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# Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?

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ABSTRACT

The Fourth Industrial Revolution poses significant challenges to manufacturing companies from the technological, organizational and management points of view. This paper aims to explore how top executives interpret the concept of Industry 4.0, the driving forces for introducing new technologies and the main barriers to Industry 4.0. The authors applied a qualitative case study design involving 26 semi-structured interviews with leading members of firms, including chief digital officers and chief executive officers. Company websites and annual reports were also examined to increase the reliability and validity of the results. The authors found that management desire to increase control and enable real-time performance measurement is a significant driving force behind Industry 4.0, alongside production factors. Organizational resistance at both employee and middle management levels can significantly hinder the introduction of Industry 4.0 technologies, though these technologies can also transform management functions. Multinational enterprises have higher driving forces and lower barriers to industry 4.0 than small and medium-sized companies, but these smaller companies have good opportunities, too.

## 1. Introduction

The Fourth Industrial Revolution, which is currently taking place, sets a number of challenges for manufacturing companies from the technological, organizational and management points of view. With the application of new technologies and the transformation of processes, significant changes are expected in the field of work, and future production systems demand new competencies from employees. Work organization is expected to become more flexible in time and space, with workflows becoming more transparent, decentralized, and less hierarchical (Münchner Kreis, 2013; Picot and Neuburger, 2014). The exact risk of digitization is difficult to forecast, but nowadays it is becoming clear that workers in some countries are more defenseless than others. For example, in some regions, more than 25% of jobs are at high risk of automation (Segal, 2018).

In the world of future production systems, some processes are expected to be simplified, and others to become much more complex and embedded. This is likely to lead to an increase in the number of higher skilled jobs and a reduction in jobs requiring lower qualifications (Brühl, 2015; Spath et al., 2013). Industry 4.0 will therefore have a significant impact on both the labour market and society. According to Kovács (2017b), the success of Industry 4.0 will be a function of both technical feasibility and the social acceptability of the whole transformation process. Vacek (2017) emphasized that if technological changes are not accompanied by significant changes in socio-economic systems, social cohesion may weaken. Industry 4.0 is therefore both a technological and socio-economic phenomenon (Szabó et al., 2019).

According to Hüther (2016), the likely changes may put pressure on economic policy and regulators, and the new skills and competences required by new technologies will require changes to education systems. In the context of Industry 4.0, Brettel et al. (2014) emphasized that the relocation of production activities to low-wage countries primarily affects the production of standardized mass products, but high-wage countries need to resolve the contradictions between economies of scale and scope.

In line with the expected changes, companies are becoming increasingly interested in the application of new technologies to ensure long-term competitiveness and enable them to adapt to dynamically-changing environmental conditions such as shortening product life-cycles, increasing diversity and changing consumer expectations (Adolph et al., 2014; Bauer et al., 2015; Lasi et al., 2014; Spath et al., 2013). In spite of the increasing pressure, a number of factors can be identified that could hinder manufacturers in implementing Industry 4.0. Researchers have pointed out that the lack of skilled workforce and financial resources, standardization problems and cybersecurity issues may be particular problems (Kiel et al., 2017a; Kovács, 2017b; Müller

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and Voigt, 2016; Nagy, 2019). However, research on this topic is still in its infancy. Only a few authors have made empirical examinations of this phenomenon and the most important driving forces and barriers to Industry 4.0 (see e.g. Basl, 2017; Müller et al., 2018; Nagy, 2019). It is also unclear how far the various driving forces and inhibiting factors will have different effects on small and medium-sized enterprises (SMEs) and multinational enterprises (MNEs).

This study aimed to explore how top executives, particularly chief executive officers (CEOs) and chief digital officers (CDOs) interpret the concept of Industry 4.0, and identify both the driving forces for introducing new, digital technologies and the main barriers and challenges to Industry 4.0. It was designed to contribute to the overall picture of the concept of Industry 4.0. We also analysed how SMEs and MNEs are affected by the driving forces and barriers identified. We carried out a qualitative exploratory study among top executives of companies. The study companies operated in different industry sectors, and were all either suppliers, users or both (dual role) of Industry 4.0 technologies.

## 2. Theoretical background

### 2.1. Digital transformation

The traditional approach to digitization defines it as *"the use of computer and internet technology for a more efficient and effective economic value creation process"* (Reddy and Reinartz, 2017). Digitization is a phenomenon affecting all sectors, where traditional products are either replaced with digital counterparts or at least equipped with new digital features (Prem, 2015). However, digital transformation, or digitalization, goes beyond product and process improvement, to affect business models, organizational and management aspects and entire supply chain processes, creating significant challenges for companies (Bleicher and Stanley, 2016). In other words, digital services and digitalization itself not only affect physical products, but also the nature of business, and organizational structure and strategy (Chahal, 2016; Dremel et al., 2017; Matt et al., 2015). Seufert and Meier (2016) suggested that to successfully complete digital transformation, companies needed to first analyse and identify consumer needs and preferences. Subsequent consumer-oriented changes within the organization should then address these needs. Berman and Bell (2011) emphasized that *"the challenge for business is how fast and how far to go on their path to digital transformation"*.

Toanca (2016) suggested that creating a digital strategy was at least as important for small and medium-sized businesses as for large ones. There is still, however, little literature on the question of how managers should approach and handle digital transformation, and implement related strategies (Hess et al., 2016). Generally, and in this study in particular, Industry 4.0 refers to the digitalization of production (Erol et al., 2016), so digital transformation can be considered as an overarching concept, with Industry 4.0 as a sub-concept.

### 2.2. The concept of Industry 4.0

The beginning of the original industrial revolution was at the end of the 18th century, when mechanical production facilities powered by water and steam were first used. The second industrial revolution began to unfold at the beginning of the 20th century, when mass production became possible with the use of electricity and division of labour. The third industrial revolution, which is still in progress, began in the 1970s. This is characterized by a higher level of automation of production and different work processes, achieved through the industrial application of electronics and information technology (Ghobakhloo, 2018; Kagermann et al., 2013; Shrouf et al., 2014). According to Lee et al. (2018), the fourth industrial revolution can be considered as a result of the horizontal expansion of information technology. Information and communication technologies are used in a much more extensive way than before in all spheres, including business, government and everyday life (Kovács, 2017a). Interconnectedness is a fundamental element (Aichholzer et al., 2015). The concept of Industry 4.0 was introduced in 2011 by the German Industry–Science Research Alliance (Buhr, 2017).

In the fourth industrial revolution, new avenues of production are emerging through communicating objects, learning machines and autonomous robots (Valenduc and Vendramin, 2016). The term "Industry 4.0" describes the increasing digitization of the entire supply chain, which makes it possible to connect actors, objects and systems based on real-time data exchange (Dorst et al., 2015; Spath et al., 2013). As a result of this interconnection, products, machines and processes with artificial intelligence will be able to adapt to changing environmental factors (Hecklau et al., 2016). Posada et al. (2015) and Roblek et al. (2016) defined the five key elements of Industry 4.0 as: (1) digitization, optimization and customization of production; (2) automation and adaptation; (3) human–machine interaction; (4) value-added services and stores, and (5) automatic data exchange and communication. According to Zezulka et al. (2016), the term Industry 4.0 is used for three factors: (1) digitization and integration of networks, (2) digitization of products and services, and (3) new market models. These elements are mutually interconnected. Hermann et al. (2015) identified four main elements of Industry 4.0: cyber-physical systems, Internet of Things, Internet of Services and smart factories. Perales et al. (2018) defined the main features of Industry 4.0 as virtualization, interoperability, automation, flexibility, real-time availability, service orientation and energy efficiency. The application of digital technologies in manufacturing processes is also called "smart manufacturing", "integrated industry" and "industrial internet" (Hofmann and Rüsch, 2017).

Schuh et al. (2014) defined Industry 4.0 as: *"The integration of information and communication technology into the industrial environment"*. Mario et al. (2017) defined it as, *"…a collective term for technologies and concepts of value chain organization"*. Schmidt et al. (2015) said it was*: "the embedding of smart products into digital and physical processes"*. According to Thramboulidis (2015) and Lee et al. (2015), the application of connected and embedded systems with software solutions makes it possible to control and monitor production through the processing and analysis of information extracted from the production process. Ghobakhloo and Modares (2018) emphasized the role of decentralization, modularity and product personalization in Industry 4.0. Overall, Industry 4.0 technologies support decision-making and therefore contribute significantly to increasing productivity (Saucedo-Martínez et al., 2017; Zhong et al., 2017).

### 2.3. Driving forces behind Industry 4.0

As well as understanding the concept of Industry 4.0, it is important to discuss factors that may encourage companies to move towards this approach. Ongoing changes on a global level have led to a networked society, affecting both business and private life. They have also resulted in a number of changes for manufacturing companies (Bauer et al., 2015). Kaivo-oja et al. (2017) claimed that we are moving towards a ubiquitous knowledge society, in which smart and autonomous machines are inevitable. It is also important to address social challenges in many developed societies, including Western Europe. These challenges include reduced workforce numbers because of a declining population and aging society (Jankowska and Götz, 2017). They and may be addressed by developing and applying new technologies (Wang et al., 2016).

Growing levels of competition have made it essential for companies to increase their innovation capacity and productivity and reduce their time-to-market (Bauer et al., 2015; Lasi et al., 2014). Investments in new digital technologies allow companies to improve their comparative advantage and create a decisive advantage over their competitors (Hortoványi, 2017, 2016). Change is also forced by decreasing product life cycles, changing consumer expectations and needs, and markets becoming more heterogeneous over time (Adolph et al., 2014; BMBF, 2014; Karre et al., 2017; Spath et al., 2013). Nagy (2019) noted that previous production systems are outdated, and no longer meet today's expectations, often causing environmental damage. By improving productivity, the quality of manufacturing can be significantly increased and waste reduced (Paritala et al., 2016). Significant improvements can also be achieved in energy efficiency (Kovács, 2017b; Lins and Oliveira, 2017). de Sousa Jabbour et al. (2018) were the first to note that Industry 4.0 can positively affect environmentally-sustainable manufacturing, with the development of green products, manufacturing processes, and supply chain management.

Companies can therefore draw on Industry 4.0 to increase sales volumes, achieve significant cost savings (Kiel et al., 2017b) and provide radical micro-level performance improvements (Losonci et al., 2019). Collecting and processing production data from the field also supports other benefits, e.g. faster decision-making and support for knowledge management (Cimini et al., 2017; Inezari and Gressel, 2017; Uden and He, 2017). Industry 4.0 technologies help to manage production planning and scheduling, capacity utilisation, maintenance and energy management (Szalavetz, 2018).

Industry 4.0 may also lead to significant changes in existing business models, allowing new ways to create value. These changes are expected to result in the transformation of traditional value chains and create entirely new business models that enable higher levels of consumer involvement (Kagermann et al., 2013; Ustundag and Cevikcan, 2017). Müller et al. (2018) noted that Industry 4.0 affects three elements of manufacturing SMEs: value creation, value capture and value offer. Prem (2015) suggested that as products and services become more and more digital, channels will be increasingly digitized. This may lead to changes in customer relationships and increase innovation in product and service design. Industry 4.0 can therefore be defined as a basic pillar in the future competitiveness of manufacturing companies. Firms will, however, face challenges in implementing it. Frank et al. (2019) concluded that Industry 4.0 technologies enable the servitization of manufacturing companies. However, innovative manufacturing business models should be protected by both data security methods and use of patents (Smit et al., 2016). The driving forces identified from the literature on companies are shown in Table 1.

### 2.4. Barriers to Industry 4.0 implementation

Adolph et al. (2014), Erol et al. (2016), Shamim et al. (2016), Karre et al. (2017), Müller and Voigt (2017) and Kiel et al. (2017a, 2017b) all agreed that one of the major challenges to the implementation of Industry 4.0 is the lack of skilled workforce, and the requirement to retrain staff to fit changed circumstances. In the future, new ways of working are needed, which may have positive and negative effects on employees (Smit et al., 2016). Changed working conditions may lead to conflicts in business organizations (Bauer et al., 2015).

A number of sources (Erol et al., 2016; Kiel et al., 2017a, 2017b; Müller and Voigt, 2016; PwC, 2014) have suggested that shortage of financial resources is also a significant obstacle to implementation. Müller and Voigt (2016) found that low degrees of standardization, poor understanding of integration and concerns about data security could also hinder Industry 4.0 adoption. Nagy (2019) noted that standardization problems may occur in inter-organizational relationships, as well as in the tools and systems inside manufacturing companies.

Data security issues were supported by other studies (Cimini et al., 2017; Kiel et al., 2017a, 2017b; McKinsey& Company, 2016). These studies emphasized concerns about cybersecurity and data ownership. Weber and Studer (2016) also discussed the legal issues affecting cybersecurity. Kovács (2017a, 2017b) noted that the spread of new technologies meant that fears about the safe handling of private information and data were expected to intensify in the future. It is also important to highlight the role of privacy-enhancing technologies, which aim to protect individual data and privacy through technological solutions (Heurix et al., 2015). However, there are a number of risks associated with these technologies. For example, de Montjoye et al. (2015) emphasized the risk of re-identification.

The development of manufacturing systems also significantly affects the risk of fragility, creating further uncertainties in the ecosystem (Kovács, 2018). Kiel et al., 2017a, 2017bfound that the most important inhibitory factor was the need for technological integration. Successful integration of components, tools and methods requires the development of a flexible interface, because the synchronization of different languages, technologies, and methods can lead to significant challenges (Zhou et al., 2015). The reliability and stability of the systems must also be ensured, and this is a critical factor in machine-to-machine communication (Sung, 2018; Varghese and Tandur, 2014).

A study by McKinsey& Company (2016) suggests that the intensive communication required by Industry 4.0 projects, and therefore the introduction of new technologies, may be significantly affected by the difficulty of coordination across organizational units. A study from PwC (2014) found that many companies have not yet developed business cases and feasibility studies that clearly support the need to invest in the data and systems architecture required for the introduction of

**Table 1**
Driving forces behind Industry 4.0 identified from the literature.

| Driving force | Sources |
|---|---|
| Growing competition | Bauer et al. (2015); Lasi et al. (2014) |
| Increased innovation capacity and productivity | Bauer et al. (2015); Lasi et al. (2014); Paritala et al. (2016) |
| Expectations of customers | Adolph et al. (2014); BMBF (2014); Karre et al. (2017); Nagy (2019); Spath et al. (2013) |
| Efforts to save energy and improve sustainability | de Sousa Jabbour et al. (2018); Kovács (2017a); Lins and Oliveira (2017); Nagy (2019); Paritala et al. (2016); Szalavetz (2018) |
| Financial and performance factors | Kiel et al. (2017b); Losonci et al. (2019) |
| Support for management activities | Cimini et al. (2017); Inezari and Gressel (2017); Szalavetz (2018); Uden and He (2017) |
| Opportunity for business model innovation | Frank et al. (2019); Kagermann et al. (2013); Müller et al. (2018); Prem (2015); Smit et al. (2016); Ustundag and Cevikcan (2017) |

**Table 2**
Barriers to Industry 4.0 identified from the literature.

| Barrier | Sources |
|---|---|
| Human resources and work circumstances | Adolph et al. (2014); Bauer et al. (2015); Erol et al. (2016); Karre et al. (2017); Kiel et al. (2017b); Müller and Voigt (2017); Shamim et al. (2016); Smit et al. (2016) |
| Shortage of financial resources | Erol et al. (2016); Kiel et al. (2017b); Müller and Voigt (2016); PwC (2014) |
| Standardization problems | Müller and Voigt (2016); Nagy (2019) |
| Concerns about cybersecurity and data ownership issues | Cimini et al. (2017); Kiel et al. (2017b); McKinsey and Company (2016); Weber and Studer (2016) |
| Risk of fragility | Kovács (2018) |
| Technological integration | Kiel et al. (2017b); Sung (2018); Varghese and Tandur (2014); Zhou et al. (2015) |
| Difficulty of coordination across organizational units | McKinsey& Company (2016) |
| Lack of planning skills and activities | Basl (2017); PwC (2014) |
| Organizational resistance | Automation Alley (2017); Kiel et al. (2017b); von Leipzig et al. (2017); Vey et al. (2017) |

Industry 4.0 applications. This creates a further barrier to Industry 4.0 adoption. Similar conclusions were drawn by Basl (2017), who noted that many companies are not clear on the benefits of using Industry 4.0 technologies.

It is also essential to emphasize the role of organizational culture in transformation. This is usually not identified even though the management of organizational resistance and achieving cultural acceptance of innovations is generally a priority task during Industry 4.0 projects (Automation Alley, 2017; Kiel et al., 2017b; Vey et al., 2017; von Leipzig et al., 2017). The barriers identified from the literature are shown in Table 2.

### *2.5. SMEs versus MNEs in the context of Industry 4.0*

Most companies today recognize the likely impact of Industry 4.0. However, SMEs are generally less well-prepared for the new technologies and expectations (Smit et al., 2016). Many authors have pointed out that the lack of financial resources can significantly hinder SMEs in development projects (e.g. Kocsis, 2012; Mcmahon, 2001; Mittal et al., 2018). In contrast, MNEs have much greater opportunities to invest in new technologies, and therefore tend to apply more advanced manufacturing technologies than SMEs (Dangayach and Deshmukh, 2005). This suggests that MNEs have competitive advantages over SMEs.

Other scholars, however, have argued that slack resources can be a disadvantage and lead to suboptimal organizational performance (March and Simon, 1958; Mishina et al., 2004; Penrose, 1995; Simon, 1957; Wiseman and Bromiley, 1996). They suggested that resource constraints can be enabling in certain conditions like crowded, resource-poor, and small markets (Hortoványi, 2012; Jarillo, 1989; Katila and Shane, 2005; Rao and Drazin, 2002).

Kennedy and Hyland (2003) noted that manufacturing SMEs can take advantage of their operational capabilities against large multinational companies. However, their relative lack of financial resources and experience, as well as capacity constraints, can form a major drawback and limit their development opportunities. MNEs' larger resource pool and capacity mean that they have more opportunities to carry out research projects (e.g. technology research, market research).

Mittal et al. (2018) reviewed other studies to compare SMEs and MNEs along 17 dimensions and highlight their different possibilities in the context of Industry 4.0. The dimensions were financial resources, use of advanced manufacturing technologies, software umbrella, research & development, nature of product specialization, consideration of standards, organization culture/leadership flexibility, company strategy, decision-making, organizational structure, human resources engagement, exposure to human resource development, knowledge and experience of the industry, alliances with universities or research institutes, important activities, dependence on collaborative networks, and customers and suppliers. The authors concluded that SMEs possess weaker network connections and have fewer suppliers, making them much more dependent on them.

Mishra (2016) found that MNEs' manufacturing systems are more flexible, which is inevitable as competition becomes more intense. Lower manufacturing flexibility in SMEs can be traced back to lack of knowledge, low levels of support from the top management and suppliers, and fear of increased costs. This dual embeddedness means that these subsidiaries have more opportunities to use positive network effects (e.g. increasing innovation performance) (Figueiredo, 2011).

Subsidiaries of MNEs, however, are embedded in both the parent MNE's network and more local networks (Meyer et al., 2011). SMEs and MNEs therefore have different opportunities and their competitiveness is determined by several factors. It is important to examine their situation in the context of Industry 4.0 and see whether there is a difference in the driving forces and barriers of Industry 4.0 experienced by each type of company.

### *2.6. Research gaps*

There are very few empirical studies on Industry 4.0, and the research sample in these papers is usually small. Studies on the driving forces and barriers of Industry 4.0 often focus only on one factor, and several studies are limited to the technological side. However, Industry 4.0 is much more complex. This study therefore aimed to understand the whole phenomenon, and analysed business, management and technological issues. Unlike previous studies, this paper pairs the driving and inhibiting factors to provide a complex interpretation of Industry 4.0. As far as we are aware, no previous papers have considered the context of MNEs and SMEs, and the results were not based on a specific ecosystem, which is essential for understanding the phenomenon. This study aimed to investigate the key actors in the Hungarian ecosystem, and we therefore tried to ensure that the sample included suppliers, users and those with both roles. Finally, in each case we interviewed the top managers of the selected companies. Details of the relevant papers, including the methodologies used, are in Appendix 1.

## 3. Research methods

### *3.1. Data collection*

This study explores the interpretation of Industry 4.0, and its driving forces and barriers, and analyses how SMEs and MNEs are affected by the factors identified. We used a grounded theory approach and interviews.

Grounded theory aims to develop comprehensive explanations about a given phenomenon. The method is generally used for building theories based on data that are systematically collected and analysed (Glaser and Strauss, 1967). According to Strauss and Corbin (1990), *"the objective in grounded theory studies is to explain phenomena in light of the theoretical framework that evolves during the research itself"*. Grounded theory uses a systematic set of techniques to identify concepts and build theory based on qualitative data collection (Corbin, 2008). In line with the principles of grounded theory, we collected and analysed our data iteratively to reach a point of theoretical saturation.

According to Miles and Huberman (1984), *"qualitative research is conducted through an intense and/or prolonged contact with a 'field' or life situation"*. The aim of qualitative research is to gather data through the perception of local actors, paying considerable attention and drawing on empathic understanding. Researchers can isolate themes and phrases, but their original form must be preserved (Szabó Zs, 2012).

After weighing up the advantages and disadvantages of in-depth interviews and focus groups, we decided to conduct semi-structured interviews rather than focus groups. The disadvantages of focus groups include that responses are unstructured, so their coding and analysis is more difficult. Respondents may also feel that they are under social pressure and want to meet the expectations of the group, affecting their responses (Acocella, 2012; Malhotra, 2010).

We conducted semi-structured interviews with top executives including CDOs and CEOs. The interviews were conducted in two phases between July and October 2017 and between February and May 2018. After the interviews, we wrote memos to record the most important learning points, experiences and ideas. The memos helped us to look at the data from a different perspective (Charmaz, 2003).

We aimed to select companies that varied across five aspects:

1. Role in Industry 4.0;
2. Company size;
3. Commitment;
4. Industry sector; and
5. Domestic or multinational enterprise.

We defined three roles in Industry 4.0, **providers**, or Industry 4.0 technology manufacturers, **users** of Industry 4.0 technologies, and **providers and users**, or companies that both manufacture and use Industry 4.0 technologies. We used the company size categories defined by the European Union, with firms that employed fewer than 50 people being defined as **small enterprises**, those with 50–249 employees as **medium-sized enterprises**, and those with 250 or more employees as **large enterprises**. Commitment was examined by assessing whether the company was a member of the national technology platform (participation in an alliance system).

We conducted interviews with top executives of 26 companies. The interviews lasted between 60 and 240 min and were all recorded and transcribed. The 26 interviews provided more than 360 pages of interview data. The detailed list of companies is in Table 3.

Our interview guide was developed from the literature, and served as a navigation tool during the research. In line with Agee (2009), the interview guide allowed us to explore completely new, unexpected areas and therefore discover new aspects of Industry 4.0. The interview consisted of two main parts. In the first part, we discussed general issues such as the company's activities and history, the interviewee's position and experience and the company's movement towards Industry 4.0. In the second part, we examined the interpretation of digital transformation and Industry 4.0, driving forces, challenges, and other organizational and management aspects of Industry 4.0.

**Table 3**
Details of companies involved in interviews.

| Interviewee ID | Role in Industry 4.0 | Company size | Technology platform membership | Industry sector | Domestic or MNE? |
|---|---|---|---|---|---|
| 1. | Provider | Medium-sized | Yes | Machine engineering | Domestic |
| 2. | Provider | Medium-sized | Yes | Industrial automation | MNE |
| 3. | Provider | Small | No | Industrial automation | MNE |
| 4. | Provider | Small | Yes | Technical software development | Domestic |
| 5. | Provider | Small | No | Industrial automation | MNE |
| 6. | Provider | Small | No | Industrial automation, machine engineering | MNE |
| 7. | Provider | Small | No | Electronics | Domestic |
| 8. | Provider | Medium-sized | No | Technical software development | Domestic |
| 9. | User | Medium-sized | No | Tool manufacturing | Domestic |
| 10. | User | Small | No | Food and beverages | Domestic |
| 11. | User | Medium-sized | Yes | Electronics | Domestic |
| 12. | User | Medium-sized | No | Bakery | Domestic |
| 13. | User | Medium-sized | No | Logistics and freighting | Domestic |
| 14. | User | Large | No | Car manufacturing | MNE |
| 15. | User | Medium-sized | No | Aluminium production | MNE |
| 16. | Provider and user | Medium-sized | No | Machine engineering | Domestic |
| 17. | Provider and user | Large | Yes | Industrial automation, drive technology building technology, energy | MNE |
| 18. | Provider and user | Small | Yes | Machine engineering, industrial automation | Domestic |
| 19. | Provider and user | Medium-sized | Yes | Machine engineering | MNE |
| 20. | Provider and user | Medium-sized | No | Machine engineering | Domestic |
| 21. | Provider and user | Large | No | Industrial gas production | MNE |
| 22. | Provider and user | Large | No | Machine engineering | Domestic |
| 23. | Provider and user | Medium-sized | No | Machine engineering, industrial automation | MNE |
| 24. | Provider and user | Medium-sized | No | Machine engineering | Domestic |
| 25. | Provider and user | Medium-sized | No | Machine engineering | Domestic |
| 26. | Provider and user | Small | No | Industrial automation | Domestic |

Notes: MNE = multi-national enterprise.

**Table 4**
Conceptual interpretation of Industry 4.0.

| Interviewee ID | Conceptual interpretation |
|---|---|
| 1 | Extracting information through programmed controllers that give you the ability to optimize the process. In summary: we can get information containing a useful message, which is very important for business decisions. With digitization, you can naturally extract information from the manufacturing process, and use it to improve the manufacturing process itself. |
| 4 | Continuous analysis in autonomous systems by built-in sensors and creation of predictions of possible errors and intervention needs for the system. |
| 5 | Intelligence is already at the lowest level of production. |
| 9 | Digital measurement to help reduce errors and improve the scrap ratio. |
| 16 | The digital formatting of data generated in daily activities and the digital control of machines (during manufacturing activities). |
| 17 | Industry 4.0 is a subset of digitalization. |
| 18 | Industry 4.0 is basically about efficiency gains. The development is induced by mass production. Its purpose is to reduce the human factor or to subtract it as far as possible. |
| 19 | Industry 4.0 includes manufacturing technology, products and data management. |
| 21 | The essence of Industry 4.0 is that processes within the company and between companies are increasingly intertwined, and there are artificial intelligence interfaces between each point of attachment. |
| 22 | Industry 4.0 refers to the application of new production technologies, complemented by information and communication technologies, in a common network system in which data exchange is fully autonomous. |
| 25 | Transforming the manufacturing and processing of products, enhancing their efficiency, productivity, flexibility and quality with the introduction of automation, IT and digitization systems. |
| 26 | Industry 4.0 describes an efficient organization of production processes in which devices communicate independently and work in a coordinated manner along the material stream. |

We did not set up hypotheses about the interviews or use any predefined answers in the interview questions, to avoid processing errors and bias (Solt, 1998). Based on guidelines from Patton (2002) and Golafshani (2003), we triangulated the research data by checking company websites and annual reports to increase the reliability and validity of our research. Interviewees were assured of anonymity and confidentiality, to reduce bias and increase the reliability of the results.

### 3.2. Data analysis

The data were analysed using grounded theory. After transcribing the interviews, the texts were coded using QSR NVivo software. The coding process is crucial, and its success defines the conclusiveness of the research (Gelencsér, 2003). We analysed the data using Strauss and Corbin's (1994) recommendations, building on three coding phases: open, axial and selective coding. Firstly, we applied open coding and examined the transcripts line-by-line to understand the data and identify key terms. During the axial coding, we evaluated the categories identified to create links between them and their dimensions. This phase included organizing similar concepts into groups and then creating higher-level categories (Mitev, 2012). During the selective coding phase, we defined key categories and sub-categories after a systematic analysis. We ignored any categories that were not sufficiently related to the key categories and therefore could not be used in theory development. During each phase, we made notes to help us to determine the direction of the analysis and highlight the relationships.

The coding process provided nine main factors defining Industry 4.0, plus five main driving forces and five barriers to the application of new digital technologies in manufacturing processes. These were compared to previous studies to highlight items and results that had not previously been identified.

## 4. Results

### 4.1. Interpretation of Industry 4.0

Several interviewees suggested that it was important to clarify the concept of Industry 4.0 to provide a uniform interpretation. Proper interpretation of the concept is required for companies to set up Industry 4.0 goals and to develop appropriate training programs. Interviewees also emphasized that digitalization and Industry 4.0 cannot be considered synonymous. Both the interviews and the literature review suggest that digitalization is the main concept, with Industry 4.0 as a sub-concept.

> *"The introduction of Industry 4.0 technologies first requires a common understanding."*
>
> (Interviewee 17)

Interviewees also noted that the introduction of uniform standards would be necessary for the fourth industrial revolution. However, they saw positive opportunities in many areas. The conceptual interpretations formulated by the interviewees are shown in Table 4.

> *"Industry 4.0 is one of the greatest opportunities for performance, energy and process optimization."*
>
> (Interviewee 2)

The main factors of the fourth industrial revolution are summarized in Table 5.

The first factor is data collection and processing. During production processes, a large amount of data is generated. By processing these data, companies can gain a lot of benefits including support in decision-making. New digital technologies can also provide a lot of information about customers (e.g. based on usage data extracted from systems placed at customer sites). Processing these data will allow companies to increase customization of products and create targeted customer programs. However, it is important to extract and process only data that are really useful. Processing of data requires a highly qualified workforce with advanced statistical and analytical capabilities.

> *"We use only one millionth of production information, so we need to determine the necessary data."*
>
> (Interviewee 1)

The information obtained could help to optimize production processes in a number of ways. Digital data processing can significantly reduce scrap percentage and error rates. Production forecasts can be used to create an optimal production plan, increasing cost-effectiveness

**Table 5**
The main factors and elements of Industry 4.0.

| Factor | Elements |
|---|---|
| Data collection and processing | • Data collection<br>• Big data<br>• Data processing<br>• Data analysis |
| Optimization of the production process | • Production optimization, using production data<br>• Reduction of scrap percent by digital data processing<br>• Forecasting<br>• Application of production control systems<br>• Increasing designability of production |
| Machine-to-machine communication | • Integration of systems<br>• Sensors e.g. intelligent and vibration sensor<br>• IO-Link<br>• Application of cameras<br>• Wireless technologies |
| Traceability of production | • Precise tracking of the production process<br>• Unique identification of products and product components |
| Work without human intervention | • Work with robots<br>• Application of collaborative robots to R&D tasks<br>• Replacing human senses<br>• Self-learning systems, self-regulation<br>• Automatic movement of products and conveyors without human intervention |
| Preventive maintenance | • Monitoring the condition of systems<br>• Avoiding stoppage of production<br>• Self-monitoring systems |
| Visualization | • Visual display of information: human–machine interface<br>• Pick-to-light systems<br>• Intelligent industrial lighting systems |
| Augmented reality | • Linking virtual reality and reality<br>• Supporting step-by-step processes<br>• Maintenance including performance measurement<br>• Quality control<br>• Training solutions |
| Intelligent warehousing and logistics | • Intelligent warehouse systems<br>• Radio frequency identification (RFID)<br>• Intelligent logistics |

and consumer satisfaction. Applying production control systems can determine optimal production schedules and production can be adjusted as a result of any changes. Overall, by using Industry 4.0 technologies, more predictable production can be achieved.

By integrating individual systems, using sensors, special cameras and wireless technologies, machine-to-machine communication (M2M) becomes possible. The integration of systems is feasible within one company but can also allow communication between systems in different companies across the whole supply chain. M2M applications result in significant time savings, and reduce risks and energy consumption during the production process. Industrial sensors have many areas of application. They are suitable for measuring temperature and vibration, or detecting difficult-to-see objects. IO-Link is an input/output technology that enables communication with sensors and actuators, allowing monitoring of the production process. The use of special cameras enables continuous feedback, and reduces errors and therefore the scrap ratio. Besides quality control and tracking the state of the machines, industrial cameras allow production to be documented, facilitating traceability and compliance with standards. An example of the documentation is that images of products and product components identified with unique QR codes are saved in databases. If there are consumer complaints, the images can be extracted and verified, supporting quality management. Wireless technologies speed up communication. They and other technologies allow the connection of individual workstations by the use of touch buttons and keyboards, so that employees can easily contact their supervisor if necessary. The application of these solutions therefore increases productivity and efficiency, and reduces downtime. Wireless technologies also enable tracking of employee performance, as the number and frequency of requests, and the time required to resolve them can easily be documented. These data can be incorporated into the corporate performance appraisal system. The application of Industry 4.0 technologies also helps to track production processes and products. Using unique identifiers (e.g. radio frequency identification), each component and product can be tracked.

Work without human intervention is primarily the use of collaborative robots during the production process. There are also solutions where robots are involved in research and development tasks or equipped with a camera, replacing the human eye. Self-learning systems reduce the reliance on human work by learning complex tasks, significantly affecting the future of production. This factor also involves the moving of components and products to the right place in the manufacturing process without human intervention.

The next point is preventive maintenance. The application of Industry 4.0 technologies allows the condition of systems to be monitored in real time. By analysing condition data, maintenance work can be done proactively to prevent, inter alia, stoppage of production. The systems themselves can also send notification of their condition and immediately notify the responsible person (e.g. the maintenance engineer) in the event of a problem.

Visualization includes both the display of data on a screen, and all systems helping the production process through visual signals. By applying human–machine interfaces, production data extracted from industrial control systems can be displayed (e.g. temperature, system status). Pick-to-light systems support operators with a light signal to gather the right components needed to produce a particular product, eliminating human errors. These systems are usually used for difficult-to-automate, monotonous tasks. Their ergonomic design reduces the joint pain of the workforce. Pick-to-light systems can also support measurement of staff performance by recording work data with sensors and cameras. The use of smart industrial lighting technologies is also very important in Industry 4.0, and can give feedback about the status of each machine using different colours.

The application of augmented reality systems supports workers in a number of ways. These technologies can help with step-by-step processes by linking virtual reality and reality. Augmented reality-supported maintenance can reduce execution times and human error rates. The technology also helps with employee performance measurement, and makes it possible to check whether each product complies with quality standards. Last but not least, augmented reality-guided training is increasingly effective.

The last factor that emerged from the interviews was intelligent logistics and warehousing. The application of intelligent warehouse solutions allows product flow to be optimized in real-time and support provided for optimal management of stock and inventory. Warehouse systems often involve radio frequency identification (RFID), using tags, readers and antennae to track products. Intelligent logistics systems deliver material to fit the loading order of the trucks and optimize shipment routes.

### *4.2. Driving forces and barriers to Industry 4.0*

We identified several factors that support or inhibit the introduction of Industry 4.0. An overview is shown in Table 6.

The first group of factors is human resources. Interviewees highlighted increasing labour shortages as one of the main drivers of digital transformation:

> *"There are many problems on the human resources side, which mean that the workforce is going to be replaced by robots and digital technologies."*
>
> (Interviewee 3)

> *"We will do everything we can to compensate for labour shortages by increasing efficiency."*
>
> (Interviewee 11)

By expanding the use of Industry 4.0 technologies, many companies aimed to be able to allocate employees to tasks that generate higher added value:

> *"With the use of digital technologies, we aim to take daily, weekly routine jobs from the workers' hands. This way they can work on tasks that generate much higher added value."*
>
> (Interviewee 11)

One major challenge in implementing Industry 4.0 technologies is that companies do not currently have skilled workers with the competences required in future. It may also be challenging to retrain employees, because this takes a long time, increasing costs.

The next group of factors is financial resources and profitability. Increasing digitization of production processes provides a number of financial benefits, including significant reduction in cost of human resources, inventory management and operations. However, the introduction of Industry 4.0 technologies also requires a significant amount of financial resources, which may hinder companies. Many companies were concerned about profitability and the return on investment in new technologies. Limited access to financial resources (e.g. through tenders) is also an obstacle. The interviewees suggested that the availability of financial resources may be hampered, inter alia, by shortcomings in tendering systems. This regulatory gap also results in the evaluation period for tenders being too long.

> *"Before these projects, the biggest question is whether a digitization project is really worth it. The concrete question is whether the project is financially worthwhile for the company."*
>
> (Interviewee 15)

Intense market competition and pressure from competitors are additional driving forces. Companies can increase their market share and competitive advantage through innovative developments based on Industry 4.0 technologies. There are also opportunities to develop new business models and renew the value proposition, which may create many additional benefits. Providers who mainly deliver to foreign markets with more developed economies may find that digitization is an essential condition for staying in the market.

> *"Constant competition with competitors makes it essential for the company to be up-to-date and innovative in both its production and process management."*
>
> (Interviewee 14)

> "*Without digitization, we would not be competitive, we could not cooperate with most of our partners."*
>
> (Interviewee 20)

> *"There are small companies that have developed organically with the big foreign car manufacturers, but because they have not introduced new digital technologies, they have lagged behind."*
>
> (Interviewee 11)

Expectations from management can also encourage the introduction of Industry 4.0 technologies. Top managers often want to increase control by using digital technologies. Their goal is to have continuous, real-time performance measurement. Interviewees mentioned a number of technologies that would allow data to be integrated into the enterprise performance measurement system (e.g. pick-to-light systems, smart cameras), and therefore be used for employee performance appraisal.

> *"It is important to me that the indicators which measure the performance of the company can be accessed and verified in real time."*
>
> (Interviewee 13)

Analysing the other side of market conditions and management expectations, management reality is also a barrier. As production processes are digitized, companies need a leader with the necessary skills and experience to control Industry 4.0 projects. Interviewees suggested, however, that not having such a leader was mainly an issue in smaller businesses. Finally, during the introduction of Industry 4.0 technologies, proper planning is necessary from the very beginning of the projects, to define objectives, and the steps and resources necessary to achieve them, by time period. Industry 4.0 projects cannot succeed without conscious planning.

Another important aspect is productivity and efficiency, which covers several factors. The first is the effort to reduce error and scrap ratio. Reduction in lead times and increased production efficiency also

**Table 6**
Driving forces and barriers of Industry 4.0.

<table>
<tr><th>Driving force</th><th colspan="2">Factor</th><th>Barrier</th></tr>
<tr><td>Increasing labour shortages<br>Reducing human work<br>Allocating workforce to other areas (higher added value)</td><td colspan="2">Human resources</td><td>Lack of appropriate competences and skilled workforce<br>Longer learning time (training of staff)</td></tr>
<tr><td>Reducing costs e.g. human resources, inventory management and operating costs</td><td colspan="2">Financial resources and profitability</td><td>Lack of financial resources<br>Return and profitability<br>Shortcomings in tendering systems<br>Long evaluation period for tenders</td></tr>
<tr><td>Market competition<br>Follow market trends<br>Increasing pressure from competitors<br>Business model innovation</td><td>Market conditions and competitors</td><td rowspan="2">Management reality</td><td rowspan="2">Lack of a leader with appropriate skills, competencies and experience<br>Lack of conscious planning: defining goals, steps and needed resources</td></tr>
<tr><td>Demand for greater control (from top management)<br>Continuous monitoring of company performance</td><td>Management expectations</td></tr>
<tr><td rowspan="2">Reducing the error rate<br>Improving lead times (compliance with market conditions)<br>Improving efficiency<br>Ensuring reliable operation (e.g. less downtime)</td><td rowspan="2">Productivity and efficiency</td><td>Organizational factors</td><td>Inadequate organizational structure and process organization<br>Contradictory interests in different organizational units<br>Resistance by employees and middle management</td></tr>
<tr><td>Technological and process integration, cooperation</td><td>Lack of a unified communication protocol<br>Lack of back-end systems for integration<br>Lack of willingness to cooperate (at the supply chain level)<br>Lack of standards incl. technology and processes<br>Lack of proper, common thinking<br>Unsafe data storage systems<br>The need for large amounts of storage capacity</td></tr>
</table>

play a prominent role. Overall, by implementing all of these factors, more reliable operations can be achieved.

> *"There is a strong focus on improving efficiency, especially reducing lead times, as this is a crucial success factor for us to adapt flexibly to customer needs."*
>
> (Interviewee 19)

By improving productivity and enhancing quality, companies also aim to increase customer satisfaction and reduce complaints. High quality was defined by interviewees as a basic condition for participating in market competition. By increasing flexibility, companies will also be able to respond to individual customer needs more quickly.

> *"If our customers see that we deliver the products exactly, always on time and in the right quality, they will not choose another supplier instead of us."*
>
> (Interviewee 17)

However, besides efforts to increase productivity, companies need to account for various organizational barriers. The success of Industry 4.0 technology implementation can be affected by organizational processes and structure. If corporate processes are not properly optimized and the structure is not flexible, and does not support fast flow of information or fit other requirements, the introduction of new technologies is expected to fail.

> *"Many companies are not yet ready for Industry 4.0."*
>
> (Interviewee 4)

Organizational resistance and inadequate management of it can also be a major obstacle. In many cases, contradictory interests among organizational units, lack of understanding of the new technology, and fear of the unknown are likely to be experienced. Organizational resistance may be seen in both lower level employees and middle managers. Employees may be frightened of losing their jobs with increasing digitization, and afraid of not having the appropriate skills to handle new technologies. Over time, the scope of activities of middle managers will also be completely transformed and their role will change to include some new tasks that may need more expertise.

**Table 7**
The level of effect of the driving forces identified on SMEs and MNEs.

| Driving force | SMEs | MNEs |
|---|---|---|
| Human resources | High | Low (locally high) |
| Financial resources and profitability | Medium/low | Medium/high |
| Market conditions and competitors | Low | High |
| Management expectations | Low | High |
| Productivity and efficiency | Medium | Medium/high |
| Customer satisfaction | High | Medium/high |

**Table 8**
The level of effect of the barriers identified on SMEs and MNEs.

| Barrier | SMEs | MNEs |
|---|---|---|
| Human resources | High | Medium |
| Financial resources and profitability | High | Low |
| Management reality | High | Medium |
| Organizational factors | Low | High |
| Technological and process integration, cooperation | Low | High |

*"Despite the fact that new technologies are a positive change, workers still feel that as a burden and therefore resistance is inevitable. We have to invest a lot of extra energy to handle this."*

(Interviewee 9)

*"During the digitization projects, we saw people clinging to the accustomed, and changes were cumbersome and uncertain. There must be a cultural change, which is time-consuming, and no immediate results should be expected."*

(Interviewee 14)

Inhibiting factors around technological, process integration and cooperation issues need to be considered when trying to increase productivity and respond to customer demands. Industry 4.0 technologies require systems integration both within and beyond the company. To ensure technological integration across the entire supply chain, it is important to develop a unified communication protocol. It is also essential to develop back-end systems with business intelligence to support the processing of large amounts of data generated during production processes. The integration of Industry 4.0 technologies across the supply chain can be hampered by a lack of willingness to cooperate and lack of standards. Lack of standards covers both the need for technology standards and also the importance of process standardization. It is also essential to develop a common way of thinking at all levels of the company.

*"If there is no change in thinking, then there will be no change in the company either."*

(Interviewee 11)

Companies also need to build secure data storage systems to ensure data security. The increasing amounts of data may require additional data storage capacity.

### *4.3. The effect of the factors identified on SMEs and MNEs*

This section discusses the different effects of the driving forces (Table 7) and barriers (Table 8) on SMEs and MNEs. For SMEs, the increasing labour shortages are crucial, because they are heavily dependent on local human resources. Many SMEs are therefore using Industry 4.0 solutions as a way to address human resource problems. MNEs have greater opportunities for recruitment, because they source talent on a global scale. If they do not find adequate human resources in a given region or country, they can move their production activities to another region.

Financial and profitability driving forces are not very important for SMEs, because they do not necessarily use new digital technologies primarily to reduce costs but to tackle other challenges (e.g. the lack of human resources). Their profitability expectations are lower and they often undertake projects with lower returns to meet personal and other management goals. For MNEs, this factor is more important, because they have higher cost reduction and profitability expectations.

SMEs are also less dependent on market conditions as driving forces. They strive to find niche markets and are less flexible than MNEs so are less able to change their operational processes. SMEs' business model innovation aspirations are often not conscious and not handled as an opportunity but rather as a compulsion. MNEs, however, face pressure from their competitors. These companies are constantly following each other's activities and act immediately if they see new developments elsewhere. SME managers may be less aware of the monitoring and other opportunities offered by new digital technologies. In contrast, the top management of MNEs aims to monitor and control the whole operation and performance of the company in real time through the application of Industry 4.0 technologies. Productivity and efficiency factors are important for SMEs, but have a more dominant role in MNEs, which are constantly striving to improve efficiency, especially in production departments.

Customer satisfaction is crucial for SMEs. As a result, they try to fulfil all exceptional requests of their customers to ensure those clients will return. MNEs may be similarly motivated for large customers, but for smaller clients, this factor is less important.

Human resources-related barriers are crucial for SMEs, because they often struggle to find employees with appropriate competences. MNEs recruit on a global scale, so this factor is mitigated. However, the number of artificial intelligence, big data and Industry 4.0 experts is currently low at the global level and the number of vacancies in this area is high.

Financial resources and profitability pose a high barrier for SMEs since these companies have fewer financial resources and are often unable to invest in new technologies. They mainly expect support from tenders, in which many shortcomings can be identified. For MNEs, the situation is much better because they can allocate significant amounts of financial resources to new developments and find and expend additional resources. The only questions may be around how the management tolerates uncertainty, and how much they are willing to experiment.

Management issues are also crucial for SMEs because their top management may be unable to identify the additional opportunities offered by Industry 4.0 technologies. The generation gap between employees is also a major problem. In MNEs, there are only a few managers who see through the whole supply chain and understand interdependencies.

Organizational factors are not a major barrier for SMEs. If the CEO is committed to innovative technologies, then all members of the organization will follow the CEO's lead and no or minimal organizational resistance is experienced. In MNEs, organizational resistance is much higher, especially from the middle management because they often do not want suppliers to introduce new technologies. The last barrier—technological and process integration, and cooperation—is low for SMEs, because they are not looking for technology integration at the supply chain level and instead solve emerging problems within their own organization boundaries. In contrast, this factor is a major challenge for MNEs because their primary goal is to integrate at the level of the entire network.

## 5. Summary and discussion

This study examined how companies interpret the concept of Industry 4.0, and the driving forces and main obstacles to introducing new, digital technologies under Industry 4.0. It also assessed the different level of effect of each of these factors on SMEs and MNEs. Discussing the interpretation of the concept, it was apparent that suppliers mostly highlighted the technology side, but users mainly focused on the management aspects of Industry 4.0. Companies with a dual role emphasized both factors equally. In line with our preliminary determination, interviewees also defined digitalization as the overarching issue, with Industry 4.0 as a sub-category. However, to drive successful adoption of Industry 4.0 technologies, companies need to create a common understanding of the change, and develop innovative forms of training that help to develop employee competences in a rapidly changing environment. In line with Kiel et al. (2017a) and Ríos et al. (2017), we also suggest that manufacturing companies should actively cooperate with universities and other educational organizations to develop educational programs covering multiple fields including mathematics, engineering, programming, and data analysis and processing.

This paper identified five main driving forces and five barriers to the application of new digital technologies in manufacturing processes. Our aim was to provide a more detailed and accurate description of these than previous studies. Management expectations emerged as an important driving force behind Industry 4.0 adoption, but this is not usually discussed in the literature. Management aspiration to increase control and enable real-time performance measurement may be a significant driving force behind the introduction of Industry 4.0 technologies. By applying digital technologies, corporate managers can improve both their decision-making and employee and company performance appraisal.

Both the literature and our research results show that the fourth industrial revolution presents a number of challenges for companies. We identified a new factor not covered in previous studies: that companies' concerns about profitability and uncertainties in tendering systems can significantly hinder companies from introducing Industry 4.0 technologies. As with any change, organizational resistance can be expected to the introduction of new technologies. This may be the most powerful barrier to change, and if not properly handled, can significantly impede the successful introduction of new technologies. Organizational resistance may come from employees who are afraid of losing their jobs over time or do not have the necessary skills for new technologies, but also from middle managers. Loss of employees disrupts the social environment within the company. As the organization becomes flatter, middle managers' role will change away from managing people and towards more expert work requiring higher qualifications.

Among the emerging barriers and challenges of Industry 4.0, standardization and management and leadership aspects are also important. The introduction of new digital technologies requires technological standards and standardization. We also found that companies need a process-centred operation for the successful implementation of new technologies. They also need open-minded, creative leaders who are thinking at both organizational and whole-network levels during the development process. Another new element identified in this study is that the lack of network-level willingness to cooperate and integrate technologies at the supply chain level—one of the key elements of Industry 4.0—can significantly hinder the integration and implementation of these technologies.

MNEs and SMEs do not have equal opportunities in the area of Industry 4.0. MNEs have higher driving forces and lower barriers than SMEs across nearly every aspect. However, SMEs have advantage over MNEs, including their lower profitability expectations. Customer satisfaction is also a stronger driving force for change in smaller companies. Organizational factors are less complex in SMES, so implementing new Industry 4.0 technologies, processes and management innovations is easier. SMEs also have fewer technological dependencies, and fewer barriers to cooperation.

Besides technological and organizational changes, management functions will also be significantly transformed. *Objective setting and strategy creation* will require more steps and much more iteration in the future. An agile approach within organizations is inevitable as well as more frequent revision of objectives and strategy. To ensure *organizational function*, the proper design of structures and processes will become even more important in a rapidly changing environment. Continuous rethinking of structure and processes will be necessary, together with an approach to problem-solving that looks at both individual problems and system-level interventions. The third feature is *personal leadership*, which will also significantly change. Social support will be even more important for employees remaining in the company and organizations must take care of the social security of their staff. To support *control* as a management function, traceability will be improved and it will be possible to track employee performance in real time. Up-to-date information will mean that employees become more accountable. Individual responsibility will also increase, and the cost of measurement will be significantly reduced for well-defined activities.

The examination of organizational and management aspects of Industry 4.0 is still in its infancy. The volume of literature is limited, which leads to several new research questions. In future, researchers should explore management aspects and best practices supporting companies implementing Industry 4.0 projects. Another important issue is how changed working conditions affect workers and what challenges can be identified at the social level. It may also be useful to extend the geographical focus of Industry 4.0 research, to compare similarities and differences across regions. Finally, in line with studies by Prem (2015) and Müller and Voigt (2017), it is also necessary to study the effects of Industry 4.0 on business models.

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## Appendix 1. Papers about the driving forces and barriers to Industry 4.0 with details of the methodologies used in each.

| Author(s) | Applied methodology |
|---|---|
| Adolph et al. (2014) | Literature review |
| Automation Alley (2017) | Survey of 150 senior technology executives and 150 senior manufacturing executives |
| Basl (2017) | Quantitative survey of 25 companies (mainly top management) |
| Bauer et al. (2015) | Literature review/expert opinion |
| BMBF (2014) | Expert report |
| Cimini et al. (2017) | Literature review |
| de Sousa Jabbour et al. (2018) | Literature review |
| Erol et al. (2016) | Literature review, case study (Learning Factory) |
| Frank et al. (2019) | Literature review/conceptual paper |
| Inezari and Gressel (2017) | Literature review and analysis of knowledge management and data analysis systems |
| Kagermann et al. (2013) | Expert report |
| Karre et al. (2017) | Literature review and one case study (LeanLab) |
| Kiel et al. (2017b) | 46 semi-structured interviews with managers |
| Kovács (2017a) | Literature review |
| Kovács (2018) | Literature review/conceptual paper |
| Lasi et al. (2014) | Literature review/conceptual paper |
| von Leipzig et al. (2017) | Literature review and one case study |
| Lins and Oliveira (2017) | Survey of more than 300 policies |
| Losonci et al. (2019) | Analysis of financial indicators of companies and the Industry 4.0 maturity of different sectors |
| McKinsey& Company (2016) | Survey of 300 manufacturing experts |
| Müller and Voigt (2016) | 68 interviews with CEOs, CTOs and heads of different departments |
| Müller et al. (2018) | 68 interviews with CEOs, CTOs and heads of different departments |
| Nagy (2019) | Four semi-structured interviews |
| Paritala et al. (2016) | Literature review |
| Prem (2015) | Literature review of case studies |
| PwC (2014) | Survey of 235 German industrial companies |
| Smit et al. (2016) | Analytical study based on relevant statistical data and information |
| Spath et al. (2013) | Analytical study based on relevant statistical data and information |
| Sung (2018) | Literature review |
| Szalavetz (2018) | 16 in-depth interviews with CEOs and CTOs |
| Uden and He (2017) | One case study |
| Ustundag and Cevikcan (2017) | Literature review |
| Varghese and Tandur (2014) | Literature review |
| Vey et al. (2017) | Literature review |
| Weber and Studer (2016) | Literature review and analysis of two legal instruments |
| Zhou et al. (2015) | Literature review/conceptual paper |

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