KRISZTINA DEMETER – DÁVID LOSONCI – RÓBERT MARCINIAK – JUDIT NAGY – PÉTER MÓRICZ – ZSOLT MATYUSZ – MÁTÉ BAKSA – ANNA FREUND – ZSÓFIA JÁMBOR – BENCE PISTRUI – ORSOLYA DIÓFÁSI-KOVÁCS

INDUSTRY 4.0 THROUGH THE LENSES OF TECHNOLOGY, STRATEGY, AND ORGANIZATION: A COMPILATION OF CASE STUDY EVIDENCE

IPAR 4.0 A TECHNOLÓGIA, STRATÉGIA ÉS SZERVEZET SZEMSZÖGÉBŐL: ESETTANULMÁNY-ALAPÚ EREDMÉNYEK

In the last few years, the management literature has become noisy with Industry 4.0 (I4.0). Although several concepts and typologies intend to make the phenomenon more understandable, these endeavours generally focus on technological aspects or specific issues. Therefore, integrated approaches of the I4.0 transformation on the business side and a comprehensive investigation of this phenomenon on the academic side are still needed. This paper synthetizes the lessons of 15 case studies from five sectors (automotive, FMCG, logistics services, retail, and business services) and places them in a triadic framework of technology, strategy, and organization. The case studies are based on interviews, internal documents and public information. This paper reveals that the analysed companies focus on I4.0 technologies that are substantially related to the development of core activities. Companies in a highly competitive global environment (e.g., automotive industry and business services) are more prepared and progress faster with I4.0 technology implementation.

Keywords: **Industry 4.0, strategy, organization, Industry 4.0 technologies, digital transformation**

Az elmúlt években a menedzsmentirodalom az Ipar 4.0-tól (I4.0) vált hangossá. Bár számos koncepció és kategorizálás létezik, amelyek igyekeznek érthetővé tenni a jelenséget, ezek gyakran a technológiai szempontokra vagy néhány konkrét megoldásra fókuszálnak. A cikk a digitális transzformáció üzleti szempontú, komplex és integrált megközelítését adja a technológia-stratégia-szervezet keretrendszer alkalmazásával. A kutatás öt ágazat (autóipar, FMCG, logisztikai szolgáltatások, kiskereskedelem és üzleti szolgáltatások) 15 vállalatának tapasztalatait szintetizálja. A részletgazdag esettanulmányok interjúkon, valamint céges és publikus dokumentumokon alapulnak. A kutatás eredményei szerint a vizsgált cégek aktívan foglalkoznak az I4.0 technológiákkal, legfőképpen az elsődleges értékteremtő folyamatok fejlesztése kapcsán. A globálisan kiélezett versenyhelyzetben lévő vállalatok (járműipar, üzleti szolgáltató központok) felkészültebben indulnak és gyorsabban is haladnak az I4.0-val.

Kulcsszavak: **Ipar 4.0, stratégia, szervezet, Ipar 4.0 technológiák, digitális transzformáció**

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Authors/Szerzők:
Dr. Krisztina Demeter, DSc, professor, Corvinus University of Budapest (krisztina.demeter@uni-corvinus.hu)
Dr. Dávid Losonci, PhD, associate professor, Corvinus University of Budapest (david.losonci@uni-corvinus.hu)
Dr. Róbert Marciniak, PhD, associate professor, Corvinus University of Budapest (robert.marciniak@uni-corvinus.hu)
Dr. Judit Nagy, PhD, associate professor, Corvinus University of Budapest (judit.nagy@uni-corvinus.hu)
Dr. Péter Móricz, PhD, associate professor, Corvinus University of Budapest (peter.moricz@uni-corvinus.hu)
Dr. Zsolt Matyusz, PhD, associate professor, Corvinus University of Budapest (zsolt.matyusz@uni-corvinus.hu)
Máté Baksa, assistant lecturer, Corvinus University of Budapest (mate.baksa@uni-corvinus.hu)
Anna Freund, assistant lecturer, Corvinus University of Budapest (anna.freund@uni-corvinus.hu)
Zsófia Jámbor, assistant lecturer, Corvinus University of Budapest (zsofia.jambor@uni-corvinus.hu)
Bence Pistrui, assistant lecturer, Corvinus University of Budapest (bence.pistrui@uni-corvinus.hu)
Dr. Orsolya Diófási-Kovács, PhD, senior assistant lecturer, Corvinus University of Budapest (orsolya.diofasi@uni-corvinus.hu)

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The phenomenon of the Fourth Industrial Revolution permeates everything. It has completely subverted several service sectors (e.g., retail, banking, and music) and cannot be neglected in either processing industries or whole supply chains. Digitalization in this paper is used as a synonym for I4.0, and even though the difference between the two is well-known (Demeter & Losonci, 2020), it is accepted here as a common practice among both researchers and practitioners.

Despite the tremendous impact of I4.0, the analysis of it is still in its infancy. One obvious reason is that many different perspectives (e.g., business, design, maturity, and implementation) (Demeter & Losonci, 2020) and several ad hoc categories are used for examining new emerging technologies. Furthermore, the more-trivial representatives of 4.0 technologies, such as 3D printing and big data analytics, are usually discussed in academic studies as specific and separate issues, where the most frequent unit of analysis is the project. Although it supports an understanding of the narrow phenomenon, project-focused approach offers much less insight into company level efforts using I4.0. Moreover, managers can be confused when reading two extreme examples, namely, studies on the best companies (see World Economic Forum, 2019) and studies regarding the evidence and expectations of less-experienced companies (Dalenogare, Benitez, Ayala, & Frank, 2018). Therefore, this "granular" approach and ambiguous research context create strong barriers, among others, and practically hinder the development of proper recommendations to companies managing I4.0 transformation issues.

To address these shortcomings, our business-oriented paper aims to draw a complex and integrated view of companies' I4.0 transformation. To grasp the phenomenon in this manner, we applied a technology-strategy-organization framework.

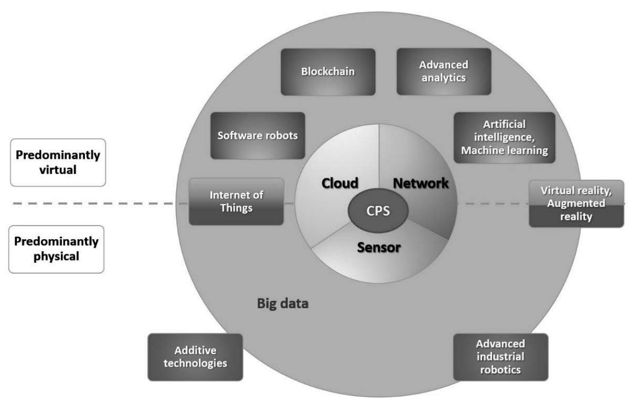
The structure of the article is as follows. To propose a common understanding, our paper first briefly classifies the I4.0 technologies and then examines the main features of the I4.0 transformation at the business unit level, including the internal factors of contingency (Soliman, 2014) (strategy and organization) and technology. Following the literature review, the case study methodology and data collection protocol are described. A total of 15 case reports were used to identify business unit practices. Business units were selected from different positions in different supply chains. Relying on this cross-case analysis, the results section provides insights into the differences in the transformation patterns. Highlights and future research directions are detailed in the conclusion.

Literature review

Technologies

Although I4.0 technologies are rooted in the Third Industrial Revolution, they extend far beyond this period. Ubiquitous computing, a specific attribute of the Fourth Industrial Revolution, was the prerequisite for I4.0 technology development. The research emphasized three elements that provide the foundations of I4.0 technologies: sensors, networks, and the cloud (Figure 1). *Sensors* are the parts of a machine or product that sense its operation and environment (Lee, Kao, & Yang, 2014). A sensor can be an RFID tag, a scale, a camera that can monitor a product, or a process, and it records and transmits data. *The network* ensures communication connectivity between devices via the Internet (wired or wireless). Networked and sensor-based production systems allow real-time communications and interactions in which the product can be clearly identified and traced during production and use (Prause, 2015). The *Cloud* is a tool for storing, manipulating and sharing large amounts of data generated by the previously described elements (Ghobakhloo, 2018). These three technologies form the cyber-physical system (CPS), where physical devices and the virtual world are connected. According to Monostori (2014), the CPS is composed of collaborative computing units that are connected to the physical world (objects and devices) and its processes and can share data continuously in a network. According to Brettel (2014), the CPS can establish a communication link between people, machines, and products. In Brettel's view, the CPS is capable of an end-to-end integration of business processes and services.

Figure 1.
The interdependence of I4.0 technologies



Source: own compilation

I4.0 technologies are based on these outlined fundamentals. The research distinguishes between technologies that are dominantly virtual (advanced analytics, software robots, blockchain, machine learning and artificial intelligence), those that are dominantly physical (additive production and advanced robotics) and two that are balanced combinations of virtual and physical elements (IoT and virtual/augmented reality). This is very similar to the approach by Culot, Nassimbeni, Orzes, & Sartor (2020), who categorized technologies on a scale from hardware to software.

In the *blockchain*, all agreements, processes, tasks, and payments have a digital code and imprint that are clearly identifiable, authentic, and stored in the same format at each shared location. This allows individuals, organizations, machines and algorithms to freely conduct transactions and interact with each other (Hammond, 2017; Iansiti & Lakhani, 2017).

Artificial intelligence (AI) is the ability of a computer to think, perform tasks, interact, and act as a human in areas that humans are capable of (Dirican, 2015). *Machine learning*, a branch of AI, computer systems that can automatically improve with experience, has been used in many aspects of business where large amounts of data are generated, including after-sales services, diagnostic functions of complex systems and control of logistics chains and intelligent automation software (Jordan & Mitchell, 2015).

At the interface of predominantly physical and virtual spaces, solutions are based on a combination and use of both spaces, such as the *Internet of Things* (IoT) in networking and data sharing, and *augmented and virtual reality* (AR/VR) in repair and maintenance. The IoT is a summary description of solutions that allow objects equipped with sensors to network, communicate, and share data (Hermann, Pentek, & Otto, 2016). Further, the IoT embraces older machine-to-machine (M2M) technologies as well as the typical industrial machines that communicate directly using various communication channels. According to Azuma (1997), augmented reality is the integration of virtually rendered objects into the environment in real-time. From Azuma's perspective, virtual reality is another version of augmented reality.

Advanced industrial robotics (AIR) is a branch of robot development that enables machines to perform intelligent tasks with sensors and dynamic programming with greater flexibility and precision than conventional robots (Eurofound, 2018; Lorenz et al., 2015).

Robotic process automation (RPA) is a software robot (bot) that automates rules-based, repetitive, labour-intensive tasks to replace the human workforce, e.g., in an office environment (Lacity, Willcocks, & Craig, 2015). Installed on a computer, RPA is a software solution that uses IT systems through user interfaces in the same way that a human does (Asatiani & Penttinen, 2016).

Additive technology, or 3D printing, significantly accelerates and simplifies the production of a prototype and the release of the first version of a product (Dalenogare et al., 2018). It increases customer satisfaction through an accelerated process and offers design freedom, supply chain simplification, rapid prototype production and small series availability (Ghobakhloo, 2018).

Storing a huge amount of data generated in these systems is a tremendous task for companies, and these data must be structured, refined, and analysed with various algorithms and software. While *advanced analytics* generates relevant and structured information from available data (Wang, Wan, Li, & Zhang, 2016), social media analytics help clarify buying habits and patterns, and helps companies develop offers that consumers are more likely to accept (Ghobakhloo, 2018). Business intelligence (and analytics) summarizes techniques, technologies, systems, practices, and applications that can be used to gather and analyse critical business information (Chen, Chiang, & Storey, 2012).

All the technologies shown in Figure 1 have some relation to data; i.e., they either generate, use or analyse them. While there are many other categorizations of technologies, Figure 1 shows the important relationships between them, it is not a mere list. Furthermore, as indicated in this figure, horizontal and vertical integration, which is frequently listed as an I4.0 technology, is clearly not a technology but is the result of using the aforementioned technologies.

Strategy and Organization

Studies of the digital transformation of organizations usually focus on various I4.0 technologies and the business and technological issues they solve because, without these innovations, there could be no discussion about the transformation of organizations or industries. However, fewer articles address the role of strategy, structure, organizational culture, project management, and other organizational characteristics regarding the successful adoption of these new technologies. The research has gathered and structured the key strategical (see Table 3) and organizational factors (see Table 4) that either foster or hinder the environment for I4.0 technology-driven projects.

I4.0 means linking different digital technologies into one integrated phenomenon, and the integration of these technologies greatly depends on a clearly defined digital strategy. Kane et al. (2016) argued that creating a clear and coherent digital strategy is vital for the digital maturity of organizations because it enables the use technologies not for solving individual problems with individual technologies but for promoting business transformation with integrated I4.0 technologies. However, less-mature organizations do not have a clear or intended strategy to drive transformation. The factors of a digital strategy can be divided into intracompany and competitive level categories. While some factors explain how a digital strategy forms the internal organization, competitive level factors explain how a strategy changes the company in the external competitive environment.

Considering the extent to which a strategy is articulated, Mintzberg (1977) and Andrews (1987) differentiated the explicit strategy and the implicit strategy. The more formulated and explicated the strategy is, the easier to implement it, because the participants are aware of it; however, the higher the bureaucracy with it, as well. Under some circumstances, different explicit and implicit strategies exist in parallel; for example, a centralized strategy is formulated by headquarters, but another business unit or department-level strategy also has formulated a strategy within the organization. Furthermore, based on the autonomy of the organization, the decentralized strategy can also be explicit and determinative. Herbert (2017) argued that establishing real digital transformation requires that three different areas of the organization be address: the business model, customer experiences and internal processes. Daubner et al. (2017) created a more exhaustive categorization for digital transformation with the digital transformation of products/services and divided the internal processes into core and support roles. The digital strategy can positively or negatively influence the relative position of the company in the corporate hierarchy, or the company position can remain unchanged. Renjen (2019) highlighted the significance of the financial conditions of I4.0 projects. Some implementations are financed by a dedicated corporate project fund, and others are financed through a local decentralized budget, external sources, or a combination of sources. The financing mechanism is dependent on the innovation culture, whereas earnings support is underpinned by accurate planning.

Regarding the *competitive level of the strategy*, Gilbert (1994) argued that some changes are dramatic in their scope and impact and clearly fall within the radical category; however, other changes are more incremental and slower. The changes may have the same strategic value, and the outcomes may be the same but are reached more slowly. The digital strategy may focus on change in the competitive edge of the organization by cost-decreasing or customer value-increasing approaches. A cost-decreasing strategy involves the adoption of new technologies that increase efficiency efficient, whereas a value-increasing strategy does not necessarily reduce costs but creates new value through the implementation of new technologies. In some cases, external conditions prompt a change, and in some situations, a mixed approach is the optimal option for the organization. According to Szász, Demeter, Rácz, & Losonci (2020), I4.0 supports both cost-decreasing and value-increasing approaches.

Gilbert (1994) stated that innovative strategies that favour the development and introduction of innovation, require radical, inventive and quick planning and involve higher costs and risks of failure, while also offering greater rewards and improvement. Hence, these strategies are referred to as proactive. On the other hand, a strategy that is incremental, imitative, and relatively late is called reactive. A preactive strategy does not create but rather predicts the future. I4.0 technological change is seen as the driving force of the organization. If an organization has a plan, then it can take advantage of current change. A passive or inactive strategy focuses on preserving the advantages of the present into the future. Moreover, a digital strategy can alter, either positively or negatively, the external position of the organization in the value chain or in the market

Various organizational factors can influence the success of technological implementations. These factors can be structured to link *management issues, ways of working and characteristics of human resources*. Davis-Peccoud et al. (2018) argued that the commitment of management can be assessed by the extent to which dedicated leaders and organizational units responsible for digitalization are established. Shared managers and shared groups/departments have other responsibilities in the organization that can hinder the comprehensive exploitation of new technologies. Accordingly, some organizations build formal organizational units, such as centres of excellence/exercise (CoEs), and foster more-informal groups, such as communities of practice (CoPs), to stimulate new sources of knowledge and perform internal experiments, but others obtain them from outside the organization or use internal and external sources. Agostini & Filippini (2019), Renjen (2019) and Kane et al. (2016) focus attention on the fundamental role of the innovation culture in digital transformation. Organizations with a strong innovation culture (characterized by a shared innovation mindset, risk-taking, collaborative work style, individual incentives, and major standard processes to foster innovation, seem to be more successful with respect to technological adoption and the exploitation of benefits. A weak innovation culture is characterized by individual initiatives, a risk-averse attitude, an independent work style, manager contract/business unit level incentives, and, primarily, ad hoc processes to stimulate innovation. Agostini & Filippini (2019) stated that the success of a technological project depends on the attributes of human resources. The more educated**,** skilled and younger the workforce employed in the organization, the likelihood of deploying I4.0 technologies successfully increases. Keszey & Tóth (2020) reached similar conclusions. Finally, company size and geographical coverage of an organization (global/local) can also influence the spread of I4.0. According to international survey results (Szász et al., 2020), larger companies invest more in I4.0 technologies, but multinational companies do not have advantages over local firms. Nevertheless, in their literature review, the authors listed many studies that reached different conclusions.

Some aspects of I4.0 projects are independent of organizational and strategic factors. While an organization may embrace, for example, a cost-decreasing strategy, an I4.0 project may aim to increase customer value. Furthermore, I4.0 projects can have other characteristics with respect, for example, the role of technology and its interactions with human resources (e.g., replacing humans with technology, providing humans with technological support, or extending human capabilities, e.g., the exoskeleton), the level of human resistance against technology, the internal or external direction of project initiatives (e.g., clients, suppliers, etc., from both a top-down and bottom-up approach), or the financial preparation of a project for approval (i.e., argument based or calculation based). However, due to space limitations we do not deal with project-level issues in this paper.

Based on the different issues discussed in the literature review thus far, it is evident that achieving a digital transformation is a complex task for companies. Therefore, providing detailed case study results may reveal the paths that companies and/or sectors follow and may also support researchers as they strive to understand the relationships between various factors. Providing this support is the objective of our paper.

Methodology, data collection and data analysis

There are many reasons to choose the case study research approach. First, as presented previously, the available fragmented experiences regarding I4.0 and the prescriptive and expectations-based nature of many I4.0-related works currently do not foster a complex picture of the lived experiences or the true policies of companies and plants. Furthermore, since it is a relatively new phenomenon, the more flexible data collection process of the case method provides advantages that enabled us to gain more valid data by addressing the managers in charge.

We followed the convenience sampling approach searching for units that are more mature in and/or open towards I4.0 initiatives. The sampling process included only one specific factor: we aimed to study both a) subsidiaries of international corporations and b) locally owned units or units with local HQs. Initially, we believed that the opportunities are considerably different for these two groups. We also expected that the diversity of ownership, industry and size would reflect the potential for different approaches.

The data were collected on 15 case units representing 14 different corporations from five sectors of the economy representing supply chains: 1) automotive manufacturing and 2) food producing companies, 3) logistics service providers, 4) retail companies, and 5) business service centres (BSCs) (Table 1). The data collection process was formalized by a 20-page data collection guide that suggested a structure for the case description. The main highlights of the guide were industry- and corporate-level 4.0 experiences and a detailed summary of unit-level I4.0-related changes. It also integrated the introduction of the two most important projects. The data collection guide defined the most relevant aspects of the inquiry, and the supplement suggested a protocol for semi-structured interviews, which were conducted and subsequently transcribed. The case description combined data from these interviews, public data, and descriptions of experiences obtained from visits. For several units, the (long-range) research cooperation ensured the data. Each case description was sent to the unit's representative to validate the content and to make improvements, if necessary. Data collection and processing were supported by doctoral and undergraduate university students under the supervision of the researchers.

Table 1.

Main characteristics of the cases (sectors separated by grey-white cell colour)

Sector	Case plant	Main industrial activity	No. of employees of the case plant	No. of employees of the corporation	HQ is in	Main focus of technological and digital developments
Auto-motive	M-Conn	automotive connectors	1,500+	100,000+	Western Europe	e-lean solutions, predictive maintenance, dashboard on shop floor
	H-Elect	automotive electronics	1,500+	10,000	Hungary	automation, better organization based on integrated data collection system
	H-Plast	customer goods and automotive	1,400+	10,000	Hungary	improve core and support technologies and machines; provide better organization and tighter control
	M-Elect	automotive electronics	1,800+	200,000+	Western Europe	establish simulation-based new production lines with advanced robotics
Logistics	H-Log	transportation, logistics services	1,000+	1,000+	Hungary	improve efficiency of service, support human workforce
	M-Log	transportation, logistics services	250*	7000+	Turkey	improve efficiency of service, support human workforce
Retail	Sport	sports retail	1,500*	40,000+	Western Europe	improve back-end processes and support human workforce, enhance customer experience
	Fashion	fast fashion retail	100*	11,000	Western Europe	improve back-end processes and support human workforce
Food	Milkprod	food industry	100	700	Hungary	improve core technology, assure food safety and quality
	Milkproc	food industry	450	1,000	Western Europe	provide automation and robotization, improve core technology, assure food safety and quality
	Pasta	food industry	100	100	Hungary	provide automation of the core technology and robotization in support processes
BSC	US	business services	2,000+	40,000+	US	support and replace human workforce
	TechB	business services	1,000+	100,000+	US	support and replace human workforce
	Alpha	business services	1,500+	100,000+	US	support and replace human workforce
	IT	business services	4,500+	200,000+	Germany	support and replace human workforce

* in Hungary

Source: own compilation

While the units were open to show their I4.0 efforts, many requested anonymity. As the data were not distorted, contingency-related problems were also studied.

The study included 47 interviews with 52 people from diverse positions between the mid-2018 and the mid-2019. More than one interviewee participated in some of the interviews, which is the reason that the number of interviewees exceeds the number of interviews. Details about the interviewees' positions and the dates of the interviews are summarized in Table 2. The interviews lasted between 40 and 90 minutes, and when feasible, two researchers conducted the semi-structured interviews. If the interviewee asked about the research project, the researchers sent them the data collection guide or the interview protocol in advance by e-mail.

While we had an initial understanding of the technology, organization, and strategy (covered by the data collection guide), after the completion of the case description, we refined this preliminary framework. On the one hand, the literature helped us crystallize the specific dimensions of these categories (e.g., more specific dimensions of strategy development and deployment and integration of lean and I4.0 efforts). On the other hand, the experiences of the units revealed important, previously neglected aspects of the transformation process (e.g., the importance of budget and the availability of financial sources). We arrived at the final framework in an iterative way by combining the cycles of senior researchers' preparations and presentations and workshops with discussions that involved 8-12 participants. Building on the case description and the final framework, a two- to three-page within-case analysis was written about each unit. The next section explains the cross-case comparison.

Results

Technologies

Case companies in all sectors focus on the predominantly digital technologies, such as sensors, the Cloud, IoT, and big data (see Table 3). However, the least-used technologies, that is, blockchains and AR/VR are also predominantly digital. The negligible use of the latter two technologies may be the results of their low maturity.

In addition to the common digital base, significant sectoral differences were revealed. In sectors with physical products (produced, transported, or sold), companies highlight sensors, which enable the transformation of physical activities into digital data. However, only these companies invest in advanced robotics (for manufacturing or transport) and additive manufacturing, which is used in

Table 2.

Case data collection summary (sectors separated by grey-white cell colour)

Sector	Cases	Position of interviewees	# interviewees	# interviews	Date
Auto	M-Conn	Head of digital/lean department; senior lean engineer; IT business analyst and developer; member of digital/lean department	4	3	July 2018
	H-Elect	CEO; director of sales, engineering and purchasing; chief technical expert	3	3	May, Nov 2018
	H-Plast	CEO; head of engineering; production manager (former lean expert); facility manager	4	4	June 2018
	M-Elect	Head of digital department; head of lean group; expert	3	3	Mar-May 2019
Log	H-Log	Chief digitalization officer; IT project manager; head of innovation and projects; project manager	4	4	Sep 2018
	M-Log	Country manager; digitalization team leader	2	2	Nov 2018
Ret	Sport	Chief customer experience officer; fitness department manager; fitness department digital ambassador; two employees	5	5	Aug-Sep 2018
	Fashion	Country manager; HR business partner; HR trainer; area manager; assistant store manager; brand manager	6	6	Sep-Nov 2018
Food	Milkprod	Farm manager	1	1	Feb 2019
	Milkproc	Plant manager	1	1	Apr 2019
	Pasta	Plant manager	1	1	Aug 2018
BSC	US	CEO and automation lead	2	2	Nov 2018
	TechB	Managing director; HR services (external); procurement; Q2C (sales support); chief information officer; indirect tax; accounts payable; HR transformation (internal)	8	5	Oct-Nov 2018
	Alpha	Site executive; head of automation; service quality analytics expert	3	3	Jan 2019
	IT	Security lead; expert architect; IoT portfolio unit lead; managing director; business unit lead	5	4	Dec 2018
		Sum of interviewees and interviews	52	47	

Source: own compilation

the creation of an automotive after-sales market. Software robots, such as chatbots and RPA, constitute another set of sector-specific technologies that are used in each BSC, but nowhere else. Although chatbots can be efficiently applied to customer services in other sectors, Machine learning is used most frequently in the BSC sector. Logistics firms can also use it efficiently for routing, warehousing, or truck loading optimization. These sector-specific technology sets may reflect different I4.0 directions even in the mid-term.

Finally, within-sector differences are also relevant and explained by technology maturity level, innovativeness, and specific contextual factors. Firms' different technology maturity levels may be the result of industrial "standards" amplified by their respective, current supply chain position. All these factors might lead to differences in the level to which a specific technology is adopted, which is not evident from the table data. For example, M-Conn, a TIER 2 firm in the automotive sector has a machine connectivity (IoT) of approximately 60%, while another parts supplier, a TIER 3 manufacturing company is limited to only M2M solutions. While the innovativeness of a firm's culture reflects its openness to low maturity I4.0 technologies, the context also determines, to some extent, their usage. For example, despite its maturity in IoT, M-Conn does not invest in robots due to product complexity and variety.

Based on Table 3, there are no major differences in the number of technologies used by companies, with the numbers varying between 2 and 7 and a median value of 5, which means that companies usually invest in several technologies simultaneously. This practice is understandable given that big data analytics in manufacturing settings requires sensors, the cloud, connected devices (IoT), and big data.

Table 3.

Technologies used in case companies (sectors separated by grey-white cell colour)

Sector	Cases	Technologies											Σ
		Sensor	Cloud	IoT	Big data	Big data analytics	Blockchain	Software robots	AI	AR/VR	Addit. mfg.	Ind. robots	
Auto	M-Conn	x	x	x	x	x					x		6
	H-Elect	x	x	x								x	4
	H-Plast	x	x	x	x	x							5
	M-Elect	x	x	x							x	x	5
Log	H-Log	x	x	x	x	x			x			x	7
	M-Log	x		x									2
Ret	Sport	x	x	x	x	x							5
	Fashion	x	x		x	x							4
Food	Milkprod	x			x	x						x	4
	Milkproc	x	x	x	x	x						x	6
	Pasta	x	x	x	x							x	5
BSC	US		x		x	x		x					4
	TechB		x		x	x	x	x	x				6
	Alpha		x		x	x		x	x	x			6
	IT		x	x	x	x		x	x				6
All	# Appl	11	13	10	12	11	1	4	4	1	2	6	

Source: own compilation

Strategy

While several aspects are considered, the picture remains quite vague (Table 4).

Strategy visibility. Even if one-half of the case companies have an explicit corporate or company level digital strategy to deploy, many others have only an implicit digital strategy or no strategy at all. There does not seem to be any sectoral or general pattern with respect to this issue.

Level of centralization. The lack of a pattern also holds for this variable. There is not a single sector for which each company follows the same policy. However, at some companies there is a balance between centralized decisions and local initiations. For example, at *M-Conn* there is a local budget devoted to small digitalization projects, but for major actions they require approval and financial support from their headquarters. At *M-Elect* the headquarters provides direction, but the sites must make the decisions regarding the deployment of the strategies. At others, there is little room left for local actions. At *Fashion,* for example, the shops have no voice in the decisions; they must follow central orders. In contrast, there are companies where everything is decentralized with the sole requirement that each reaches its profit targets.

Level of transformation. The majority of companies in this study (13 of 15) usually make efforts to transform their core processes, although there are examples of companies making business model changes and engaging in product/service development. For example, at *Sport*, a kiosk has been added where customers can place orders directly in the shop for products not available at the moment; at *IT*, an advanced Cloud-based solution was developed with computing and data analysis capabilities, which can be used both in-house and by clients. At *Milkprod*, the production process is completely digitalized and capable

Table 4.

Strategic issues at case companies (sectors separated by grey-white cell colour)

Sector	Cases	Corporate level				Competitive level		
		Visibility[a]	Centralization[b]	Transform[c]	Internal position[d]	Pace of change[e]	Innova-tiveness[f]	External position[g]
Auto	M-Conn	Exp. corp	Balanced	3	Improved	Increm.	Proactive	No change
	H-Elect	Implicit	No	3	n.r.	Increm.	Reactive	No change
	H-Plast	Implicit	No	3	n.r.	Increm.	Reactive	No change
	M-Elect	Exp. corp	Balanced	3,4	Improved	Increm.	Reactive	No change
Log	H-Log	Explicit	Centralized	3,4	n.r.	Increm.	Proactive	No change
	M-Log	Exp. corp	Balanced	3,5	Improved	Increm.	Reactive	No change
Ret	Sport	Exp. corp	Balanced	2,3,4,5	No change	Increm.	Proactive	No change
	Fashion	Exp. corp	Centralized	3,4,5	No change	Increm.	Proactive	No change
Food	Milkprod	Not exist	Centralized	1,3,4	n.r.	Radical	(Pre)active	No change
	Milkproc	Not exist	Balanced	3	No change	Increm.	(Pre)active	No change
	Pasta	Explicit	Decentr.	3,4	n.r.	Radical	Proactive	Improved
BSC	US	Not exist	Centralized	3	Improved	Increm.	Reactive	No change
	TechB	Implicit	Decentr.	1	Improved	Radical	Proactive	No change
	Alpha	Implicit	Decentr	1,3,5	Improved	Increm.	Proactive	Improved
	IT	Exp. corp	Balanced	2,4	Improved	Increm.	Proactive	Improved

Source: own compilation

a) Visibility/articulation variables: explicit and deployed from corporate level, explicit, implicit, does not exist

b) Level of centralization: centralized, decentralized, both, no

c) Level of transformation: 1) business model, 2) product/service, 3) core processes, 4) support proc., 5) customer proc.

d) Internal relative position change: improved, declined, unchanged, not relevant (n.r.)

e) Pace of change: radical, incremental

f) Innovativeness: proactive, (pre)active, reactive, passive

g) External position change: improved, declined, unchanged

of providing detailed data for internal and external purposes about the health status of the cows, the quality and quantity of their milk, food safety, etc.

Internal (within corporation) and external (on market) positions. Internal position is relevant only for multinational companies where subsidiaries can upgrade themselves in the internal value chain. While companies usually experience improved positions within their corporation to earn more and/or offer higher value-adding activities within their network, this improvement is much less visible at the competitive level. Only the managers at *Pasta,* which has a large-scale, completely new digital plant, think that they can improve their position by expanding to new markets.

Pace of change and innovativeness. There seems to be a relationship between the existence of strategy and innovativeness, indicating that proactive innovation requires some strategy, while companies with no explicit digital strategy are reactive. However, there are exceptions in both directions. For example, although *M-Log* has an explicit corporate strategy, it is still reactive, while milk-producing and processing companies do not have any strategy and are (pre)active. We can also see examples of radical changes, e.g., the new digital plant at *Pasta* and the digitalized milk production process at *Milkprod*. Furthermore, at *TechB,* as the digital strategy is deeply rooted in the corporate culture, the developments change the business model via automation, robotics, and machine learning. Nevertheless, there are cases where the changes are still slow, and progress is made at a stepwise incremental pace.

Organization

There are extensively heterogenous solutions at the organizational level (Table 5).

Responsibility and digital (government) unit. At some companies, the people responsible for digitalization are either in top managerial positions (C-level) or, at the very least, dedicated to digitalization. However, some managers (shared managers) have to handle tasks in addition to I4.0. Only one company had no management level representation in its digitalization field. Even though I4.0 is represented at all but one company by a manager in a high position, not every manager has a dedicated or shared unit supporting his/her work. For example, we did not find this type of unit in the retail or the food sectors as the retail sector is too centralized to allow for local experiments, and food sector players are too small to operate this type of unit efficiently.

Innovation processes. The innovation processes are usually standardized regardless of the project purpose. For example, at *M-Conn* standard digitalization projects differ from lean projects. Digitalization projects are more complex and involve more people and more roles for participants.

Companies with less frequent experimentation are not at a level capable of standardizing digital-based innovation (e.g., *M-Log* and *Pasta*).

Ways of working. The sample is quite diverse in this aspect. Considering the analysed project, we noted that, at some companies, ideas are obtained from customers, and thus, they are pushed to innovate. In these companies, the culture of innovation is not exceptionally strong, but they are, nevertheless, willing to keep pace with their customers. Other companies have a strong innovation culture, thus moving towards I4.0 is easier as the people are ready to make changes and learn new things. Some companies from the automotive and BSC sectors have lean culture, which helps make continuous improvements and combine their lean culture with digitalization.

Employees. Digitalization does not depend on employee characteristics. Some companies exhibit good progress with trained workers, (i.e., they have engineers, but the ratio is quite small and skilled workers, e.g., BSC organizations). Similarly, no difference is found for age. For example, *H-Log* with older employees seems to be more committed to digitalization and ahead in the digital journey than *M-Log* with a younger generation, a result that may be due to the stronger innovation culture of the former.

Table 5.

Organizational characteristics of case companies (sectors separated by grey-white cell colour)

Sector	Cases	Organization factors						
		Management			Ways of working		Employees	
		Responsibility[a]	Governmental unit[b]	Innovation processes[c]	Source of knowledge[d]	Innovation culture[e]	Education level[f]	Age[g]
Auto	M-Conn	Dedicated	Dedicated	Standard	Both	Strong (lean)	Balanced	Balanced
	H-Elect	Shared	Shared	Standard	External	n.i.	Trained	n.i.
	H-Plast	Shared	Shared	Standard	External	n.i.	Trained	n.i.
	M-Elect	Dedicated	Dedicated	Standard	Both	Strong (lean)	Trained	n.i.
Log	H-Log	C-level	Dedicated	Standard	Internal	Strong	Balanced	Older
	M-Log	Dedicated	Dedicated	Ad hoc	External	Weak	Balanced	Younger
Ret	Sport	C-level	Not exist	Balanced	Both	Strong	Balanced	Balanced
	Fashion	Shared	Not exist	Standard	Both	n.i.	Balanced	Younger
Food	Milkprod	Shared	Not exist	Balanced	Both	Strong	Balanced	Balanced
	Milkproc	Shared	Not exist	Balanced	Both	n.i.	Balanced	Balanced
	Pasta	Shared	Not exist	Ad hoc	n.i.	Weak	Trained	Balanced
BSC	US	Dedicated	Shared	Ad hoc	Internal	Strong (lean)	Balanced	Balanced
	TechB	Not exist	Shared	Balanced	Both	Strong	Skilled	Younger
	Alpha	C-level	Dedicated	Balanced	Internal	Strong	Skilled	Younger
	IT	Shared	Shared	Balanced	Both	Strong	Skilled	Younger

Source: own compilation

a) Responsibility: C-level executive, dedicated manager, shared manager, does not exist

b) Governmental unit: dedicated department, shared department, does not exist

c) Innovation processes: major standard processes, mainly ad hoc processes, both

d) Source of knowledge: internal, external, both, not identified (n.i.)

e) Innovation culture: strong, weak, lean, not identified (n.i.)

f) Educational level: mainly educated, skilled; mainly trained, balanced

g) Age: mainly y generation or younger, mainly older than y gen, balanced, not identified (n.i.)

Discussion

The research synthesizes the daily I4.0 experiences of 15 different supply chain actors from five sectors in the technology-strategy-organization (TSO) triad. Each leg of the triad framework represents a distinct, however converging approach of the I4.0 journey. Our study is among the first (another is Demeter, Losonci, Szász, & Rácz, 2020) that applies the three perspectives of TSO to the examination of firms' digital transformation. Applying this theoretical framework to a wide variety of corporate experiences provides opportunities to explore specific trajectories and patterns. We believe that this study's complex approach complements the loud discourse and wide-spread narratives of one-sided interests (e.g., specific technology, project level, or indicator-focus).

Technology

While the power of I4.0 is the consequence of the combined availability of many technologies, and synergy is possible, the modular design implies that these technologies can be used independently. Given the maturity of individual technologies (Demeter et al., 2020), it is not realistic in today's environment for a company to combine these technologies into one cyber-physical system. Even in the cases of companies with higher technological levels, only *mature technologies* are implemented; these companies consciously avoid novel, less mature technologies or reach only pilot status with them (e.g., in big data analytics). Off-the-shelf, boxed products are not yet available.

The empirical analysis of different sectors provides further insights into technology usage. The findings emphasize that there has been a commonly used set of core technologies (e.g., IoT, big data and analytics, cloud, and sensors) (see Frank et al., 2019) from the very first steps of digital transformation. Furthermore, this cross-sectoral research has revealed that in addition to this common set of technologies, different sectors also require and use different applications. A major difference between companies with *physical products* (e.g., automotive components) and those offering services is that the former have an additional layer from which to collect data; that is, they must build sensors into machines to make the production status digitally available. This may be one of the reasons BSCs are in the forefront with respect to the use of the cutting-edge digital technologies that are currently still neglected by manufacturing plants.

Strategy

In contrast to often optimistic expectations (Dalenogare et al., 2018), self-assessment based findings (i.e., López-Gómez, McFarlane, O'Sullivan, & Velu, 2018), and summaries of highly successful digital transformations (World Economic Forum, 2019), our research found that, in most cases, technology upgrades are required to maintain a company's competitiveness. In other words, by neglecting digital-based innovation, companies will lose customers and markets. It should be added, however, that competitiveness might depend on the types of innovations companies create (process, product/service or business model). We found very few examples of business model or product/service innovations, which may explain why these companies are unable to gain a competitive advantage. Making improvements only to processes does not attract new customers (Herbert, 2017); these improvements are only the start of a digital transformation. Nevertheless, they can create some internal advantages within the corporation by obtaining more business from other business units. Reactive companies seem to be pushed into their digitalization journeys as many of them have external opportunities they wish to pursue, and thus, they start the digitalization process because of their partners' expectations.

Furthermore, the research demonstrated that among the strategic characteristics, technologies can be used for a wide range of purposes: business model, product, and process changes. Therefore, digitalization can potentially affect the majority of companies. Companies operating with less-advanced technology select from the pool of I4.0 technologies based on their current innovation orientation. In many of our case companies, this orientation equates to the development of operations and support technologies. Nevertheless, some of our case plants made leap-frog type progress due to their core technology development.

Organization

While we talk about a major wave of digitalization in the environmental context, the most important question is whether the attitudes of companies change with this context. The diversity of *organizational solutions* suggests that an openness towards innovation is "present" before digitalization. In other words, our results suggest that a culture of innovation determines the level of adaptation (the whole business or only manufacturing processes) to the changes; that is, culture affects adaptation not vice versa (adaptation affects culture). A lean culture with continuous improvement efforts reflects an innovation culture and seems to play a key role in supporting and boosting digitalization.

However, there is still an unresolved problem with respect to procedures. While new machines, which are sometimes complete manufacturing systems, acquired today often include sensors for data collection and control, as well as machine connectivity opportunities, *business management decisions* do not usually incorporate the big data from these sources, even though they are currently available.

Global network aspects

Relying on a TSO framework, we discovered specific aspects related to larger corporations and global networks. In the context of digitalization, *innovation* must *quickly become formalized* in large corporations; otherwise, these corporations cannot coordinate and eliminate parallel efforts. Therefore, large corporations tend to follow a formalized approach of innovation. This formalized approach leads to a *deployment process* at the subsidiary level while also limiting experimentation at the local level. Although the directive of the corporation headquarters is carefully considered, local experts and managers may identify ways to adapt the central direction of the corporation. Accordingly, manufacturing subsidiaries that strive for "differentiation" can seek their own path, e.g., launching a pilot project in the business unit at the local plant, joining domestic I4.0 programs or developing a centre of excellence at the same location, as suggested by Davis-Peccoud et al. (2018). A fortunate coincidence is realized when the central direction fully reflects the needs of the plant, e.g., robot installation when a workforce shortage is a daily issue.

Subsidiaries of global corporations built on standard processes show similarities, especially in the manufacturing and BSC sectors. The consequences for large, global corporations are more similar consequences than those within the overall industry. Although there are differences with respect to the adopted technology, formalized solutions at the strategic and organizational levels as well as clearly defined digital roadmaps are common, thus leading these companies towards faster business transformation, as argued by Kane et al. (2015). The experiences of these subsidiaries also suggest that their solutions cannot be replicated by smaller companies. While smaller companies may use the same technology, the underlying formalized solutions will be different (as in our food sector examples).

Thus, the question arises, how can small companies gain access to these practices? While the economy of scale seems to work with respect to digitalization, is it valid for each technology? These differences were also identified by Horváth & Szabó (2019).

Accordingly, we cannot confirm that global companies necessarily perform better than local firms (e.g., the logistics companies), as found by Szász et al. (2020). What we can say, however, is that the process of digital transformation, including the deployment process and the level and speed of standardization, are definitely different between the two groups of companies.

Conclusion

The objective of our business-oriented paper was to develop a complex and integrated picture of the I4.0 transformation of firms. To achieve this goal, we proposed a triad framework based on TSO and examined 15 case studies from different sectors. Our TSO framework has revealed many relevant variables that promote the understanding of the digital transformation. These relevant variables may describe important differences between companies and explore differing patterns between sectors. The results indicate that companies are following a large variety of approaches and that there is not a single or best approach. Companies can reach similar I4.0 maturity with or without a strategy, with or without a dedicated unit, etc. Our findings have two important implications. First, while larger companies (especially global ones) gravitate towards formal institutions, the first steps may be led by local curiosity. Second, the innovativeness of the firm culture, reflected by using lean management in many cases, is a decisive factor. While I4.0 does not change the current culture, an innovative culture enhances I4.0. Furthermore, while every firm deploys base digital technologies, in the adoption of additional technologies, we saw sector-specific directions. Finally, we determined that manufacturing is biased towards physically dominated technologies and that BSCs are biased towards chatbots, RPA or AI.

There are limitations of our paper. The 15 case studies prevented us from providing deep insights in this short paper but are insufficient to generalize the results. By segmenting the topics and sectors, we can conduct a deeper analysis in the future; however, for this paper, we intentionally chose a more comprehensive, integrated approach. We believe that, after some rigorous tests, this triad and collection of important TSO variables can be the bases for developing a questionnaire that validates and deepens our generalizable understanding and knowledge.

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