, goal setting and standardisation of work traditionally aim at imposing guardrails and constraints on employees that may divert them from the common lean goals and thus could hamper a successful lean implementation (Beraldin et al., 2019; Mawritz et al., 2014; de Treville & Antonakis, 2006).

Managers who tailor the management infrastructure too much toward commanding and micro-management may, therefore, restrict their employees, depriving them of opportunities to initiate improvements and running the risk of losing the broader vision for the actual purpose of their lean programmes. We, therefore, conclude that a commandment-oriented use of instructions and objectives as limiting and rigid measures could have exhibited coercive forces and was possibly the reason for the observed negative effects.

3.6.4. Enabling Potential of Standardisation and Goal Setting

In the previous section, work standardisation and objectives received a negative connotation. In the following, we intend to put this into a different perspective. While instructions and objectives prescribe how work should be done, they can also be very supportive of lean by providing employees with opportunities for continuous improvement, given employees have the freedom and authority to act on them (cf. Giddens, 1984; Liker, 2004).

To illustrate this with an example, standardised work set-ups in pharmaceutical firms are examples of organisational infrastructure that influence the actions of the workforce. They constrain human behaviour and innovation, as they specify how procedures are to be performed. By the same token, they can also enable the workforce to perform their tasks more efficiently or can act as a basis for continuous improvement (Adler & Borys, 1996). Liker (2004, p. 147) noted that ‘standards have to be specific enough to be useful guides, yet general enough to allow for some flexibility.’ Similarly, Camuffo and Gerli (2018) distinguish a good lean manager as someone who does not micromanage but develops standards in collaboration with their team and uses them as a baseline for continuous improvement. Correspondingly, the other soft lean practices, *employee empowerment, performance measurement, visualisation, training and goal setting,* can also enable and constrain individual actions depending on how managers interpret them.

We conclude that by determining the organisational infrastructure for lean implementation, managers take on a crucial role in enabling or constraining greater worker commitment to successfully implement lean. There is a fine line between commitment-oriented and commandment-oriented management, which can be crucial for the success of lean implementation.

3.7. Conclusion

Many manufacturing companies have been struggling with the effective implementation of lean programmes. The purpose of this study was therefore to help reduce the number of these cases by providing a better understanding of how *soft lean practices* influence the success of lean programmes in pharmaceutical manufacturing companies. To fulfil this purpose, we analysed global survey data and established relationships between three constructs: *soft lean practices*, *hard lean practices* and *operational performance*.

As many researchers do not clearly separate between soft and hard lean practices, our first contribution was to create a theoretical setting that explains how organisational behaviour in manufacturing firms can be influenced and to separate hard lean practices from soft lean practices. By distinguishing hard from soft lean practices, it was possible to study their impact on performance separately as well as their interaction effects. Particularly, the latter have not been studied to such an extent before, to the best of our knowledge, despite numerous studies indicating that the success of lean programmes depends on human factors (e.g., Bortolotti et al., 2015; Camuffo & Gerli, 2018; Netland et al., 2015). By adding interaction terms between soft lean practices and hard lean practices to our model, we increase the model fit and find significant moderation effects, which suggests a contingent relationship between lean and operational performance.

Second, our results further provide empirical evidence for the collective use of soft lean practices and their effects, which have not been studied comprehensively before in pharmaceutical lean programmes. The pharmaceutical industry differs significantly from discrete manufacturing and presents individual characteristics, that have significant effects on the interaction between the social and technical production system. We delineate these characteristics and discuss how they influence the use of soft lean practices and their effects on the link between hard lean practices and operational performance.

The third contribution of this study was to show that the application of common *soft lean practices* in lean systems can lead to positive but also negative performance effects. Our results showed that *soft lean practices* like *employee empowerment*, *visualisation* or *performance measurement* can indeed help support the effectiveness of lean programmes, whereas *work standardisation* and *goal setting* can show the opposite effect. Given these two-directional performance effects, while at the same time observing a unidirectional implementation of soft lean practices, we conclude that behavioural implications of soft lean practices play an important role in the implementation of lean systems.

3.7.1. Managerial Implications

For managers, this study raises awareness regarding the socio-technical implications of implementing lean programmes. The implementation of lean includes both hard and soft lean practices that affect different parts of the organisation but are still interrelated. Due to the complexity of socio-technical systems (Soliman et al., 2018), the successful implementation of lean depends on a delicate configuration of these parameters.

It has further been shown that potentially unintended consequences can result from the application of certain soft lean aspects in pharmaceutical lean systems. Managers, particularly in the pharmaceutical industry, are therefore advised to pay close attention to the definition of goals as well as standardisation policies, being aware of potential negative impacts on the effectiveness of lean efforts. Therefore, they should not be discouraged in their lean implementation efforts in cases of unintended consequences but should instead adopt a situational approach to soft lean practices integrating forms of both commitment and commandment in suitable ways.

3.7.2. Limitations and Future Research

This study focuses on the pharmaceutical industry, which is a highly regulated, technology-intensive context and includes industry-specific obstacles to change or improvement. It is therefore difficult to claim generalisation of our findings to other industrial contexts. Second, while quantitative models are well-suited for establishing correlational associations between variables, this does not necessarily imply causal relationships. We cannot rule out potential endogeneity issues. For example, better-performing plants might be rather able to afford investments in the implementation of hard and soft lean practices. Third, we cannot rule out the possibility of other firm- or plant-level variables being correlated with the independent variables but omitted by our model. And lastly, our moderated regression could only test two-way interactions, whereas the implementation of lean is a complex socio-technical undertaking that involves many more variables and effects at the same time. To some extent, our approach is therefore limited in capturing the whole picture of relevant effects, which could, however, be tackled in future research with qualitative research designs.

While lean literature identifies the need for the optimisation of both the social and the technical lean sub-system (Bortolotti et al., 2015; Hadid & Mansouri, 2014; Shah & Ward, 2003), contextual lean studies still provide little systematic guidance for implementing lean practices under consideration of both infrastructural and behavioural management aspects. In this light, contextual lean research would benefit from adopting more integrated perspectives that explicitly consider both dimensions. Thus, one pathway for further research is to explore how soft lean practices can support or even inhibit the performance effects of hard lean practices in different contexts.

In our study, soft lean practices alone did not show any direct performance effects. It is, however, questionable if this was due to the specific research setting in the pharmaceutical industry or if this is a generally occurring phenomenon. Future lean studies are therefore encouraged to emphasise the analysis of soft lean practices in other research contexts. It would be interesting to test if this effect can be replicated in different manufacturing industries to verify whether a successful implementation of lean actually depends strongly on the implementation of the technical aspects of lean, or if social aspects alone (e.g., empowerment or cross-functional teams) can already enhance firm performance.

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3.9. Appendix 1

Table 28 – Measurement items of soft lean practices

Item	Management Control Practice
EE1	Shop-floor employees are encouraged to actively drive suggestion programmes
EE2	Our plant forms cross-functional project teams to solve problems
EE3	We have implemented tools and methods to deploy a continuous improvement process
Tr1	Each of our employees within our work teams is cross-trained so that they can fill in for others when necessary
Tr2	At our plant, we have implemented a formal programme to increase the flexibility of our production workers. Employees rotate to maintain their qualification
Tr3	We continuously invest in the training and qualification of our workers. We have a dedicated development and qualification programme for our production workers
Std1	We emphasise standardisation as a strategy for continuously improving our processes, machines, and products
Std2	We use our documented operating procedures to standardise our processes
Std3	Optimised operating procedures are documented as best-practice processes and rolled-out throughout the plant
Vis1	Performance charts at each of our production processes indicate performance objectives
Vis2	Charts showing current performance status are posted on the shop floor and visible to everyone
Vis3	Charts showing current tact times and schedule compliance are posted on the shop floor and visible to everyone
Vis4	Technical documents and workplace information are posted on the shop floor and are easily accessible and visible to everyone
GS1	Our vision, mission, and strategy are broadly communicated and lived by our employees
GS2	The goals and objectives of the manufacturing unit are closely linked and consistent with corporate objectives. The production site has a clear focus
GS3	The overall objectives of the production sites are closely linked to the team or personal objectives of our shop-floor teams and employees
PM1	We continuously measure the quality of our processes by using process measures
PM2	Our process measures are directly linked to our plant objectives

3.10. Appendix 2

Table 29 – Operational Performance Measurement

Dimension	Indicator	Unit	Optimisation direction	Score calculation	Operational performance
Quality	Rejected batches	%	Down	1-Percentile	Average of all eight calculated scores (0-1)
Quality	Customer complaint rate	%	Down	1-Percentile	
Dependability	Unplanned maintenance	%	Down	1-Percentile	
Dependability	Production schedule adherence	%	Up	Percentile	
Dependability	On-time delivery	%	Up	Percentile	
Speed	Deviation closure time	Days	Down	1-Percentile	
Cost	Raw material turns	1	Up	Percentile	
Cost	Finished good turns	1	Up	Percentile	

3.11. Appendix 3

Table 30 – Operational Performance Measurement Definitions

Indicator	Definition
Rejected batches	Number of rejected batches as a percentage of all batches produced
Customer complaint rate	Number of complaints as a percentage of all customer orders delivered
Unplanned maintenance	Proportion of unplanned maintenance work as a percentage of the overall time spent for maintenance
Production schedule adherence	Number of orders finished in the correct week and volume (+/- 10%) of total number of orders planned for completion that week
On-time delivery	Perfect order fulfilment to your customer as percentage of orders shipped in time from your site (+/- 1 days of the agreed shipment day), in the right quantity (+/- 3% of the agreed quantity), and in right quality
Deviation closure time	Number of deviations per month that arise from raw materials purchased, production components (equipment), and product or process specifications
Raw material turns	Annual cost of raw materials purchased divided by the average raw material inventory
Finished good turns	Annual cost of goods sold divided by the average finished goods inventory

3.12. Appendix 4

Table 31 – Correlation Analysis of Real Performance Metrics

Measurement	Mean	S.D.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rejected batches	0.522	0.299	–							
Customer complaint rate	0.515	0.296	.118**	–						
Unplanned maintenance	0.522	0.286	0.020	0.049	–					
Production schedule adherence	0.459	0.279	0.089	-0.064	-0.023	–				
On-time delivery	0.477	0.280	0.065	0.035	-0.019	.281***	–			
Deviation closure time	0.522	0.287	0.007	0.005	-0.065	0.019	-0.031	–		
Raw material turns	0.490	0.294	.132**	0.053	-0.039	.281***	-0.044	.182**	–	
Finished good turns	0.495	0.292	.134**	-0.093	-0.092	0.006	-.242***	.214**	.346***	–

*p < 0.1; **p < 0.05; ***p < 0.01.

Chapter 4

4. The Role of Managerial Perceptions and Behaviors in Lean Programs

This chapter is based on a manuscript submitted to the *International Journal of Operations and Production Management* on 3. July 2022.

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4.1. Abstract

Purpose – Do managers at different hierarchical levels perceive the effectiveness of lean programs differently, and does it matter? Does perception affect commitment to the program and actual implementation? Our study sheds light on these questions by analyzing the perceptions and behaviors of middle and top managers in a global manufacturer deploying a lean program.

Design/methodology/approach – We collect survey data from a manufacturer in the process industry that has been implementing lean in its global production network over several years. We then test our hypotheses by performing hierarchical linear regression and structural equation modeling.

Findings – We find that middle-managers perceive lean programs as more effective than top managers. Top managers' commitment to the program, however, affects the perception of middle managers and supports the organizational infrastructure for lean implementation.

Practical implications – The results of our study imply that for a lean program to succeed, it takes efforts from the whole organization. Top managers alone cannot do the work but significantly support hierarchically lower levels during implementation. Effective measures from top managers were for example Gemba walks or hands-on involvement in the implementation, whereas middle managers effectively implemented lean with the help of regular meetings, training, and implementation guidelines for example.

Originality – Our study is the first to study perceptions of and commitment to lean programs at different hierarchical levels. We contribute novel insights into why many lean programs halt and what it takes to sustain commitment to them.

Keywords: Lean, management commitment, strategic alignment, behavioral operations

4.2. Introduction

In search of productivity improvement, manufacturing organizations often launch lean programs. Many organizations, however, struggle in managing them, obtain disappointing results, and lose momentum in their implementation efforts (Sadun et al., 2017). While the technical aspects of lean and their link to operational performance have been widely understood (Shah & Ward, 2003; Womack et al., 1990), there is still little knowledge about the social factors surrounding lean implementation. It has been speculated that the lack of understanding of human factors is one of the main reasons for the failure of lean programs (Losonci et al., 2017; Wiengarten et al., 2015). Only recently, research has started to fill this gap by studying organizational infrastructures and behaviors (Bortolotti et al., 2015; Cadden et al., 2020; Galeazzo et al., 2017).

Inspired by the celebrated Toyota Production System, lean programs can be conceptualized as systems of interrelated organizational practices (Furlan et al., 2011; Galeazzo & Furlan, 2018; Shah & Ward, 2003). Their implementation is a complex socio-technical undertaking that involves people at all hierarchical levels. Dissensus between managers about the need or type of change can lead to conflict and undermine implementation efforts (Floyd & Lane, 2000). One reason for dissensus can be different perceptions of the value of lean. For example, Wemmerlöv (2021) shows that there is limited evidence that such programs improve firms' financial performance, whereas operational improvements are recognized more evidently (e.g., Shah and Ward, 2003; Netland et al., 2015). However, for an organization to develop actual continuous improvement (CI) capabilities, strategic alignment is considered an important precondition (Galeazzo et al., 2017). Despite its claimed importance, only very few studies have investigated organizational consensus in lean organizations. One of them studied expected returns on investment and found significant differences among different hierarchical levels of the organization (Lodgaard et al., 2016).

Besides perception, managerial behaviors have been recognized as another crucial success factor of lean programs. For example, Netland et al. (2015) and Camuffo and Gerli (2018) studied various management practices, such as the development of lean-focused performance reports or collaboration within teams, and established positive links between them and the implementation of lean. In another study, van Dun et al. (2017) studied the behavior of effective lean managers and characterized it as attentive, appreciative, and oriented towards human relations at work. Still, research on the behavior of middle managers and their teams when implementing lean is very scarce. Furthermore, research that studies the cognitive underpinnings leading to such behaviors is in its infancy (e.g., Arellano et al., 2020).

In this study, we aim to address these gaps by analyzing how managerial perceptions differ across different layers of the organizational hierarchy and how these differences manifest themselves in terms of managerial behaviors. We draw on survey data from a company that has been implementing a lean program in its global production network since 2016. Our empirical approach is threefold. First, we test whether there are any differences in how top managers and middle managers perceive the effectiveness of the program. Second, we test if the perception of top managers affects their commitment to the implementation of it. Third, we test to what extent top-management commitment permeates throughout the organization by studying the effects on middle managers' perception of the lean program, their commitment to lean program implementation, and ultimately the actual degree of lean program implementation.

4.3. Theoretical Background and Hypothesis Development

The organizational practices and principles of lean management that companies employ today were developed at Toyota Motor Corporation and were popularized by the seminal book 'The Machine that Changed the World' by Womack et al. (1990). What followed has been their widespread adoption by companies from various sectors and the development of an academic discipline (Cusumano et al., 2021; Hines et al., 2004; Holweg, 2007). Despite thorough studies of its technical aspects, organizations have still been struggling to implement lean (Pay, 2008; Sadun et al., 2017; Spear & Bowen, 1999).

Lean is a socio-technical system, comprised of technical and people-related elements (Bortolotti et al., 2015; Shah & Ward, 2007). Accordingly, the role of managers—who are responsible for bridging the gap between lean tools and lean thinking (Mann, 2009)—has more and more come to focus in the latest lean studies (e.g., Netland et al., 2015; van Dun et al., 2017; Camuffo and Gerli, 2018). Thus, leadership has been recognized as one of the most important success factors of lean (Flynn et al., 1995; Seidel et al., 2019).

However, each managerial position requires a different type of leadership. Netland et al. (2019) distinguish the work of lean managers according to their hierarchical level. Roles and responsibilities differ substantially between top managers, middle managers, and operational managers (Floyd & Lane, 2000). While top managers commit through indirect support, governance, and monitoring, middle managers translate organizational strategy into operational routines (Mann, 2009; Marksberry, 2010; van Dun et al., 2017). Hence, frontline managers engage directly with lean practices.

As roles among managers differ, so could their perceptions about lean. Boyer and McDermott (1999), for example, find that there is substantial disagreement across different hierarchical levels of the manufacturing firm when rating investments in technology. Similarly, Lodgaard et al. (2016) find that leaders at different hierarchical levels perceive different barriers to lean implementation. This indicates a potential lack of alignment within organizations aspiring to become lean.

To achieve alignment between hierarchical managerial levels, organizations first need to break down their overall objective into individual goals and align them toward the same strategy, which is generally achieved in a cascading manner involving all hierarchical levels (Netland et al., 2019). Second, it requires a change of behavior and, arguably, more importantly, a change of mindset. The phenomenon of 'strategic role conflict,' in which managers have divergent expectations about the need to develop new competencies, can be a key problem in this regard (Floyd & Lane, 2000). According to Emiliani (2003, p. 905), managers need to "develop new beliefs" to implement lean. Many lean transformations fail because of mistaken beliefs about the actual purpose of the program (Mann, 2009).

Considering this background, we ask the following research question: Are there differences in the perception of lean effectiveness between top and middle managers? And, if so, how do they affect managerial behavior aimed at lean implementation?

4.3.1. Differences in Managerial Perceptions

While lean research has increasingly focused on social factors (Bouranta et al., 2021), cognitive aspects in the form of beliefs and values have also come into focus lately, as they are determining factors of organizational behavior. For example, van Dun et al. (2017) identified different values and behaviors of effective lean managers, including self-transcendence and openness to change. Similarly, a recent study by Arellano et al. (2020) investigated managerial beliefs and found different belief configurations that drive commitment to practice adoption. Social learning theory states that individuals observe, learn, and adopt values displayed by their role models (Bandura & Walters, 1977), but there exist many more influencing factors on what individuals think of lean programs (Losonci et al., 2011).

In the process of strategic reorientation and organizational change, the roles of top, middle, and operating-level managers differ along the dimensions of time, information, and core values (cf.

Mann, 2009). These differences can result in dissensus between managers, which is labeled 'strategic role conflict' (Floyd & Lane, 2000). Strategic role conflict is a common phenomenon in manufacturing organizations, as the literature provides evidence that managers from different hierarchical levels think differently about strategic initiatives and lean programs in particular.

In an empirical study on strategic consensus, Boyer and McDermott (1999) found substantial disagreement between operators and managers. Operators tended to view investments in technology as significantly more important than managers did. In a two-year in-depth case study, Lodgaard et al. (2016) studied the differences between the perceptions of middle and top managers in the context of lean implementations. The results showed significant differences in the perceived barriers. Further, managers from higher positions tended to emphasize more tools and practices relative to hierarchically lower positioned managers.

The higher the manager's position, the more distant they are from the shop floor, thus the fewer operational insights they may have. While operational and middle managers are responsible for carrying out the main work for the implementation of the program, top managers might see the lean program as one initiative in a pool of various initiatives (Kellermanns et al., 2005). As a consequence, top managers may be less exposed to the positive effects that lean programs can have on operational performance. We therefore posit:

H1: Top managers perceive lean programs as less effective compared to middle managers.

4.3.2. Managerial Perceptions and Behaviors Influencing Each Other

As roles and responsibilities differ depending on the manager's position, we conceptualize managerial behaviors in two different ways. Top managers' behaviors aimed at lean implementation are characterized by individual actions. Top managers tend to exercise their leadership through individual actions directed towards the support of the programs they commit to. We bundle these behaviors as "top management commitment", which, for example, can be expressed through Gemba walks, direct communication with employees, or dedication of resources to the program (van Dun et al., 2017).

As middle managers work more often in teams, their commitment to lean program implementation is rather expressed as collective behaviors by the organization, as opposed to top managers' individual behaviors. Examples are training of shop floor employees, regular team meetings to discuss the implementation, or the development, distribution, and use of guidelines. We, therefore, bundle middle managers' commitment to lean program implementation as collective organizational efforts of developing a lean-supportive "organizational infrastructure" (cf. Anand et al., 2009; Galeazzo et al., 2017).

Theoretically, there exist two main drivers for adopting new behaviors: legitimacy drivers and efficacy drivers (Leseure et al., 2004). Whereas legitimacy drivers motivate compliance and increased validity in the eyes of stakeholders, efficacy drivers intend to increase operational performance. According to Arellano et al. (2020), the latter has a stronger influence. In a similar vein, Vasilash (2000) states that the more people believe in the success or effectiveness of a certain philosophy, the greater improvements are possible.

Top managers have direct responsibility for the firm's performance, depending on which they might even receive individual bonuses and adjust their behavior (Kerr & Slocum, 2005). In addition, lean programs are generally initiated at the highest managerial level (Netland et al., 2019), where top managers then need to allocate resources and develop organizational infrastructures for their implementation (Mann, 2009). Therefore, we hypothesize that top managers will be motivated to support the implementation of lean programs through more commitment when they perceive higher effectiveness of these programs in improving firm performance.

H2: Top managers' perception of lean program effectiveness is positively associated with top managers' commitment to lean program implementation.

The argument leading to our next hypothesis is not very different from the previous one and based on efficacy drivers as well. Individuals who believe in the effectiveness of a certain practice will be more committed to the adoption of that practice (Arellano et al., 2021). Similarly, Lozeau et al. (2002) argue that managers will 'corrupt' the adoption of new practices when they do not perceive that it fits their organizational context or could be helpful in any other way.

One reason for such behaviors lies in individuals' concerns about the consequences of their actions (Ajzen, 1991). Accordingly, middle managers will assess the value of practice adoption based on the benefits that the organization as a whole, or they as individuals, can obtain from it. In some cases, middle managers might receive financial rewards or even a promotion for performance improvements they are responsible for (Hines et al., 2011). Research has shown that non-financial rewards, such as praise from the superior, can have an even stronger effect on the implementation of lean programs than financial rewards (Netland et al., 2015). Similarly, Womack and Jones (1996) explain that traditional rewards systems might become obsolete when employees notice the improvements they can make in the production system or when experiencing the effects they can have on customer satisfaction.

We, therefore, hypothesize that middle managers who perceive the lean program to be effective will engage more in organizational efforts supporting the program than middle managers who do not perceive it as effective.

H3: Middle managers' perception of lean program effectiveness is positively associated with organizational infrastructure for lean program implementation.

We also hypothesize that besides middle managers' commitment in the form of organizational infrastructure, also top managers' commitment will affect the setup of a lean-oriented organizational infrastructure. Top managers' commitment provides employees with a clear focus and helps them coordinate their efforts (Sull, 2003). Additionally, through the active participation of more senior managers, the rest of the organization is coached, encouraged to think critically, and constantly challenged (Dombrowski & Mielke, 2014; Liker & Convis, 2012; Rother, 2010). At the same time, employees become aware of critical issues, which unlocks further improvement potential (Hirzel et al., 2017).

Dobrzykowski et al. (2016) found that lean leaders who endorse values like waste elimination or process improvement induced better team communication. Ng et al. (2006) also found that managerial communication about changes in organizational procedures supports organizational commitment. This effect can be amplified when employees are actively involved in decision-making concerning organizational procedures and have the chance to influence their own work (Deming, 1982).

H4: Top-management commitment to lean program implementation is positively associated with organizational infrastructure for lean program implementation.

So far, we have only hypothesized that managerial perception influences managerial behavior, but we see also potential for a relationship in the opposite direction. Specifically, top management signaling can affect the *perception* of middle managers, particularly at the beginning of the implementation when improvements are still to be obtained (cf. Losonci et al., 2011). Commitment by top managers makes the program look more credible to hierarchically lower managers (cf. Emiliani and Stec, 2005; Liden et al., 2008). Further, by communicating the strategy or results to their employees, top managers can transform employees' beliefs and create a vision (Brown & Treviño, 2009; Kotter, 1995; Wang et al., 2018).

We, therefore, hypothesize that as middle managers recognize that top managers spend time and resources on the implementation of the lean program, they will perceive the lean program to be more effective.

H5: Top-management commitment to lean program implementation is positively associated with middle managers' perception of lean program effectiveness.

Organizational infrastructure for lean implementation includes, among others, the definition of a team that is specifically dedicated to leading and supporting the lean implementation, training workers, regular meetings to discuss the implementation, and the development and use of implementation guidelines. These measures shall facilitate the organization to implement lean (Furlan et al., 2019; Netland, 2016; Wiengarten et al., 2015), which, in turn, includes the development of new skills, establishing a pull production, standardizing processes, and making general improvements like eliminating waste.

Setting up an organizational infrastructure aimed at lean implementation goes hand in hand with new learning mechanisms for the organization. Many studies have highlighted that organizational learning is an essential part of lean implementation and arguably the most important one (e.g., Galeazzo et al., 2017; Tortorella et al., 2020; Hardcopf et al., 2021), as it helps employees to understand the underlying principles of the lean program (Secchi & Camuffo, 2016). Since increased understanding will help employees to implement lean principles more effectively, we hypothesize:

H6: Organizational infrastructure for lean program implementation is positively associated with lean program implementation.

By combining all hypotheses, we create one overall theoretical model that explains relationships between organizational perception and organizational behavior considering two different hierarchical levels of the organization, top and middle managers (see Figure 22).

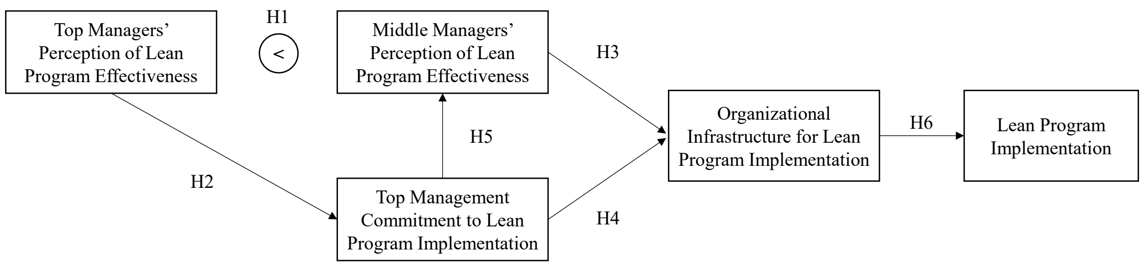

Figure 22 – Theoretical Model

4.4. Research Design

We collect our data from a global manufacturer in the process industry that is producing variants of the same chemical product – a resin-based liquid or powder product. It has been implementing a global production improvement program in its nearly 40 globally dispersed factories over the last five years.

4.4.1. Sample and Survey Design

To test our hypotheses, we used survey data that we collected in the global production network of our partnering company in fall 2017. Since we study the relationships between perception and behavior throughout the implementation of production improvement programs, each respondent has been in some way involved in the program implementation. In our survey, we asked individual managers and supervisors from different organizational units and hierarchical levels to assess their strategic priority, the current level of implementation of the production improvement program (2017), and the implementation level they had two years before (2015), organizational practices employed in the past two years, and perceived effectiveness of the program on operational performance. We refrain from using plant-level data, as the survey respondents work in different organizational units, and program implementation, as well as performance effects, may vary across these units (e.g., production planning, quality control, warehouse management).

We used close-ended questions on a 5-point or 7-point Likert scale to operationalize the application of organizational practices (from 1 = never, to 5 = very frequently), the implementation level of the program on different dimensions (from 1 = low, to 5 = high), and the perceived effect of the program on various performance measures (from 1 = significant negative impact, to 7 = significant positive impact).

In total, we obtained 280 responses, which were mostly represented by production supervisors, operations managers, production planners or managers, general managers, and managers from other functions (an average of approximately 8 respondents per plant). The distribution of the respondents and other sample characteristics are provided in Table 32. Figure 23 provides a general overview of how different plants have on average improved their program implementation degree over two years.

Table 32 – Sample Characteristics

Sample characteristic	Number of responses	Classifications	Totals	Percent
Respondent's position	280	Top management	34	12.1
		Middle management	246	87.9
Unionized	260	Majority unionized	106	40.8
		Minority unionized	24	9.2
		Not unionized at all	130	50.0
Respondent's years of experience within firm	279	< 5 years	60	21.5
		5-10 years	85	30.5
		10-15 years	57	20.4
		> 15 years	77	27.6
Plant start-up year	267	< 1980	15	5.6
		1980-1999	114	42.7
		2000-2009	77	28.8
		> 2010	61	22.8

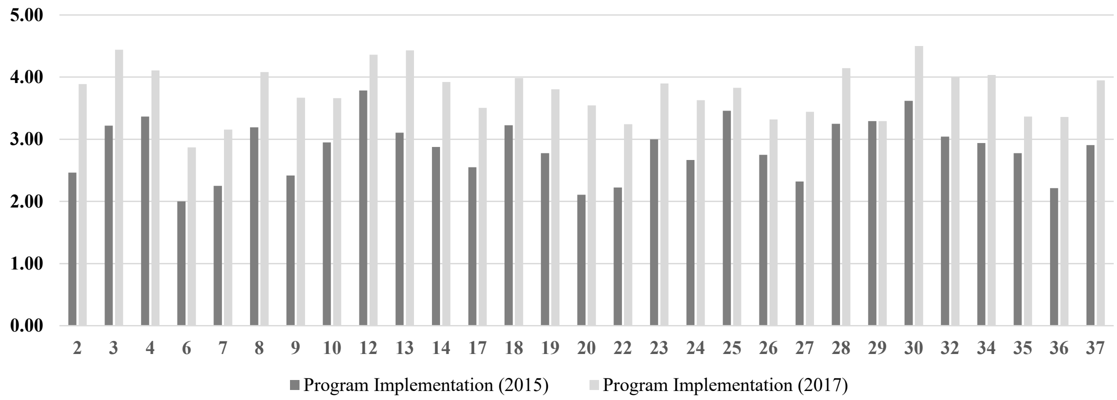

Figure 23 – Program Implementation Degree per Plant

To ensure common method variance was not an issue, both procedural and statistical remedies were followed based on Podsakoff et al.'s (2003) recommendations. On the one hand, we randomized the order of questionnaire items that represented the same constructs to avoid associations between them. We considered only key respondents who were actively involved in the implementation of the improvement program. Moreover, we reviewed the survey format and wording multiple times to exclude any misunderstandings. On the other hand, we performed Harman's single factor test to estimate the effect of common method variance. Following the idea of principal component analysis, we loaded all items of this study into an exploratory factor analysis as a post-hoc marker variable analysis (Malhotra et al., 2006). Potential bias exists if most of the variance is explained by one single factor. Our test showed that the first factor accounted for only 31.54 percent of the variance, indicating low concerns for common method bias in the sample.

4.4.2. Data Analysis

To test our hypotheses, we employ two different methods of statistical analysis. We test our first hypothesis by running a hierarchical linear model on the full sample (n=280) to identify differences between top managers (n = 34, with one top manager per plant; e.g., plant managers, managing directors, heads of production, etc.) and middle managers (n = 246; e.g., warehouse managers, quality controllers, production planners, etc.) in their perceptions of how effectively the improvement program has affected operational performance (H1). Instead of just comparing averages of these two groups, the regression model allows us to control for various variables, such as the plant age or experience of the manager.

Second, we create a structural equation model to operationalize our conceptualizations of middle and top managers' perception of lean effectiveness, top management commitment, organizational infrastructure for program implementation, and program implementation. We perform maximum likelihood estimation using Stata 16 to analyze direct and indirect effects (H2-H6). This way, we are able to capture managerial commitment and the plant's involvement in program implementation as latent variables and simultaneously analyze their effects on program implementation (Gefen et al., 2000). We run a robustness check by calculating the same model but replacing program implementation, which was measured in 2017, with the difference in program implementation measured in 2015 and 2017.

In our analyses, we control for managers' experience, plant age, location, product type, and unionization. Using data from one single firm, we implicitly control for industry, organizational culture, as well as process- and product complexity.

4.4.3. Measures

In our structural equation model, we use five main constructs that we measure as reflective constructs, each one composed of multiple independent survey items: perceived effectiveness of the lean program by top managers and by middle managers, top management commitment, organizational infrastructure, and lean program implementation.

Given the multidimensionality of production improvement programs, we need to capture perceived performance effects on many levels. Hence, we operationalize the perceived effectiveness of the improvement program using four different performance dimensions: (MP01, TP01) On-time delivery, (MP02, TP02) Throughput time, (MP03, TP03) Productivity of machines and labor, and (MP04, TP04) Percentage of right-first-time products. Specifically, we asked managers to assess the effect that program implementation had on these performance dimensions over the last two years. Based on this conceptualization, we measure perceived performance effects separately for the top and middle managers in our model.

We operationalize *top management commitment* using three behavioral items: (TMC01) Hands-on involvement in program implementation, (TMC02) Gemba walks, and (TMC03) Mandating the implementation. The first item measures to what extent top managers are involved in driving the program implementation themselves. Such behavior testifies that they care about the program themselves. The second item, Gemba walks, measures how frequently top managers visit the shop floor to follow up on the implementation of the program. This includes observing the processes and communicating with employees, which indicates explicit interest by top managers in program implementation. The third item measures to what extent top managers have communicated the implementation as a key objective in the plant's long-term strategy. This form of strategic commitment ensures that top managers put weight on the implementation and support it not only operationally but also strategically, for example by dedicating resources such as time or money. All in all, these measures comprise what prior studies have identified as critical top management behaviors for lean implementation (van Dun & Wilderom, 2012; Worley & Doolen, 2006), and thus serve well as measures for top managers' commitment.

We measure organizational infrastructure for the program's implementation as (OI01) Teams dedicated to leading and actively supporting the implementation of lean, (OI02) Formal program training of shop floor workers, (OI03) Regular meetings to discuss the implementation, and the (OI04) Development and use of implementation guidelines. According to Anand et al. (2009), a CI infrastructure provides an organizational context that enables the coordination and sustainability of organizational learning and systematic improvement efforts. In this sense, the definition of a team dedicated to the implementation of an improvement program, formal training, regular meetings, and implementation guidelines create an organizational infrastructure that supports the implementation of an improvement program.

The implementation level of the production improvement program is based on four different items: (PI01) Process improvements, (PI02) Competence development, (PI03) Management by planning, and (PI04) Stable processes. These items are common among production improvement programs (Netland, 2013) and similar to those cited in other recent studies (Distelhorst et al., 2017; Netland & Ferdows, 2016). We use the program implementation in 2017 as dependent variable. As a robustness check, we also run a model that employs the difference in program implementation between 2017 and 2015 as dependent variable.

4.5. Results

4.5.1. Hierarchical Linear Modeling

We run a hierarchical regression to test our first hypothesis. Table 33 shows the results, including the control variables plant age, experience, and unionization as independent variables in Model 1. Model 2 adds an independent dummy variable representing middle management to compare middle managers' perceptions against top managers' perceptions (set as the baseline). The results show that middle managers perceive the effect of the improvement program on operational performance to be statistically significantly higher than top managers. We also find a minor but statistically significant effect for the control variable experience. Overall, the two models showed statistical significance in the description of the perceived effect of program implementation on operational performance.

Table 33 – Hierarchical Linear Modeling Results

	Model 1		Model 2	
	coefficients	**std. error**	**coefficients**	**std. error**
(Constant)	-0.475***	0.269	-0.913***	0.321
Plant age	0.0839	0.057	0.08	0.057
Experience	0.0158*	0.008	0.0192**	0.008
Unionization	-0.04	0.133	-0.067	0.132
Top management			reference	
Middle management			0.489**	0.199

Dependent variable: Perceived effect of program implementation on operational performance
** $p < 0.05$, *** $p < 0.01$

4.5.2. Measurement Model

The measurement model describes the conception of latent variables based on observable items. In our model, we have five latent variables using 19 items in total. We tested the measurement model regarding individual item reliability, internal consistency, and convergent validity (see Table 34 and Table 35). Starting with confirmatory factor analysis, we found that all measurement items load on their corresponding factors at statistically significant levels ($p<0.001$), thus indicating good item reliability.

To test internal consistency for each latent variable, we use three different methods. First, we calculate Cronbach alpha reliability coefficients and compare them to Nunally's (1978) minimally acceptable reliability level of 0.7. Alpha coefficients are greater than the recommended threshold for each construct.

Second, we calculate composite reliability (CR) scores for each latent variable by dividing the squared sum of the individual standardized loadings by the sum of the squared sum of the individual standardized loadings and the variance of the corresponding error terms (Fornell & Larcker, 1981). The calculated values exceed the threshold of 0.7 for each latent variable (Nunnally, 1978), and thereby suggest adequate internal consistency for our measurement model (see Table 34).

Third, we measure the amount of variance that is captured by a construct in relation to the amount of variance due to measurement errors by calculating the average variance extracted (AVE) for each latent variable. To do so, we divide the sum of the squared item standardized loadings by the sum of the squared item standardized loadings and the sum of the variance of the error terms. According to Fornell & Larcker (1981), convergent validity is given when the AVE is above the threshold of 0.50. For each latent variable, the AVE returned an acceptable value (see Table 35).

Table 34 – Confirmatory Factor Analysis, Composite Reliability, and Cronbach α

Item Code		Standardized Loadings	t value (all p<0.001)	CR	α
	Perceived Performance Effects by Middle Managers			.913	0.914
MP01	On-time delivery to customers	0.8	24.79		
MP02	Throughput time	0.89	41.1		
MP03	Productivity of machines and labor	0.91	46.24		
MP04	Percentage of Right-First-Time products	0.8	25.22		
	Perceived Performance Effects by Top Managers			0.94	0.93
TP01	On-time delivery to customers	0.8	8.73		
TP02	Throughput time	0.96	33.9		
TP03	Productivity of machines and labor	0.95	36.36		
TP04	Percentage of Right-First-Time products	0.85	14.12		
	Top Management Commitment			.839	0.847
TC01	Hands-on involvement	0.78	22.05		
TC02	Gemba walks	0.81	20.56		
TC03	Implementation mandates	0.8	25.33		
	Organizational Infrastructure			0.883	0.866
OI01	Dedicated implementation team	0.78	24.17		
OI02	Shop-floor training	0.87	37.14		
OI03	Regular meetings	0.85	32		
OI04	Implementation guidelines	0.73	18.74		
	Program Implementation			0.867	0.868
PI01	Process improvements	0.81	25.75		
PI02	Competence development	0.76	20.44		
PI03	Management by planning	0.81	26.44		
PI04	Stable processes	0.77	21.88		

Table 35 – Tests of Convergent Validity

Latent variables	**Average variance extracted (AVE)**	**Correlations between latent variables (square root of AVE in the diagonal)**				
		(1)	**(2)**	**(3)**	**(4)**	**(5)**
(1) Mid. Managers' perception	0.725	**0.851**				
(2) Top Managers' perception	0.797	-0.05	**0.893**			
(3) Top Management Commitment	0.635	0.558***	0.02	**0.797**		
(4) Organizational Infrastructure	0.655	0.262***	0.024	.621***	**0.809**	
(5) Program Impl.	0.621	0.454***	-0.016	0.574***	0.409***	**0.788**

Note: *** Significant at the 0.01 level

4.5.3. Structural Model

Our structural equation model indicated good model fit considering χ^2 (354.927, df = 213, $p < 0.001$) with χ^2/df=1.67 being below the threshold of 3. Statistical significance suggested that the model might be inadequately specified. However, it is also well recognized that this measure is sensitive to sample size (Arbuckle, 1999). For that reason, we also take other structural diagnostics for the overall model fit into consideration that are not affected by sample size (P. M. Bentler & Bonett, 1980). The root mean square error of approximation (RMSEA) (Steiger & Lind, 1980) is one of the most widely used estimates of misfit/fit of structural equation models. It describes the discrepancy between the proposed model and the original covariance matrix of the sample (Byrne, 1998). The RMSEA is 0.056, which is below the recommended cut-off value of 0.08 (Cudeck & Browne, 1983).

Equally, the Tucker-Lewis index (TLI) of 0.937 (Tucker & Lewis, 1973) and the comparative fit index (CFI) of 0.946 (P. Bentler, 1990) exceeded the cut-off value of 0.90 (Mulaik et al., 1989). Overall, these fit indices suggest that the model has a good fit, which is further supported by comparing them also to fit indices of prior structural equation models from the field of operations management (cf. Shah, & Goldstein, 2006).

Figure 24 gives an overview of all hypothesized relationships and the corresponding regression standard coefficients. We do not find any support for Hypothesis 2, as we find top managers' perception of program effectiveness to have no significant effect on top managers' commitment to the lean program. However, we find support for our remaining hypotheses. Both top middle managers' perception and top managers' commitment to the lean program showed a statistically significant, positive effect on the development of a lean-supportive organizational infrastructure (H3: $\beta = 0.233$, $p < 0.001$; H4: $\beta = 0.828$, $p < 0.001$). In other words, a one standard deviation increment in middle managers' perception of the lean program's effectiveness led to a 0.233 standard deviation increase in organizational infrastructure. Further, top managers' commitment influenced middle managers' perception positively (H5: $\beta = 0.587$, $p < 0.001$). Lastly, we found a statistically significant effect of organizational infrastructure on lean program implementation (H6: $\beta = 0.507$, $p < 0.001$).

We also included control variables in our model, but only a few showed statistical significance in their relationships to the latent variables. We found that the experience of middle managers had a positive effect on their perceived effectiveness of the program ($\beta = 0.022$, $p < 0.05$). Top managers' perception was in turn positively affected by the unionization of the plant ($\beta = 0.199$, $p < 0.01$), but negatively associated with plant age ($\beta = -0.147$, $p < 0.05$).

In addition to this model, we also ran a robustness check by replacing the lean program implementation level in 2017 with the difference in program implementation between 2015 and 2017. The results were overall almost the same, showing very similar coefficients at the same significance levels with one marginal exception, namely the effect of organizational infrastructure on the relative lean program implementation measure being significant only at the 5%-level.

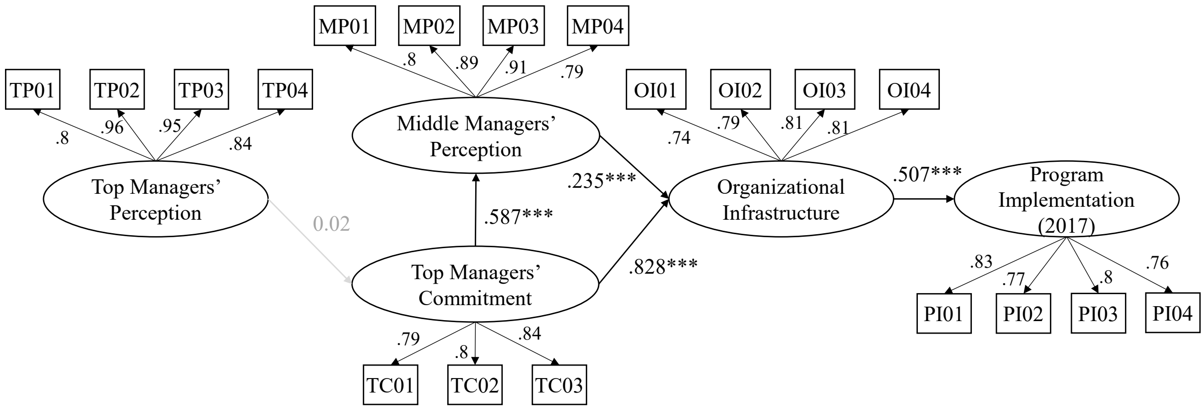

Figure 24 – Structural Equation Model with Parameter Estimates (* $p < 0.001$, ** $p < 0.01$, * $p < 0.05$) and Factor Loadings**

With regards to our model, we identified the possibility of a mediating effect, namely middle managers' perception mediating top managers' commitment effect on organizational infrastructure. Traditionally, causal step methods were employed to test mediation effects, such as Baron and Kenny's (1986) stepwise approach. According to that approach, a mediation effect exists if: (1) the independent variable significantly predicts the mediating variable, (2) the independent variable significantly predicts the dependent variable, and (3) the mediating variable significantly predicts the dependent variable while controlling for the effect of the independent variable. As shown in Table 36, the results of this test confirm a mediation effect. To ensure the robustness of our findings, we employed another parametric (Sobel, 1982) and non-parametric test (bootstrap). For our non-parametric test, we followed the bootstrap approach developed by Preacher and Hayes (2004) using a 95-percent confidence interval. Both tests confirmed what the stepwise approach had shown previously and supported the mediation effect.

Table 36 – Testing Mediation Effects

	Baron and Kenny's stepwise approach									
	Effect of X on M			Effect of X on Y			Effect of M on Y			
Mediator	**coeff.**	**T**	**p**	**coeff.**	**T**	**p**	**coeff.**	**T**	**p**	
Middle Managers' Perception	.604	7.37	.000	1.02	27.94	.000	.513	12.34	.000	*mediation supported*
	Sobel test									
	z		**p**							
Middle Managers' Perception	3.07		.002							*mediation supported*
	Bootstrapped estimate									
	Confidence Interval									
Middle Managers' Perception	.049		.258							*mediation supported*

4.6. Discussion

Despite the wide popularity of improvement programs labeled as 'lean' or 'Operational Excellence', many manufacturing organizations still face problems sustaining their implementation (Jasti & Kodali, 2015; Losonci et al., 2017; Netland et al., 2015). Prior studies have shown that leadership is a critical success factor in this regard (Camuffo & Gerli, 2018; Netland, 2016). When studying leadership in organizations, an important distinction has to be made between managerial positions, as their roles and responsibilities differ substantially (Mann, 2009; Netland et al., 2019). We, therefore, set out to study the perceptions and behaviors of two managerial levels to identify their differences and effects on the successful implementation of lean programs. By running a comprehensive structural equation model, we uncover important relationships between these variables, which we discuss in the following.

4.6.1. Hierarchical Differences in Lean Program Perception

Our results have shown that top managers are generally less convinced of the effectiveness of a lean program than middle managers, which can be due to different reasons. A top manager's job description usually includes foresight over many departments on a high level but no in-depth insights into manufacturing operations (Floyd & Lane, 2000). This leads to a focus on financial numbers and not necessarily on socio-technical mechanisms of the shop floor.

Due to their physical detachment from everyday operations, top managers will seek financial evidence for lean's success, such as increased market share, margin expansion, or revenue growth (M. L. Emiliani & Stec, 2005), and if they do not find it, they might quickly lose conviction of the program's effectiveness (Wemmerlöv, 2021). However, it is difficult to observe a direct relationship between lean and financial indicators, both for researchers and practitioners. There have been only a few attempts by lean researchers to establish such a link (Wemmerlöv, 2021). Reasons for the difficulty of establishing a relationship include, among others, a possible time lag of the effect, the difficulty to monetize it, and a large number of other influencing factors that make it hard to isolate the effect. For the same reasons, it is also very challenging for practitioners to draw a conclusion about the financial effects of lean program implementation. Moreover, lean programs should not only be valued in financial terms, as they bring additional benefits, such as workers' safety (Monden, 1993).

Middle managers, in turn, are more frequently exposed to manufacturing processes through the management of their teams but also more physically present on the shop floor. Thus, they directly observe performance changes associated with the implementation of lean programs rather more frequently than top managers. Specifically, higher program implementation is expressed as more realized process improvements (e.g., solved problems, eliminated waste), better-trained employees according to global program standards, more process stability in terms of quality, flow, and cycle time, and better management by planning (e.g., using visual boards, shift handover meetings, KPIs).

Middle managers will more quickly observe how these changes affect the productivity of their workforce or the quality of processes and the product in their daily work. On the balance sheet, these effects can however be distorted by external, economic influencing factors so that top managers might not realize the benefits of the program when looking only at financial numbers.

Overall, this finding bears important implications for organizations that aspire to implement lean programs. Top managers are usually the first to decide upon the launch and continuation of a lean program, so their conviction is very important for the program's sustainment. The fact that top managers perceive lean programs as less effective than other parts of the organization is a risk to the program's success. Considering, that it can take time until the implementation comes to fruition and yields significant performance improvements (Netland & Ferdows, 2016), it is important for top managers to remain patient and give the program some time.

4.6.2. Independence of Perception and Behavior

The reasons why we do not find a significant link between top manager perception and commitment can be manifold. Arellano et al. (2020) found that managers have individual, multi-dimensional belief configurations, which drive their commitment to practice adoption. Besides the belief in the effectiveness of a certain practice or program, belief in one's own ability to perform a certain behavior or social pressure to perform a certain behavior can just as well drive one's individual behavior (Ajzen, 1991).

Admittedly, top managers are usually loaded with a high number of responsibilities which quickly distract them from being present on the shop floor and engaged in the implementation of improvement programs (cf. Kellermanns et al., 2005). Further, the higher managers climb the hierarchical ladder, the more they are exposed to political forces or expectations from other stakeholders (Burgelman, 1994; Floyd & Lane, 2000), and have to adjust their behaviors accordingly. And the more an individual is influenced by external forces, the less their own beliefs and perceptions will drive their behaviors.

Consequently, top managers' lack of commitment, does not necessarily need to be due to a lack of belief. The special characteristics that go along with the role of top managers need to be considered, as they can explain the detachment of their perception from their behavior.

4.6.3. Interdependence of Perception and Behavior

Notwithstanding the relationship between top managers' perception and behavior, the latter can have important consequences for manufacturing firms, as top management commitment affects the organization in many ways. On the one hand, managerial commitment is seen by other employees, who will then recognize the resources spent by the top management, be it money, time, or anything else. If employees experience that senior management cares, they too will see a reason to care (Emiliani and Stec, 2005). Accordingly, our results show that the more committed top managers are, the higher the middle managers' estimate of the program's effectiveness is. What follows is that employees will be more motivated and thus more involved in the implementation (B. Emiliani, 2008; Netland et al., 2019).

On the other hand, our results show that top management commitment has an even stronger direct effect on the efforts spent on the organizational infrastructure for program implementation. As prior studies have shown, this can be due to increased face-to-face support, which shows strong engagement and helps build a relationship between top managers and shop floor operators, which can have a motivating effect on both sides (Hirzel et al., 2017; Sadun et al., 2017; van Dun & Wilderom, 2021; Worley & Doolen, 2006). Top managers can promote the program, stress its importance, foster the use of lean guidelines, or coach employees (Dombrowski & Mielke, 2014; Liker & Convis, 2012; Rother, 2010).

At the same time, direct observations on the shop floor and exchanges with shop floor employees can help direct top managers' attention to improvement potentials and demonstrate the effectiveness of the program. Lean literature stresses the importance of learning and knowledge creation for successful lean implementation (Danese et al., 2017; Secchi & Camuffo, 2016; van Dun & Wilderom, 2021). Therefore, it should be noted that the learning and knowledge transfer process is bi-directional, as top managers also learn from shop floor teams (van Dun & Wilderom, 2021), and a successful lean implementation strives under the combination and co-creation of knowledge as well as collective problem solving (Galeazzo et al., 2017; Hirzel et al., 2017).

4.6.4. Implications for Effective Lean Implementation

Regarding the degree of lean implementation, a supportive organizational infrastructure that relies on team meetings, training sessions, or guidelines appears to be an effective measure to channel these efforts and drive the implementation effectively. This is supported by Onofrei et al. (2019) who identify structural and social capital as significant factors for a successful lean implementation. Our interpretation of organizational infrastructure provides this very platform to enable codified knowledge (structural capital) and open communication (social capital).

Overall, our results show that top managers' commitment is not only important for keeping the program alive but also for supporting its implementation. Our model shows that top managers' influence on the organizational infrastructure is higher than the effect of middle managers' perception of lean effectiveness, which stresses once more the importance of top management commitment.

Another implication of our results is that the exclusive use of traditional communication structures where top managers are merely informed by direct subordinates can hamper the build-up of necessary organizational infrastructure for lean implementation. An increased exchange with top management fosters vertical communication among hierarchies, which is important for creating awareness of strategic priorities and aligning the organization (Ateş et al., 2020; Biggs et al., 2014), another driving force of lean implementation (Galeazzo et al., 2017).

Besides the importance of top managers for lean implementation, our study shows that organizations rely on the involvement of the overall workforce to implement the lean programs successfully (M. L. Emiliani, 2003). Top management commitment needs to be considered an enabler for the whole organization to effectively implement lean. This way, our study empirically confirms anecdotal evidence presented in numerous prior books and articles (e.g., Rother, 2010; Ballé et al., 2016; Netland et al., 2019).

4.7. Managerial Implications

This study demonstrates the importance of effective interaction between all hierarchical levels in manufacturing organizations that try to implement a lean program. Particularly, top managers play an important role because of their strong influence on setting up, maintaining, and supporting organizational infrastructure, strategic alignment, and dedication of resources to program implementation. Their active involvement in the implementation is important, as it fosters exchange, the transfer of knowledge, and can spark new ideas or discussions that employees can embark on and realize.

In addition, top managers are advised to not only rely on direct communication with subordinates but also supplement it with direct exchange with operational workers. Being present on the shop floor more frequently strengthens the communication and thus top managers' understanding of the program's potential, which is important for its sustainment. Having a holistic view of the overall organization, they are in the best position to interpret the program implementation and performance feedback and thus adjust the implementation process appropriately as new information becomes available.

This way, top managers have both a direct and an indirect effect on program implementation, which is driven by the collective engagement of the overall organization. Training, structured meetings, dedicated teams, and guidelines are effective means that manufacturers can employ to realize lean program implementation.

4.8. Conclusion

The purpose of this study was to analyze the influence of managerial perceptions, strategic alignment, and managerial commitment on the implementation of lean programs. To achieve this, we took a multi-level approach by distinguishing the responses of managers from different hierarchical levels in our analysis. It allowed us to analyze the differences and relationships between top managers and middle managers during the implementation of lean.

First, our results show that top managers are generally less optimistic about lean's effectiveness. Second, we provide empirical evidence of the importance of top managers' commitment to lean implementation, as it has cognitive and behavioral implications for the rest of the organization. Third, we show that successful lean implementations derive from the involvement of the whole organization (i.e. lean implementation is driven by the whole organizational infrastructure that results both from middle managers' perception and top managers' commitment). Organizations aspiring to become lean should thus question whether they are strategically aligned across all hierarchical levels. For a lean transformation to succeed, each organizational unit must be supportive of the implementation both in their mindset and behavior.

There are several limitations to our study. First, we collected data within the production network of one single firm. This research design is effective in controlling for industry effects, but it hurts the external validity of the results. Second, we conceptualize commitment and perception as latent constructs comprised of three to four items. To capture these concepts more precisely, a broader system of measures would be better. Third, our cross-sectional survey design led to a measurement of all items at the same time. A longitudinal study that considers the longevity of lean implementation efforts would allow for even more robust insights.

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Curriculum Vitae

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Education

Since 01/2018	Dr.Sc.	ETH Zürich, D-MTEC (CH) Chair of Production and Operations Management
10/2015 - 10/2017	M.Sc.	RWTH Aachen University (DE) Business Administration and Engineering
10/2016 - 04/2017	Visiting Researcher	Massachusetts Institute of Technology (US) Institute for Data, Systems, and Society
10/2011 - 09/2015	B.Sc.	RWTH Aachen University (DE) Business Administration and Engineering
08/2002 - 05/2011	Abitur	Friedrich-Bährens-Gymnasiums, Schwerte (DE)

Professional Experience

Since 01/2018	Researcher	ETH Zürich, D-MTEC (CH) Chair of Production and Operations Management
08/2014 - 02/2015	Intern	Porsche AG (DE) Production Planning and Control (918 Spyder)
01/2014 - 06/2014	Research Assistant	RWTH Aachen Laboratory for Machine Tools and Production Engineering (WZL) (DE)
05/2011 - 07/2011	Intern	Thiele GmbH & Co. KG (DE)

Scholarships and Awards

- Springorum Commemorative Coin
- RWTH Aachen University Dean's List
- RWTH Research Ambassador Scholarship
- Karl-Schlotmann-Stiftung Scholarship
- Porsche Pole Position

Voluntary activities

07/2018 - 06/2020	Board Member	Association of Scientific Staff, D-MTEC ETH Zürich
08/2015 - 07/2016	Management Board	aixsolution e.V. Junior business consulting
09/2021	Keynote Speaker	Technologie Forum Zug Presentation on "Current Challenges of Lean"
05/2013-04/2014	Advisory Board	careerloft Consulting for a student career network
11/2013-05/2014	Project Member	Goethe Institut Barcelona International project on "Talent Mobility"

Conference Presentations

Januszek, S., Siegrist, A., and Netland, T. 2021. "Blockchain for Product Authenticity in the Cannabis Supply Chain." Advances in Production Management Systems, Nantes, France, Online, September 5th-9th.

Januszek, S., Netland, T., and Furlan, A. 2021. "Role of management perception and strategic alignment in lean implementation." 28th International Conference of the European Operations Management Association (EurOMA) 2021, Berlin, Germany, Online, July 4th-7th.

Januszek, S., Netland, T., and Furlan, A. 2021. "Role of top management commitment in production improvement programs." 31st POMS Annual Conference 2021, Minneapolis (Minnesota), USA, Online, April 30th-May 1st.

Macuvele, J., Januszek, S., Friedli, T., and Netland, T. 2020. "The Role of Management Control Practices for Operational Excellence in the Pharmaceutical Industry." 27th International Conference of the European Operations Management Association (EurOMA) 2020, Warwick, UK, Online, June 29th-30th.

Januszek, S., and Netland, T. 2019. "Developing Dynamic Capabilities through Production Improvement Programs." 79th Annual Meeting of the Academy of Management, Boston (Massachusetts), USA, August 9th-13th.

Januszek, S., and Netland, T. 2019. "The Evolution of Lean: A Bibliometric Network Analysis." 26th International Conference of the European Operations Management Association (EurOMA) 2019, Helsinki, Finland, June 17th-19th.

Januszek, S., and Netland, T. 2018. "Operational excellence in process industries: In search of effective implementation patterns." 25th International Conference of the European Operations Management Association (EurOMA) 2018, Budapest, Hungary, June 24th-26th.