Contributions to Management Science

Frank T. Piller · Verena Nitsch · Dirk Lüttgens · Alexander Mertens · Sebastian Pütz · Marc Van Dyck *Editors*

Forecasting Next Generation Manufacturing

Digital Shadows, Human-Machine Collaboration, and Data-driven Business Models

Springer

Contributions to Management Science

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Marc Van Dyck
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Editors
Frank T. Piller
Institute for Technology and Innovation Management
RWTH Aachen University
Aachen, Germany

Verena Nitsch
Institute of Industrial Engineering and Ergonomics
RWTH Aachen University
Aachen, Germany

Dirk Lüttgens
Institute for Technology and Innovation Management
RWTH Aachen University
Aachen, Germany

Alexander Mertens
Institute of Industrial Engineering and Ergonomics
RWTH Aachen University
Aachen, Germany

Sebastian Pütz
Institute of Industrial Engineering and Ergonomics
RWTH Aachen University
Aachen, Germany

Marc Van Dyck
Institute for Technology and Innovation Management
RWTH Aachen University
Aachen, Germany

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Foreword[1]

The world is changing faster than ever before. Old certainties are disappearing, and with them the business models that have underpinned the global economy for decades. One of the most significant drivers of this change is the Internet, which is now being extended from the virtual world into the physical world of manufacturing, transforming the way we develop, produce, and use products. This is the world of the Internet of Production (IoP). The IoP is a key enabler of the Fourth Industrial Revolution, which is characterized by a rapid increase in the pace of technological change, the blurring of boundaries between physical, digital, and biological systems, and the increasing political, economic, and social impact of technological disruptions. The IoP is already having a major impact on industry, and that impact is only going to increase in the years ahead.

A key concept of the IoP is digital shadows that connect data, products, and equipment and are shared in cross-organizational data spaces. Their widespread use will have implications that go far beyond mere technical implementation. From a company-internal perspective, the use of digital shadows facilitates cooperation between humans, robots, and smart agents, enabling human capabilities to be complemented by artificial intelligence-based decision support systems and human-centered human–machine collaboration. From a company-external perspective, data-based value creation and capture in platform-based ecosystems changes the logic of business models. These changes were reinforced by the COVID-19 pandemic, which acted as a catalyst.

This book is the result of interdisciplinary research from engineering, information systems, social sciences, and management fields conducted in the context of the IoP. Our objective was to create a picture of the future consisting of the elements of a next

[1] Note: This foreword has been created by machine intelligence using the GPT-3 language model. Some human intelligence was applied for light editing. Refer to chapter "Hybrid Intelligence in Next Generation Manufacturing: An Outlook on New Forms of Collaboration between Human and Algorithmic Decision Makers in the Factory of the Future" for more information about this hybrid approach.

generation production system that may exist in 2030. By approaching this book with an interdisciplinary view, we make an important contribution to the still very young field of the IoP. Our work is based on the conviction that in order to make sense of the future, one must take an integrative perspective that considers different disciplinary lenses. One cannot simply extrapolate from the past or from recent trends. The world is changing too fast for that. We must instead understand the drivers of change and the interactions between them. This book is an important step in that direction. We hope that it will make a valuable contribution to the IoP research field and help shape the debates about the future of industrial production.

It is our wish that this book will inspire and stimulate debate on the opportunities and challenges posed by the IoP. We hope that it will help policymakers to develop policies that enable companies to take advantage of the opportunities presented by the IoP, and that it will help business leaders to make the decisions that will enable their companies to prosper in the IoP era. We hope that the propositions set out in this book will provide a useful framework for understanding the potential impact of the IoP on industrial production and the global economy. These would be some of my wishes for the book. The future of industrial production is uncertain, but the IoP has the potential to be a game changer. We should all be excited to see what the future holds.

Aachen & San Francisco, March 2022
Generative Pre-trained Transformer (GPT)-3, OpenAI

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Our book has been a huge team effort and is the result of a truly interdisciplinary endeavor. The editors are grateful for the backing of their colleagues in the Cluster of Excellence "Internet of Production" at RWTH Aachen. Especially, we would like to thank the spokesperson of the cluster, Prof. Christian Brecher, and its managing directors, Dr. Matthias Brockmann and Melanie Buchsbaum, for their support and encouragement in publishing this book, and for creating the open and collaborative atmosphere in which we could conduct this research project.

We especially thank Marc Van Dyck for being the project lead of the Delphi study and acting as the coordinating editor of this book. Sebastian Bouschery contributed his skills in onboarding the GPT-3 as a member of our editorial team, and we are grateful for his support. We further thank our student assistants Jennifer Liebsch and Leonid Wolsky for their support in executing the Delphi rounds. Lastly, we thank Springer Nature's executive editor, Dr. Prashanth Mahagaonkar, for guiding us through the publication process and constructively challenging our manuscript.

Finally, we thank all experts serving on our international Delphi panel for their validations of our propositions. Our experts not just provided a quantitative scoring, but contributed more than 600 detailed qualitative comments and remarks, which largely informed our analysis. We further thank all interview partners and domain experts for their input and ideas in drafting the Delphi propositions.

We hope that all these efforts are fruitful to inspire future research on the next generation of industrial manufacturing, but especially provide vision and orientation

to managers developing the future of their production system—and with this, the industrial future that is the backbone of our wealth and social wellbeing.

Aachen, Germany

Frank T. Piller
Verena Nitsch
Dirk Lüttgens
Alexander Mertens
Sebastian Pütz
Marc Van Dyck

Contents

Editors and Contributors

About the Editors

Frank T. Piller a professor of management and a director of the Institute for Technology and Innovation Management (TIM) at RWTH Aachen University. He is also the Academic Director of the Institute for Business Cybernetics (ifu e.V.), an independent research institute associated with RWTH Aachen w with a focus on applied machine intelligence, systemic change, and institutional transformations. Before, he had positions at MIT and TU Munich. As a principle investigator in the National Research Cluster "Internet of Production," he currently studies decision-making and business model transformation in the age of AI/ML, Industry 4.0, and industrial data ecosystems. He serves as a scientific advisor to Germany's national Industrie 4.0 policy. Prof. Piller has consulted with many Dax30 or Fortune500 companies and serves as an advisor for several deep-tech start.

Verena Nitsch studied applied psychology at Charles Sturt University in Australia and the University of Central Lancashire in the UK before completing her master's degree in industrial and organizational psychology at Manchester Business School. She completed her doctorate in engineering in the field of human–technology interaction at the Bundeswehr University Munich, where she became a professor of Cognitive Ergonomics and headed the Human Factors Institute (IfA) from 2016 to 2018. Since June 2018, she has been a full professor and Director of the Institute of Industrial Engineering and Ergonomics at RWTH Aachen University (IAW). She is also currently a Head of the Department of Product and Process Ergonomics at the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE.

Dirk Lüttgens heads the "Open Innovation" and "Business Model Innovation" research clusters at the Institute for Technology and Innovation Management (TIM) at RWTH Aachen University. Dirk Lüttgens has received several (inter-) national awards for his research work and his outstanding teaching activities (including the RWTH Lecturer Award). He is also a member of the editorial board of the

Journal of Business Model and a reviewer for numerous journals. His research aims to generate new evidence-based insights at the interface of technology and innovation management as well as organization and change management. The focus of his work is on questions concerning the conception, development, and marketing of technological innovations, which are not only interesting from a scientific perspective, but are also relevant from a practice-oriented perspective.

Alexander Mertens is a head of the Department of Ergonomics and Human-Machine Systems at the Institute of Industrial Engineering and Ergonomics (IAW) at RWTH Aachen University. He gained his master's degree in computer science at RWTH and received a Ph.D. in theoretical medicine in 2012 and one in engineering 2 years later. He is the founder and managing director of a company for the transfer of ergonomic findings into industrial practice, heads the Aachener DenkfabrEthik, a citizen-oriented platform for interdisciplinary discourse on the ethical, legal, and social implications of technologization, and coordinates the interdisciplinary Research School within the Cluster of Excellence "Internet of Production." His research focuses on the target group-oriented design of mobile information and communication technology, as well as on telemedical services and systems.

Sebastian Pütz M.Sc., received his bachelor's degree in psychology from RWTH Aachen University and his master's degree in human factors engineering and ergonomics from the Technical University of Munich. He is a research associate and Ph.D. candidate at the Department of Ergonomics and Human-Machine Systems at the Institute of Industrial Engineering and Ergonomics (IAW) at RWTH Aachen University. He is also the coordinator of an interdisciplinary workstream within the Cluster of Excellence "Internet of Production," which investigates the human factor in Next Generation Manufacturing. Sebastian's research focuses on the cognitive ergonomics of human–machine interfaces with the goal of optimizing operator workload in socio-technical production systems.

Marc Van Dyck M.A., is a research associate at the Institute for Technology and Innovation Management (TIM) at RWTH Aachen University. At the institute, he leads a workstream within the Cluster of Excellence "Internet of Production." His research, which he has presented at international conferences (e.g., AOM, HICSS, R&D Management), focuses on platform ecosystems in the industrial sector. For his studies, he received a doctoral scholarship from the Friedrich-Naumann-Foundation for Freedom. In addition, Marc is a Visiting Research Fellow at the Laboratory for Innovation Science at Harvard University. Prior to his doctoral studies, Marc worked as a Senior Consultant at McKinsey Digital. He holds a bachelor's degree in International Business from DHBW Stuttgart and a master's degree in Politics & Public Administration from Zeppelin University, both in Germany.

Contributors

Ralph Baier Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany

Annika Becker Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany

Philipp Brauner Human-Computer Interaction Center, RWTH Aachen University, Aachen, Germany

Florian Brillowski Institut für Textiltechnik, RWTH Aachen University, Aachen, Germany

Christian Brecher Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany

Ester Christou Institute for Technology and Innovation Management, RWTH Aachen University, Aachen, Germany

Hannah Dammers Institut für Textiltechnik, RWTH Aachen University, Aachen, Germany

Thomas Gries Institut für Textiltechnik, RWTH Aachen University, Aachen, Germany

Christian Hinke Chair for Laser Technology, RWTH Aachen University, Aachen, Germany

Matthias Jarke Chair of Computer Science 5 – Information Systems and Databases, RWTH Aachen University, Aachen, Germany

István Koren Chair of Process and Data Science, RWTH Aachen University, Aachen, Germany

Maximilian Kuhn Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany

Carmen Leicht-Scholten Research Group Gender and Diversity in Engineering, RWTH Aachen University, Aachen, Germany

Dirk Lüttgens Institute for Technology and Innovation Management, RWTH Aachen University, Aachen, Germany

Alexander Mertens Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany

Saskia K. Nagel Human Technology Center/Applied Ethics, RWTH Aachen University, Aachen, Germany

Verena Nitsch Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany

Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE, Wachtberg, Germany

Srikanth Nouduri Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany

Frank T. Piller Institute for Technology and Innovation Management, RWTH Aachen University, Aachen, Germany
Institute for Business Cybernetics (IfU) e.V., RWTH Aachen University, Aachen, Germany

Sebastian Pütz Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany

Sebastian Schneider Research Group Gender and Diversity in Engineering, RWTH Aachen University, Aachen, Germany

Alexander Schollemann Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany

Günther Schuh Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany

Linda Steuer-Dankert Research Group Gender and Diversity in Engineering, RWTH Aachen University, Aachen, Germany

Wil van der Aalst Chair of Process and Data Science, RWTH Aachen University, Aachen, Germany

Marc Van Dyck Institute for Technology and Innovation Management, RWTH Aachen University, Aachen, Germany

Luisa Vervier Human-Computer Interaction Center, RWTH Aachen University, Aachen, Germany

Marian Wiesch Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany

Martina Ziefle Chair of Communication Science, RWTH Aachen University, Aachen, Germany

How Digital Shadows, New Forms of Human-Machine Collaboration, and Data-Driven Business Models Are Driving the Future of Industry 4.0: A Delphi Study

Frank T. Piller and Verena Nitsch

Abstract Transferring the idea of the Internet to the manufacturing landscape—the Internet of Production (IoP)—fundamentally changes our understanding of how products are developed, produced, and utilized. A key concept of the IoP is digital shadows that connect data, products, and equipment and are shared in cross-organizational data spaces. These developments are also core ideas driving the evolution of the current Industry 4.0 paradigm into its next generation ("Industry 4.U") and have far-reaching implications that go beyond mere technical issues. From a company-internal perspective, managers and workers need to deal with new forms of collaboration and cooperation between humans, robots, smart machines, and algorithms. From a company-external (network) perspective, data-based value creation and capture in platform-based ecosystems change the logic of many manufacturing business models. These changes have been reinforced by the COVID-19 pandemic, which acted as a catalyst for many transformation processes. Given the high uncertainty in the likelihood of occurrence and of the technical, economic, and societal impacts of these concepts, we conducted a technology foresight study in the form of a real-time Delphi analysis to derive reliable future scenarios featuring the next generation of manufacturing systems. This chapter introduces the conceptual and technical background of this study, defines important terms and frameworks, and provides an overview of the Delphi projections that are presented and analyzed in greater detail in the remaining chapters of this book.

F. T. Piller (✉)
Institute for Technology and Innovation Management, RWTH Aachen University, Aachen, Germany
e-mail: piller@time.rwth-aachen.de

V. Nitsch
Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany

Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE, Wachtberg, Germany
e-mail: v.nitsch@iaw.rwth-aachen.de

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