Risk Assessment and Mitigation for Industry 4.0: Implementation of a Digital Risk Quick Check

Julia Arlinghaus, Falko Bendik

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Julia C. Arlinghaus[1], Falko Bendik[1]

[1] Otto-von-Guericke Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany
E-Mail address: julia.arlinghaus@ovgu.de

Abstract. While academics and professionals overwhelmingly agree that current advances in manufacturing present tremendous capabilities to advance manufacturing processes, their view and awareness of the related risk management varies widely. We have developed a method of classifying digital technologies, assessing risk factors and assigning situation-specific mitigation strategies to a variety of digital manufacturing applications. It is based on the analyses of over 350 digital manufacturing projects and over 40 in-depth interviews with academic and industry experts.
A classification of digital technologies and risk factors including fields of application serves as the basis for the web-based assessment and mitigation tool designed to evaluate digitalization projects in all areas of manufacturing and logistics as well as in all phases of development.

Keywords: Digital manufacturing, risk management, cybersecurity, digitalization

1 Introduction

Academics and professionals overwhelmingly agree that current advances in Industry 4.0 and manufacturing present tremendous capabilities. Risks associated with the implementation of digitalization technologies in all areas of production processes and logistics have largely been neglected or confined to so-called cyber risks. The corporate risks related to digitalization technologies harbor several positive and negative implications. Improved product traceability comes at the cost of greater technology dependence and vulnerability to technical failures. While visibility and integration on the business model level may improve inventory and service levels and permit segmentation and individualization of supply chain strategies, they can simultaneously increase complexity, jeopardize data ownership, and create new avenues for cyberattacks (see Fig. 1) [1]. Digitalization can generate risk factors that include vulnerability to technical malfunctions, data tampering, safety and security, health and motivation hazards, dependence on limited resources, coordination complexity, and potential additional costs after implementation [2] [3].

Fig. 1. Examples technology risk situations

Based on a set of 361 digital projects and 42 in-depth interviews with experts, we develop a method for assessing risks factors for and assigning situation-specific mitigation strategies to a set of assorted digital manufacturing applications. A classification of risk factors and fields of application serves as the basis for the web-based assessment and mitigation tool designed to prepare and evaluate digitalization projects in all areas of manufacturing and logistics. The web-based tool has value for stakeholders, ranging from small and medium-sized manufacturers, technology vendors and academics. It rapidly delivers a free and reliable overview of risks for specific combinations of technologies and processes along with the relevant mitigation strategies. Figure 2 provides an overview of company size and industry sectors compiled for the digital projects and interviews conducted with experts.

The remainder of this article is structured as follows: In section 2, we provide a survey of the theoretical background of digitalization in Industry 4.0 manufacturing applications and related digital risk management in order to identify the research gap. In section 3, we present the methodological approach applied. In section 4, we examine the study's main findings in a technology classification, a risk classification, and different risk types paired with mitigation strategies. In section 5, we present the structure and some screenshots of the method's implementation as a web-based tool and discuss some interesting facts we discerned.

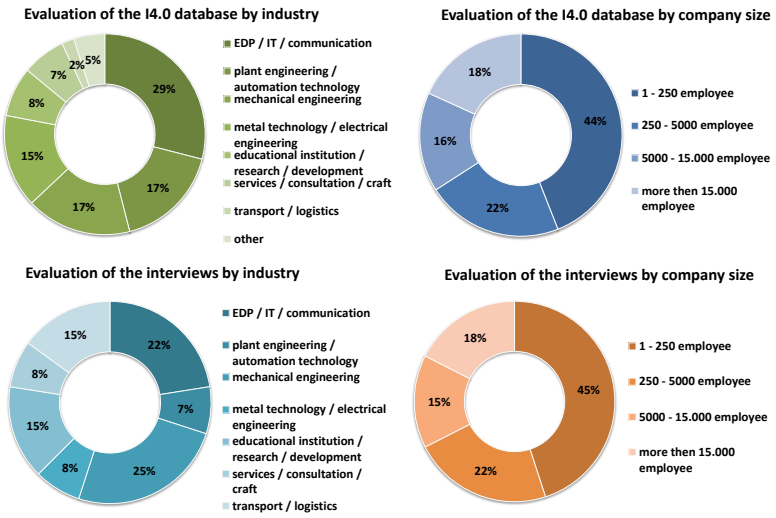

Fig. 2. Company size and industry sectors of digital projects and interviews

2 Theoretical Background

2.1 Risk Management in Industry 4.0

In the past decade, Industry 4.0 has become synonymous with innovative products, services and business models that increase efficiency, sustainability, robustness and flexibility [4]. Risk management covering more than cyber risk has emerged in research only recently in the last few years. Two risk types in smart factories arising from technical failures, specifically errors and attacks get distinguished by [5]. Errors include human, technical and organizational failures as well as force majeure. Attacks comprise targeted or untargeted malicious threats (e.g., hacking or phishing). [6] similarly identify organizational and human factors as main issues in operational risk assessments. Different risk factors and their relation to the benefits of underlying digitalization projects were mapped in [7]. Furthermore, [8] developed a risk framework for Industry 4.0 that addresses the triple bottom line of sustainability. Moreover, [1] show the impact of the ripple effect on digitalization and Industry 4.0. While they focus on the opportunities of certain digitalization applications for manufacturing and logistics, the authors identify concomitant challenges and risk factors generated by them. Big data analytics related to technology risks have been explored in several studies of manufacturing and logistics, such as [3] and [2]. Knowledge about the risks in the digital technology landscape is scant, though. On the one hand, the current literature on digital technologies tends to overemphasize the positive impacts and transformational capabilities of digital technologies, while underestimating the potential risks connected with their implementation [9]. On the other hand, the literature on

manufacturing and logistics risk management provides numerous models and frameworks for types and sources of risks as well as mitigation strategies. Recent studies, e.g. [10] on the use of big data in customer research and manufacturing and [3] on big data for demand planning and return management, [6] focus heavily on big data technologies and emphasize identifying potential applications for such technologies in supply chain operations.

2.2 Research Gap

Systematic empirical evidence of risk factors associated with the implementation of Industry 4.0 technologies is absent in the current literature. Academics and professionals both need to understand risk systematically in order to be able to mitigate and minimize it in operations management [11]; [8]. Whereas businesses are quite aware of the benefits and capabilities of digital projects, the literature still treats specific technologies, related risk and potential mitigation strategies separately. Current studies largely stress potential risks associated with the final concept of Industry 4.0 but do not provide specific insight into different risk types that typically arise in different fields of application. Moreover, tools with which critical information can be assessed in an easily structured manner are lacking in industrial practice.

3 Methodology

The methodology adopted follows a five-step research approach (see Fig. 3).

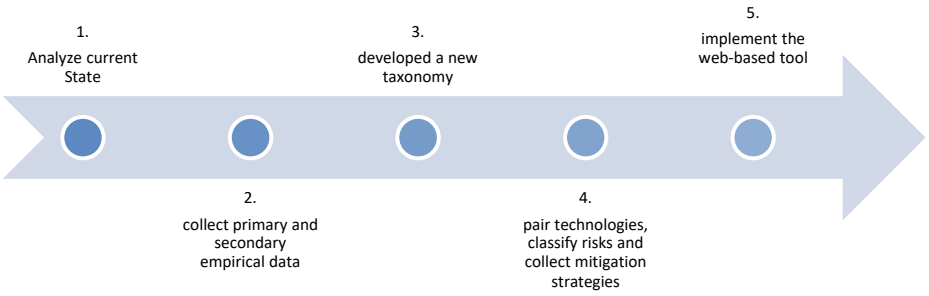

Fig. 3. Five-step research approach

First, current studies were analyzed systematically to develop a thorough understanding of the current literature on Industry 4.0, digitalization technologies and risk management. The current studies provided an introduction to risk factors and uncertainties inherent to Industry 4.0 technologies. In a second step, extensive primary and secondary empirical data were collected from 361 Industry 4.0 applications for digital manu-

facturing in Germany drawn from the "Plattform Industrie 4.0"[1] [12], and 42 in-depth interviews conducted with experts. In the third step, we developed a new taxonomy of relevant digitalization technologies and risk factors in the manufacturing environment based on the case analyses and interviews (see Fig. 4). In step 4, we paired the technology and risk classifications with fields of application and mitigation strategies and devised a three-step method that guides users from processes and potential technology applications to mitigation strategies for all areas of manufacturing and logistics. The final step was the implementation as a web-based tool.

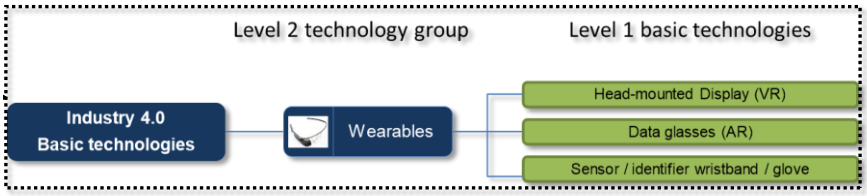

Fig. 4. Technology taxonomy example

The "Plattform Industrie 4.0" is intended as a transfer/share of know-how and best practices of Industry 4.0 project implementations. It contains structured information on developmental stages of digitalization projects, examples of products/ applications, regions and company sizes. Additionally it provides unstructured information on applied technologies, envisioned benefits; lessons learned and adopted project approaches. Interviews with experts in the database cases shall enable us to verify and improve the information from our secondary data. Forty-three 25-50 minute interviews with experts involved in the online database use cases as well as with industry practitioners and academics in the field of digitalization and Industry 4.0 were conducted face-to-face or over phone in November 2018 and March 2019. The interviewed experts primarily come from automotive, equipment, automated systems manufacturing and electrical and electronics companies (see Fig. 2). The interview guide consists of three main sections and follows a semi-structured approach: In the first portion the expert shall describes the known Industry 4.0 use cases, naming all relevant basic technologies, application/ functions and the desired goals. The second portion contains questions about risk and mitigation strategies. Interviews with experts in the database cases shall verify and improve the information of our secondary data and shall give an additional perspective of the impact of specific technologies on the risk situation.

[1] Created and managed by the German Federal Ministry for Economic Affairs and Energy in collaboration with the Federal Ministry of Education and Research.

4 Findings

4.1 Industry 4.0 Technology Risks

The use case and interview data analyzed reveal several key risk factors for Industry 4.0 technologies, specifically workplace risks and industry-specific and company-specific risks. These risk types are drawn from established risk management frameworks, e.g., [13]; [14]. Since legal risks in the workplace frequently arise during the implementation phase and primarily involve aspects of workplace law, data privacy and data protection, many experts see a need in the operation phase to address cyber risks in previously unaffected areas. Direct and indirect dependences and a lack of flexibility can pose serious industry-specific threats to companies. Various solutions require vendor-specific hardware, software and expertise. Users who integrate vendors' Industry 4.0 solutions in their systems do not have full control of their own product's reliability and are dependent on vendors when they need to repair, replace or upgrade their Industry 4.0 components. Our data reveals several important company-specific issues related to human adoption, errors and attacks. Humans come into play as a risk source during the operation phase, albeit to a lesser extent than during the implementation phase. Figure 5 presents an overview of all workplace, industry-specific and company-specific risks factors emerging from the data.

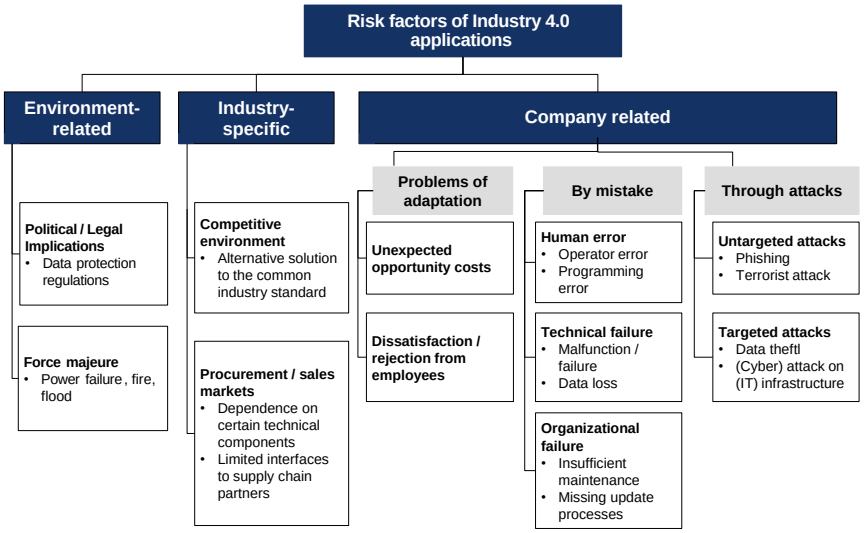

Fig. 5. Risk factors for Industry 4.0 - empirical findings

4.2 Risk Priorities, Recent Approaches and Mitigation Strategies: Empirical Findings

Specific risks of Industry 4.0 implementation and operation phases of were identified based on the empirical findings. Table 1 presents several interesting examples emerg-

ing from the data as well as the related risk priorities, risk management approaches and potential mitigation strategies.

Table 1. Overview of risk management approaches and mitigation strategies

Risk priority	Recent risk management approaches	Potential mitigation strategies
Lack of technological expertise	• Rejecting projects, maintaining the status quo	• Screening of vendor markets • Use of outside consulting services
Legal risk	• Consulting with the employee council as part of introduction	• Inclusion of the employee council • Revision of employment contracts • Technical changes, certification
Employee adoption	• Trial-and-error	• Involvement of affected employees • Skills training • Intuitive solution design
Cyber risk	• Blind trust in existing safeguards, such as firewalls	• Employee awareness creation/training, whitelisting/blacklisting • Technical measures such as IDS/IPS • Network segmentation • Backup strategy

5 Method Development and Implementation as a Web-Based Tool

We ascertained from the case analyses and the interviews with experts that the method ought to build on the idea that the situation-specific risk (mapping the risks and potential mitigation strategies) is contingent on two major impact factors: (1) the technology applied and (2) the process/operation. We therefore decided to make a combination of process and technology the main input for users. First, users can provide input related to the specific technology. A higher-order classification of available technologies was developed based on a combination of data and typologies in the literature, e.g., [15]; [16], in order to be able to cover a wide range of technologies and assess the specific risks. This step made it possible to develop a two-level typology of Industry 4.0 technologies. The rationale behind this classification is to ensure that practitioners can provide input based on simple, established technologies (level 1) while ascertaining the risk profile for technologies (level 2). The implicit assumption is that one group of technologies (e.g., wearables) will present identical types of risks in specific industrial contexts. Users of the tool provide input on both the technology and the target process for which the technology is or will be used. The output consists of situation-specific risk factors and potential mitigation strategies (see Figure 6 for input and output information).

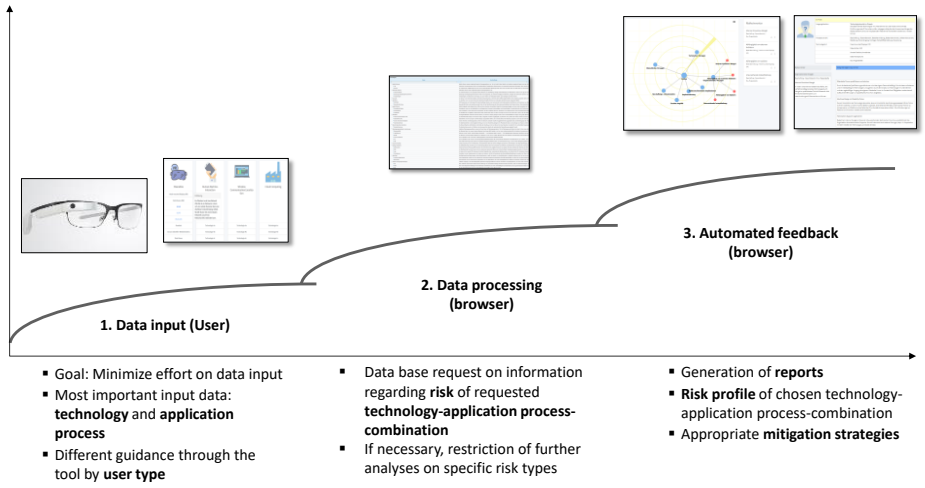

Fig. 6. How the web-based tool works

6 Discussion and Conclusion

This study presents key findings and maps risk factors associated with Industry 4.0 applications in manufacturing and logistics. An extensive literature review and the secondary and primary data collected deliver several key insights into the main risk factors in the phases of technology implementation and operation. These technologies may also pose additional risks to digitalization projects, however, namely, inflexibility, increased latency of the existing production system, increased complexity, difficult integration in current IT systems, and a lack of adequate knowledge and skills among key staff. Based on the empirical findings and current literature, we developed a web-based tool that maps and assesses risk factors related to Industry 4.0 applications. The proposed approach is rooted in the assumption that both the technology and the specific process determine the risk factors. The tool uses the individual application context and the technology as input and delivers potential risk factors together with possible mitigation strategies to the user. The new risk factor typology that emerges from the data reveals that several risk factors pose serious threats to digital projects, e.g., human factors, cyberattacks, legal issues, and dependences. This research study produced a valuable method for assessing risk factors related to Industry 4.0 applications quickly and accurately. It is intended to provide practitioners free and reliable input to assess risks and develop mitigation strategies. The tool has two novel features: its focus on “technology-process” combinations since the risks associated with certain digital technologies may arise from the characteristics of specific processes and the abstract technology classification that correlates certain risks with a given group of technologies (e.g., wearables) rather than a single specific technology. The

higher-order technology classification for assessing and mitigating risks enables the tool to cover a wider range of commercially available technologies. The web-based tool is valuable to stakeholders from small and medium-sized manufacturers, technology vendors and academics because it quickly provides a free and reliable overview of the risks of specific technology-process combinations along with relevant mitigation strategies. Even though this project can still be refined in many ways in the future, this study and the web-based tool developed already benefit industry and research now because they provide a new, empirically developed view of the risks of Industry 4.0 technologies and technology-process combinations. This study is intended to open discussion about and raise awareness of the risk associated with various Industry 4.0 technologies in certain application contexts among academics and professionals.

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