KRISZTINA DEMETER – DÁVID LOSONCI

BUSINESS AND TECHNOLOGICAL PERSPECTIVES OF INDUSTRY 4.0

– A FRAMEWORK FOR THINKING WITH CASE ILLUSTRATION

AZ IPAR 4.0 ÜZLETI ÉS TECHNOLÓGIAI VETÜLETEI

– GONDOLKODÁSI KERET ESETTANULMÁNNYAL ILLUSZTRÁLVA

In the last couple of years, we have witnessed an exponentially increasing interest of academia and professionals towards Industry 4.0 (I4.0). By focusing on the firm level of I4.0, the authors propose a framework highlighting several technical (technologies and applications, design principles) and business (vision, impact on competitiveness, integration, types of innovation, maturity) perspectives of the phenomenon. Their goal is to clarify the most frequent perspectives and by using them build a thinking framework, making readers understand what I4.0 is about. While frameworks are usually elaborated on a conceptual basis, this paper illustrates the selected perspectives and their links by an in-depth case study. A factory's digital transformation interpreted in the framework emphasizes the importance of research design and context.

Keywords: **Industry 4.0, technology, framework, digitalization**

Az elmúlt néhány évben a tudományos élet és a vállalati szakemberek exponenciálisan növekvő érdeklődését tapasztaljuk az Ipar 4.0 (I4.0) iránt. Az I4.0 vállalati szintjére összpontosítva olyan keretrendszert javasolnak a szerzők, amely kiemeli a jelenség számos technikai (technológiák és alkalmazások, tervezési alapelvek) és üzleti (vízió, versenyképesség, integráció, innováció típusai, érettség) vetületét. Céljuk, hogy a szakmai diskurzusban leggyakrabban előkerülő vetületek tartalmának tisztázása után azokból egy gondolkodási keretet építsenek. Míg a keretrendszerek általában elvi megfontolások alapján születnek, a cikk egy feldolgozóipari cég I4.0 transzformációját bemutató esettanulmány segítségével szemlélteti az egyes vetületeket és azok összekapcsolódását. A vizsgált gyár gondolkodási keretben értelmezett digitális átalakulása rámutat a kutatások tervezésének és kontextusának fontosságára.

Kulcsszavak: **Ipar 4.0, technológia, keretrendszer, digitalizáció**

Funding/Finanszírozás:
This research was supported by the project "Aspects on the development of intelligent, sustainable and inclusive society: social, technological, innovation networks in employment and digital economy" (EFOP-3.6.2-16-2017-00007). The project has been supported by the EU, co-financed by the European Social Fund and the budget of Hungary.

A kutatást támogatta "Az intelligens, fenntartható és inkluzív társadalom fejlesztésének aspektusai: társadalmi, technológiai, innovációs hálózatok a foglalkoztatásban és a digitális gazdaságban (EFOP-3.6.2-16-2017-00007)" project. A projekt az Európai Unió, az Európai Szociális Alap és Magyarország költségvetésének társfinanszírozásában valósul meg.

Authors/Szerzők:
Dr. Krisztina Demeter, professor, Corvinus University of Budapest, (krisztina.demeter@uni-corvinus.hu)
Dr. Dávid Losonci, associate professor, Corvinus University of Budapest, (david.losonci@uni-corvinus.hu)

This article was received: 03. 02. 2020, revised: 14. 04. 2020, accepted: 15. 04. 2020.
A cikk beérkezett: 2020. 03. 02-án, javítva: 2020. 04. 14-én, elfogadva: 2020. 04. 15-én.

An exponentially increasing number of articles in the international literature discusses Industry 4.0 (I4.0) (Gilchrist, 2016; Hermann, Pentek & Otto, 2015; McKinsey & Company, 2017; Viharos, Soós, Nick, Várgedő, & Beregi, 2017). By today, there are more than 100 definitions of the phenomenon (Culot, Nassimbeni, Orzes, & Sartor, 2020). In our view Industry 4.0 is the adoption of new and innovative technologies of the Fourth Industrial Revolution by manufacturing firms. The term I4.0 itself highlights that manufacturing firms are forced to explore and then exploit the novel technologies. Nevertheless, even in its German origin (Die neue Hightech-Strategie Innovationen für Deutschland, 2014; Kagermann, Wahlster, Helbig, & Acatech, 2013) the I4.0 transformation

goes beyond simple process innovation relying heavily on the digitalization of products (and services embedded in products), and on building digitally-enabled new business models. Although the physically dominated technologies (e.g. 3D printing, advanced robotics) have a crucial role in the production, the digital solutions and the intangible capital (knowledge) are the main drivers of the progress.

The complexity of I4.0 is best grasped by review papers (Xu, Xu, & Li, 2018; Liao, Deschamps, Loures, & Ramos, 2017) and frameworks (Nosalska, Piątek, Mazurek, & Rządca, 2019; Fatorachian & Kazemi, 2018). Our paper presents a framework that integrates eight related perspectives. The selected perspectives cover the most frequently analysed business (e.g., type of innovation, vision, competitive measures etc.) and technical aspects (e.g., technologies and applications, design principles) of I4.0 at the organizational level (Nosalska et al., 2019). As this list of perspectives shows, very similar topics are usually examined and constantly on agenda in the case of new business initiatives.

While the frameworks are usually conceptual or review-based, our framework is illustrated by a case study from the manufacturing sector, as the most frequent sector (Liao et al., 2017; Nagy, 2019). We analyse a factory of a leading multinational automotive supplier that is ahead in the digital transformation in its internal network.

Altogether, our main contributions are to 1) clarify different perspectives and 2) examine a single case study illustrating each perspective and their interconnectedness.

In our framework, we highlight the key role of new technologies and show how I4.0 pervades other perspectives and their links. We want to make the readers aware that these perspectives are rarely made explicit in the I4.0 research papers. We ourselves were many times confused and had difficulties to understand the key – usually implicitly emerging – perspectives, especially because they have also been frequently blurred and mixed (e.g. technologies and integration principles, types of innovation feasible). We emphasize that a better understanding of these perspectives could result in a more reliable research design of empirical works. Our illustrated framework combining scientific and professional experience could help these efforts.

The paper is organized as follows. First, we embed the phenomenon of I4.0 into a historical context. Then the different perspectives are introduced one by one based on state-of-the-art knowledge. After describing the perspectives independently, the links among them are elaborated. The empirical part of the study is developed around a case study. The concluding remarks are complemented by promising future research directions.

The industrial revolutions

From a technological evolution perspective Industry 4.0 belongs to the Fourth Industrial Revolution (Cséfalvay, 2017; Gilchrist, 2016; Liao et al., 2017; Kagermann et al., 2013). The term 'revolution' refers to the radical changes in the structure of economies and societies due to the adoption of technology. These changes took decades or even longer (see a Kondratiev cycle), as time was needed for new technologies to spread. Each era has also transformed the microsphere of the economy. The production system has evolved in the context of supply-demand relationships. Companies have developed a production system that matches the changing dimensions of customer demand (e.g., volume, variety, delivery time, individual requirements) (Yin, Stecke, & Li, 2018). In the following, we describe the industrial revolution from the manufacturing sector point of view.

The first revolution powered by steam engines had completely changed the way of work organization. It was the time when factories (instead of guilds) and the working class appeared. The second industrial revolution was powered by electricity. In the manufacturing sector firms started to produce standardized products in high volumes by mass production. The appearance of machines based on the innovations of the first two revolutions have also changed the weights of sectors in the employment and economic structure. Machines in the agriculture sector increased productivity significantly, and crowds searching for work moved to towns and applied for "routinized" manufacturing jobs. Finally, the industrialized economies produced higher and higher value-added (and so wealth) in manufacturing that outpaced agriculture. The power of the third revolution is electronics led by computers. Electronically controlled machines have been able to produce a higher variety of products, making mass customization possible. Increasing automation required less manufacturing workers, and people were absorbed by the more and more dominant service sector. During the third industrial revolution, developed nations arrived at the era of service economy and knowledge society. In the current revolution there is still no agreement on the ultimate power, but we think that mobile internet as a basis for a revolutionary new type of network is a good candidate. It bears the opportunity to connect everything (the digital and physical world, as well as things, services, people), everywhere, ubiquitously. The key component on the demand side of this revolution is the personalized product (and the aligning production). The personalization is challenging the traditional business model of manufacturing companies that was developed through the first three revolutions, and it urges them to become servitized firms. The expected productivity increase and the servitized manufacturing firms together will accelerate the decline of manufacturing measured by its share in employment and value-added in developed countries. The deeper gap between qualified and low skill workers are fuelling unbalances in societies.

Altogether, industrial revolutions are interpreted as socio-economy wide phenomena, and Industry 4.0 is a specific branch of it, a manufacturing sector-oriented approach.

At this part of the study, it is also worth clarifying the relationship between digitization, digitalization and Industry 4.0. Digitization refers to the conversion of analogue physical signals into zeros and ones to be stored, processed, transmitted by the computer (Prause,

Table 1.

Key features of industrial revolutions

Revolution	*Key technology*	*Production system*	*Labour movement*	*Society*
1st	Mechanization	Factories instead of guilds	Working class appears	Low skilled agricultural workers are absorbed by "routinized" manufacturing tasks
2nd	Electricity	Mass production	From agriculture to manufacturing	
3rd	Computers	Mass customization	From manufacturing to services	Service sector becomes more and more dominant
4th	Mobile internet	Personalization, servitization	From mass to personalized services	Further relative decline of manufacturing and sharpening tensions among high and low skilled workers

Source: own compilation

2016). Scanning a document, for example, or acquiring data by sensors from a machine. Digitalization means moving to a digital business, using e-mail, chat or social media instead of letters, papers, telephone. Going paperless is digitalization. Industry 4.0 goes beyond the "electronic-based" digitalization. It relies on new and innovative technologies to completely transform the way organizations operate and we work; it extends the boundaries of digitalization (Table 1).

Perspectives on Industry 4.0

In the following chapters, the different perspectives are discussed. We start with the technology and applications and design principles since all the others depend on them. Then continue with vision and its relation to innovation and competitiveness. We also touch upon the integration and maturity perspectives.

Technologies and applications

This chapter describes the prehistory and some predecessors of I4.0 and then reviews its core technologies. The aim is to build a solid basis for the following perspectives, so we do not go into technical details.

Technology-based developments of the recent past

Innovative (sometimes also called emerging, exponential) *technologies* are at the heart of I4.0. New technologies build on developments of the last decades, at those times called Advanced Manufacturing Technology (AMT). The highest level of these developments related to manufacturing is Computer Integrated Manufacturing (CIM). CIM could be developed in the 1980s building on "modern automation systems (often made up of embedded systems such as CNC machines) and software integration technologies (e.g. the integrations of Computer-Aided Design-CAD, Computer-Aided Manufacturing-CAM, Computer-Aided Engineering-CAE, Computer-Aided Production Planning-CAPP) systems" (Yu, Xu, & Lu, 2015, p. 6). One should note, however, that while CIM systems built on integrated data storage, and a central system supported data exchange, recently emerged technologies are built on distributed data storage and cyber system supports their data exchange (see the design principles chapter) (Yu et al., 2015). Altogether the technology-based developments of the 1980s brought the system view and integration into the forefront.

A more recent important avenue of business development based on technologies is the e-business movement. The new business model has been built on virtual markets, "in which business transactions are conducted via open networks based on the fixed and wireless Internet infrastructure" (Amit & Zott, 2001, p. 495). Companies have learned how to replace brick and mortar shops and services with electronic channels to reach customers. E-business mainly changed the marketing and sales functions within manufacturing organizations and service businesses, as well, by providing more direct, quicker, flexible and cheaper communication and contact with customers. While e-business brought crucial changes in customer-related processes and services, it did not change yet, how physical products were made. Nevertheless, it changed the information flow, ERP systems integrated real flows and connected them with other business functions.

Additive manufacturing or 3D printing, existing since the 1980's, is a bundle term for various technologies and is considered as a disruptive technology. Additive manufacturing is different from traditional subtractive technologies, as it adds layers of materials instead of taking out. Therefore, the material waste is reduced considerably, and the technology can produce very complex and diverse products. Disadvantages, however, is the high price and low variety, availability and capability of materials, the low speed of production, the extra step of finishing the final product, and the intellectual property concerns (Rylands, Böhme, Gorkin III, Fan, & Birtchnell, 2016). Additive manufacturing was used only for rapid prototyping till recently.

Technologies of I4.0

There are several different classifications of I4.0 technologies (e.g. Chiarelloa, Trivellib, Bonaccorsia, & Fantoni, 2018; McKinsey & Company, 2017; Schuh, Anderl, Gausemeier, ten Hompel, & Wahlster, 2017). Instead of analysing the available classifications, we describe shortly the most important technologies and their interdependencies.

Without any doubt, the basis of today's technologies is the cyber-physical system (CPS), which consists of *sensors/*

actuators, a network and a cloud. Sensors (translating physical features into digital data) and actuators (translating the digital instruction into physical reaction) (Difference Between Sensors and Actuators, 2018) produce and use data, the *network* for communication transmits them into the *cloud* (let it be private or commercial) to be stored or manipulated (Porter & Heppelmann, 2014). More developed CPSs are able not only to send and receive signals but also to reconfigure themselves autonomously, i.e. without people's interaction.

The CPS (both hardware and software) is embedded into products, devices, and every kind of things and it enables them to communicate with each other using a common protocol. The connection of these things is called the *Internet of Things* (IoT). As we can control our air condition, the heating, the television with our mobile phone, machines can also be controlled in a factory, or even more, they can communicate with each other, and reconfigure themselves based on information from other machines or products. Machine-to-Machine (M2M) systems is a subcategory of IoT.

There can be several sensors built into a thing (e.g. a machine) measuring different parameters, like temperature, pressure, etc. every second, generating terabytes of big data. *Big data* has three important differentiating features: volume, velocity and variety. Developments in infrastructure (like storage systems, virtual servers) were required to collect and store data, and new data analysing programs (e.g. R) and visualizing software made it possible to *analyse big data*.

Augmented and virtual reality (AR/VR) is another technology. Augmented reality puts digital pictures/objects on reality, while virtual reality shows a digital picture of the reality.

There are also more tangible types of technologies. *Advanced industrial robotics* sometimes called collaborative robotics should not be isolated from people for safety reasons. Even more, these robots are able to complement or support human work, for example lifting heavy objects. Automatic guided vehicles and mobile industrial robots also belong to this group of technologies.

Last but not least *additive manufacturing* is also considered as a manufacturing technology of I4.0. The main reason is the changed purpose of its use. This technology is matured and became economical for small-scale production. Nowadays, it is frequently used for replacing broken tools, as well, making possible to significantly reduce the level of inventory of maintenance materials.

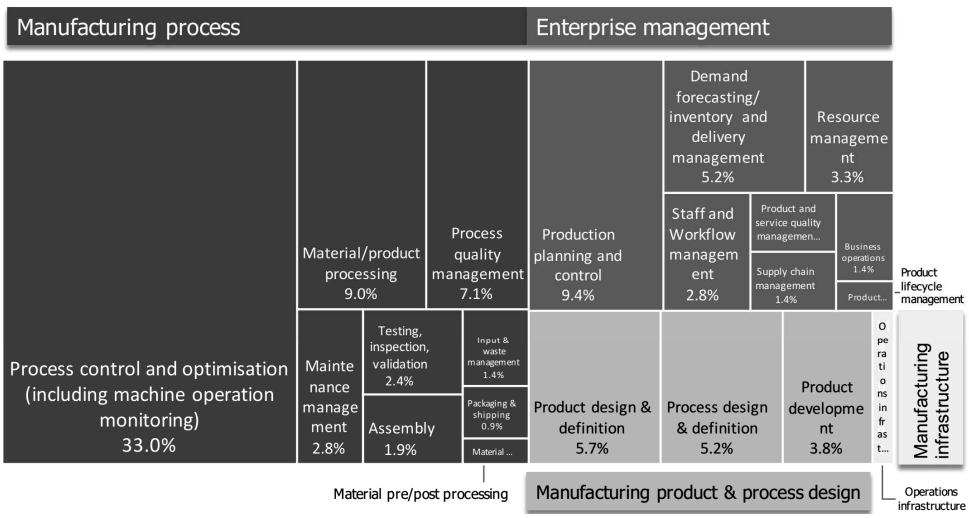
Technologies are not independent of each other. The most important connection between them is data: each of them produces and utilizes data, they 'swim in the big data ocean'.

However, the adaptation of the technologies varies extremely among groups of manufacturing companies (Frank, Dalenogare, & Ayala, 2019), indicating that a small group of firms is ahead in the digital transformation. The actual maturity of the specific technologies is a further factor that might influence their level of adaptation. E.g. AR technology is still in the experimental phase, while the cloud is a widely used mature technology. Even in the case of mature technologies, like advanced robotics, one can find some industry-specific considerations (e.g. intensity of competition, available capital and general level of technology etc.). That is why robots are more widely used in automotive and electronic industries than in any other manufacturing industries. Finally, the competitiveness of national economies (or productivity) has also a stochastic impact on the use of technologies see (Eurostat, 2019).

Sometimes *horizontal and vertical integration* or simulation are also listed as technologies. We think that integration is a different perspective of I4.0 as described in a later chapter, while *simulation* is not a separate technology, but an application, a combination of data analysis and virtual reality. *Digital twin* is similar, it uses big data and virtual reality. We consider machine learning, blockchains

Figure 1.

Applications and solutions of I4.0



Source: López-Gómez et al. (2018, p. 30)

or software robots (like chatbots) as I4.0 technologies, but they are used more in services than in the manufacturing sector (Marciniak, Móricz & Baksa, 2020). Cybersecurity is also often claimed as a technology, however, in our opinion it refers to a set of comprehensive policies and elements of infrastructure securing long-term use.

Applications and solutions

In a business environment, the listed technologies are adopted to resolve specific business problems. For example, at a lean department predictive maintenance is supported by big data analysis of sensor collected data. In other words*, applications and solutions are combinations of different technologies to serve business purposes*. Based on 212 case studies collected worldwide in the manufacturing industries, López-Gómez, McFarlane, O'Sullivan, & Velu, (2018) identified the following use of I4.0 technologies depicted by Figure 1. Most of the applications support operations management processes: the most frequent use is in process control and optimization (33%), in production planning and control (9.4%) and in material processing (9%). Enterprise support process (ca. 25%) and product design (ca. 10%) are represented by lower weights.

Design principles

Design principles help to adapt and use I4.0 technologies in an effective manner. Hermann et al. (2015) identified the specific design principles of I4.0, namely interoperability, virtualization, decentralization, real-time capability, service orientation and modularization.

Considering the mobile internet connection as the key power behind I4.0, the principle of interoperability is straightforward. Machines, people should connect and communicate with each other (to optimize the use of time and resources all over the value chain). This connection means not only the channel through which data flow but also the protocol of communication. Machines have to use the same standard in order to "understand" each other. So far, the industry-wide standards are still missing. "*Virtualization* means that CPSs are able to monitor physical processes" (Hermann et al., 2015, p. 12). It provides data for simulation and modelling, for a virtual copy of real processes. By embedded CPS, *real-time data acquisition* and interoperability enabled *decentralized decision making* becomes possible. In other words, even the operator can make the decision, having all the necessary data. Even RFID tags on products can give instructions to machines about what operations and when they should undergo. Rapid scaling and quick changeovers are further key characteristics of the new industrial reality. The *modularity* of manufacturing resources means plug & play kind of capacity changes/additions. Since hardware consists of more and more electronic and less mechanical parts nowadays (Porter & Heppelmann, 2014), changing the features of the machines or upgrading becomes much faster and easier.

Finally, *service orientation* is linked to the personalization: processes can make exactly what customers want (represented by the RFID tag). It has far-reaching consequences for the internal organization of processes: "The *services* of companies, CPS, and humans are available over the IoS [*Internet of Services*] and can be utilized by other participants. They can be offered both internally and across company borders" (Hermann et al., 2015, p. 12).

The elements of a fine web of relations that need to be managed among technologies to build an effective system around I4.0 are identified by these principles. According to this interpretation, it also means that design principles and maturity assessment are closely related perspectives.

Vision: how to succeed in the era of personalisation

I4.0 is the *new vision* of manufacturing. As announced in German documentations (Kagermann et al., 2013; Cordeiro, Ordónez, & Ferro, 2019) it embraces the key issues of personalization, co-development/co-creation (Prahalad & Ramaswamy, 2004), hybrid/servitized organization (Baines, Lightfoot, Benedettini, & Kay, 2009) and flexible factory. These new factories can handle unique request from the customer, for example by RFID chips on products, which provide the necessary information for automatic machinery. Due to the personalized production customers become partners in developing the requested product together with the producer. And producers build new capabilities, sometimes new businesses, to become service providers, as well. So, the line between services and manufacturing becomes even more blurred than before. Personalized products can be handled only by automatic and autonomous machines, multiple routing opportunities of products and dynamic planning and control equipped with real-time information from the shop floor for optimized decision-making resulting in resource productivity and efficiency.

Innovation: from processes to business models

I4.0 can be adopted to serve each *type* of Schumpeter's *innovation*: product, process, organizational, and marketing (Schumpeter, 2017; Tavassoli & Karlsson, 2015). In I4.0 it is translated for *business model innovation, product innovation and process innovation* (Gilchrist, 2016).

A business model "is about the benefit the enterprise will deliver to customers, how it will organize to do so, and how it will capture a portion of the value that it delivers" (Teece, 2010, p. 179). Therefore, *business model innovation* means an essential change in the value proposition to the customers, a significant reconfiguration of the company's and its network's processes and systems, and/or redefining the financial streams (revenue and cost structure) of the company (Horváth, Móricz, & Szabó, 2018). A business model innovation is usually disruptive, as it changes the basic routines of the company, which is extremely difficult, although sometimes happens (e.g. see the IBM transformation from a manufacturing to a service company, which changed not only the product portfolio and the revenue streams, but the organizational and governance structure, as well (Walker, 2007)). It is more

usual, that new companies innovate classical business models. For example, platform companies (Facebook, Amazon, Google, Uber, AirBnB) have done that. They provide a two-sided marketplace, where people and/or companies meet. Seemingly they offer free service for users, but they generate income from user data, selling and posting advertisements, or premium services. We argue that business model innovation should include at least two types of Schumpeter's innovations.

Digitalization has a significant impact on various elements of the business model, on the value proposition supported by big data analytics, providing real-time, predictive information to customers; on the product-service portfolio, as these additional data can manifest in new services; on the processes by automation and resource efficiency; on the sales and information channels reaching new customers and becoming bidirectional (Horváth et al., 2018). The complex effect of digitalization is well summarized in Figure 2, where we can identify the key building blocks of a business model canvas, a popular strategic analysing tool (Fritscher & Pigneur, 2009).

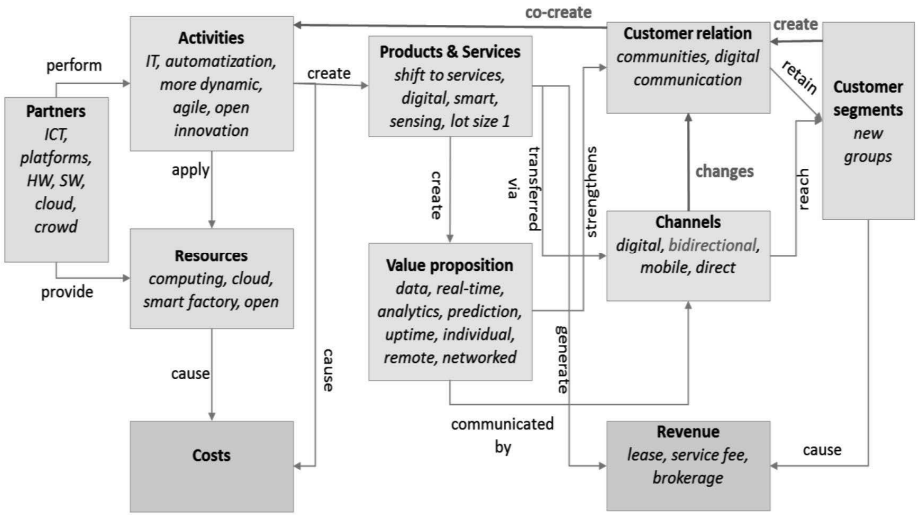
Finally, *process innovation* aims to achieve a higher level of integration in order to improve efficiency and quality. Basically, it means ensuring relevant and real-time information for decisions to different parts of the business, from the level of operators to the management and between supply chain partners. Process innovation usually addresses the core processes (manufacturing and/or service provision for customers) of the firm but supporting processes (administration) and customer-related processes (marketing, sales) also provide room for innovation (Herbert, 2017). Today, as we have shown by citing López et al.'s research, I4.0 projects are usually focused on process innovations in manufacturing companies. This I4.0-based transformation effort of the production system is called smart manufacturing (Frank, Dalenogare, & Ayala, 2019).

Competitiveness, objectives: customer value and shareholder value

The *objective* of I4.0 innovations is to increase the *competitiveness* of companies. This competitiveness can

Figure 2.

The impact of digitalization on business models



Source: Prem (2015, p. 9)

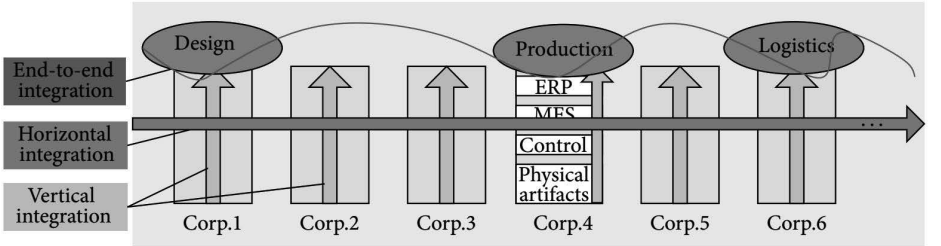
While business model innovation transforms the whole organization, *product/service innovation* embraces only a smaller part of the business. Smart products contain several sensors, which can provide information to the user and to the producer about the status and usage characteristics of the product. There is an opportunity for remote control, maintenance or upgrade (Porter & Heppelmann, 2014). The more products become smart in the portfolio and therefore lead to more and more services, the more organizational change is required by the company (Porter & Heppelmann, 2015). After a while, it can result in changes in the business model, as well. In the operations management literature this process is called servitization (Baines et al., 2009), while marketing researchers know this phenomenon as the service-dominant logic (Vargo & Lusch, 2008).

manifest in business (shareholder value), operational (customer value) and other performance measures. Shareholder and customer value creation, sometimes called double value creation, ensures the long-term prosperity of companies, as both the owners and the customers get what they want (Chikán, 2006).

The most usual measures at the *business level* are productivity (e.g. value-added per employee), and return on capital employed (ROCE) (Blanchet, 2014). *Productivity* is a complex term, but the two most frequent measures are labour productivity (when labour is considered as input) and total factor productivity (when labour and assets are both considered). It is claimed that the previous three revolutions increased productivity (value-added per employee) considerably, and the fourth is expected to increase it as well (Rüssmann, et al., 2015). Higher

Figure 3.

The three kind of integration and their relationship



Source: Wang et al. (2016, p. 2)

productivity means that companies can produce more output from the same inputs, or the same output from fewer inputs than before. Higher productivity also means higher revenue with reduced costs and reduced working capital (López-Gómez, McFarlane, O'Sullivan, & Velu, 2018, p. 25). Based on estimations ROCE can increase as products' value-added increases more than the invested capital. So, the key issue is to provide more value-added to customers through smart features or more services.

At the *operational level* we expect improvements in all classical indicators, like better quality, higher flexibility, faster delivery, as well as cheaper and more reliable products and services. And expectations are indeed very high due to published experiences so far. According to López-Gomez et al. (2018, p. 32), I4.0 applications could significantly reduce labour costs (depending on applications in average with 66-80%) and material costs (42-63%), as well as quality defects and errors (60-100%), and improve service and delivery performance (71-75%). Similar conclusion is drawn by WEF after studying "lighthouse" I4.0 factories (Martin, et al., 2018).

Sustainability can be another direction to measure the impact of I4.0 (Kamble, Gunasekaran, & Gawankar, 2018). Using smart products and processes we can save energy, reduce pollution, support communities or disabled people. Automatic factories can also provide the opportunity to use the energy, when there is no demand for it without additional costs (and with reduced energy costs) (Szalavetz, 2018), e.g. in the middle of the night. Life cycle management of products (end-to-end engineering, see next paragraph) is possible due to continuous data flow from smart products (Porter & Heppelmann, 2014).

Integration

Vertical (e.g. managing trade-off among value chain activities) and horizontal integration (e.g. managing partners in a supply chain) have been long in the focus of management. Furthermore, a life cycle management of the product is an extended horizontal integration incorporating even the customer.

There is a shared perception that I4.0 solutions enable deeper *integration of value chains,* vertically, horizontally and through engineering end-to-end (Wang, Wan, Li, & Zhang, 2016; Gilchrist, 2016) (Figure 3). Within companies, vertical integration becomes easier, as managers at all levels can get access to necessary data real-time, remotely, from their own desk. Performance and activities become transparent, and a faster decision is possible. Also, horizontal integration with customers and suppliers can be stronger as partners can collect and share more information, even real-time. Not only everyday operations can be integrated at a higher level, but end-to-end processes of engineering, along the life cycle of the product, becomes a reality. It is possible to maintain or even upgrade the product remotely while it is at the customer (think of smartwatches, mobile phone, computer software), and producers can take care of components at the end of the products' life cycle.

Maturity

Maturity models assess the road step-by-step towards I4.0 from different aspects (Viharos et al., 2017). We review here three seminal models: the study of Schuh et al. (2017) discusses maturity at the factory level, Porter and Heppelmann (2014) at the product level (that finally linked to the business ecosystem), while Lee, Bagheri, & Kao (2015) at the technology level.

Schuh et al. (2017) identifies the stages in the factories' I4.0 development path (Figure 4). It claims that I4.0 starts beyond the "pure" form of digitalization, or in other words, some digitalization (computers, connectivity) is the prerequisite for I4.0. The starting maturity level is visibility, and the final is the autonomous and self-optimizing adaptability.

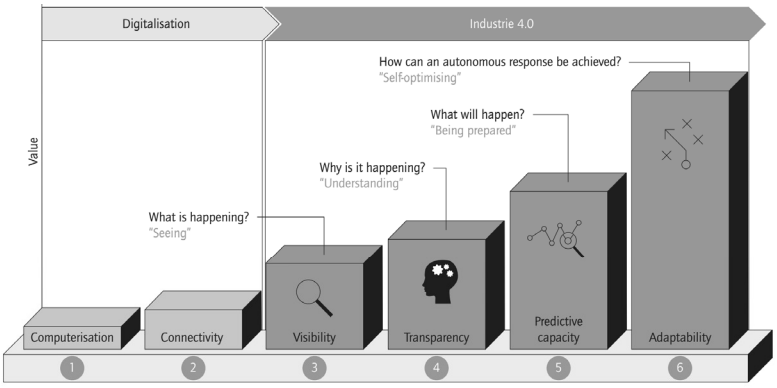
Porter and Heppelmann (2014) determined four levels of product maturity, starting from a traditional product to arriving at the connected, smart product:

1. Monitoring (sensors and other sources acquire data on the condition, environment, use).
2. Control (software embedded in product or cloud enables control of product functions and personalize user experience).
3. Optimization (algorithms based on monitoring and control enhance product performance and allow predictive diagnostics, service and repair).
4. Autonomy (combines levels 1-3 and allows autonomous product operation, self-coordination of operation with other products, autonomous product enhancement and personalization, self-diagnosis and repair).

Lee et al. (2015) have categories (5C) at the CPS level: connection (condition monitoring with sensors), conversion (self-aware, component/machine), cyber (self-compare,

Figure 4.

Factory maturity assessment



Source: Schuh et al. (2017, p. 16)

Table 2.

The perspectives of the framework for thinking about Industry 4.0

Layer	*Literature*	*Elements*				
Technologies	based on Schwab (2016)	From digitally dominated (big data analytics, simulation, cloud computing, VR/AR)	Glue (Sensors and network)		To physically dominated (Robots, 3D printing)	
Applications	WEF, 2019	e.g. digital quality, predictive maintenance, visualisation, cell design, MES				
Design principles	Hermann et al., 2015	Interoperability	Virtualization	Decentralization	Real-time capability	Modularity
Vision	Kagermann et al., 2013	Personalization, Co-development/co-creation, Hybrid/servitization, Flexible factory				
Type of innovation	www.pwc.com/industry40	Business model	Product/service		Process	
Competitiveness, objectives	Porter & Heppelmann, 2014, 2015	Business oriented (shareholder value) Productivity, profit margin	Operations oriented (customer value) cost, delivery, quality, inventory turnover		Other orientation e.g. sustainability	
Type of integration	Wang, Wan, Li, & Zhang, 2016	Vertical integration (seamless internal processes)	Horizontal integration (involving partners)		End-to-end integration (life cycle approach)	
Maturity	Lee et al., 2015	Technology: Connection, conversion, cyber, cognition, configuration				
	Porter & Heppelmann, 2014	Product: Monitor, control, optimization, autonomy				
	Schuh et al., 2017	Factory: Visibility, transparency, predictive capacity, adaptability				

Source: own compilation

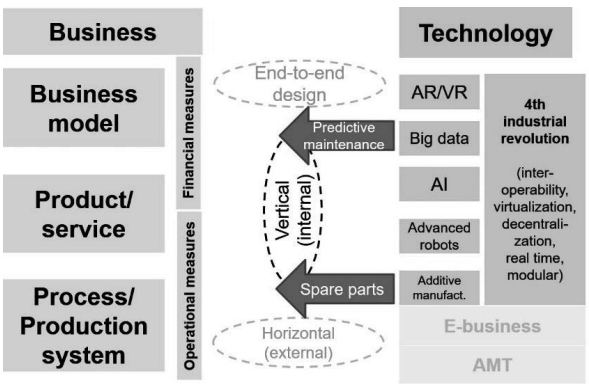
the fleet of machines), cognition (prioritize and optimize), configure (actions to avoid). Basically, the categories and hence the trajectories of the three maturity models are very similar, however, they put different aspects – the factory, the product or the technology – into the focus.

The framework for thinking about Industry 4.0

After the detailed description of the perspectives (summary in Table 2.), hereby we describe their interconnectedness in a framework. We consider Industry 4.0 as the business-oriented utilization of novel technologies by manufacturing firms (Figure 5.). Businesses pursue different types of innovations, such as business model, product/service or process/production system innovations in order to improve financial, operational (or other) measures for higher competitiveness. New technologies, built on old ones, form the basis of the 4th industrial revolution. Systems built on new technologies have specific design principles as compared to older ones. The combination of new technologies, such as augmented/virtual reality, big data analytics, artificial intelligence, advanced robots

Figure 5.

The framework for thinking about Industry 4.0



Source: own compilation

or additive manufacturing (3D printing) provides the ground for business applications, which help to solve a business problem. Applications and developments improve integration vertically, horizontally, and end-to-end engineering. And finally, all these efforts support the competitiveness of the company.

Based on this logic, Industry 4.0 is a phenomenon, where manufacturing firms combine the "core" technologies of the 4th industrial revolution to enable (different types of) business innovations.

Application of the framework for thinking at the factory level – the experience of a case factory

The case factory and methodology

Our case factory is part of a multinational corporation, having subsidiaries in several countries including Hungary. The corporation has three divisions. The case factory operates in the automotive division producing mainly connectors in large varieties. They have industrial robots and short production lines (only a few steps to produce one product).

The authors have a long-lasting link to the factory. Previously, the lean management system of the factory has been studied (Demeter & Losonci, 2019). Altogether, we have conducted 8 semi-structured interviews, the first in 2017 and the last one in February 2020. We interviewed the Lean/Digital Manager (4 times), the Supply Chain Manager, two project managers from the digital department and one software developer. The interviews lasted between 45 to 120 minutes. Several factory visits were also arranged. Furthermore, the Digital Manager and the Supply Chain Manager gave several guest presentations about the digital transformations in classes, and three students of the authors had their internship under the supervision of the Digital Manager.

The perspectives of I4.0 at the case factory

Technologies and applications, design principles

The case factory started the I4.0 transformation in the early 2010's. It installed several thousands of sensors and actuators into the machines and currently appr. 80-85% of their machines are interconnected. The factory has several applications, relying on various technologies:

- *Cloud and IoT*: The multinational corporation has industrial private clouds at two service providers including computational and security services, but subsidiaries also have their own data storage solutions, where high secret, experimental data are managed. Subsidiaries share and exchange data collected by machine sensors through the cloud for further analysis and process optimization purposes. This direct access to any type of data from any factory is considered by the company as IoT.
- *Digital andon*: andon is a signal of a problem, which requires a fast reaction from operators or maintenance staff. By digitizing the signal, the maintenance gets instant information about the problem. This solution requires the internet, mobile phones and machine data for the analysis.
- *Digital dashboards*: The "business" dashboard of the shop floor provides detailed, daily refreshed information about machines, processes and people, with some standard charts, and exploring capabilities (i.e. filtering features). This dashboard is available on managers' mobile phones, as well. Data are retrieved from shop floor control and ERP systems. They replace the paper-based, static factory KPI reports. In the manufacturing dashboard arena, there are three developments, which are based on real-time sensor data. The first one shows the operators' cycle times. This data is also visible for the operators themselves on smart screens nearby. A heat map using each operators' data at the factory level is also created, showing real-time information for managers' dashboard. 2) Several sensors monitor various parameters of machines and make alert if needed. 3) There are intelligent cameras installed in the assembly area to identify faults in products. The requirement: internet, smart screens, sensors in machines, cloud for data storage and computing, and business intelligence software for visualization.
- *E-QCPC* (electronic quality control process chart): this solution virtualizes the existing paper-based problem reporting and strengthens the escalation process. If a problem is not solved in a set time, it goes up to the next level. There are screens on the shop floor and in other parts of the company, and people can enter the problems. They can also monitor the status of previous submissions. The requirement: internet, smart screens, cloud, software.
- *OLMS* (operator learning management system): the plant has a sophisticated electronic learning platform for different levels (operators, managers), and different technologies. When an operator wants to start a task, the machine identifies the operator by his/her identity card. If the operator does not have the relevant training, the machine sends him for training on the e-learning platform on the shop floor. The managers can monitor the progress of workers and can also see, how well the operators go through the training, which can be useful information for example in case of promotions. Requirements: an online platform for training materials, sensors to identify people, training platform on the shop floor.
- *Predictive maintenance pilot*: the factory puts tremendous effort into the pilot project to extend the life of tools by predictive maintenance. They have big data collected from machines. They want to understand the patterns of signals and be able to predict the breakdown and replace the tool just-in-time. Requirements: internet, sensors, cloud, big data analytics.
- *3D printers*: the company owns metal and plastic 3D printers not only for rapid prototyping but also for printing products in small quantity for the aftersales market. Requirement: 3D printer.

- *Mobile Industrial Robots (MIRs)*: The robots deliver materials/products between the warehouse and the shop floor without human interaction. MIRs are collaborative robots, sensing the presence of humans. Requirements: internet, sensors, robots.
- *Plant simulation*: the company has 1 full-time employee making simulations for potential investments, for example, by simulating the operation for various number of MIRs to find the optimal number to buy. Requirements: internet, sensor data from the shop floor (not necessarily real-time), cloud, big data.
- *Real-time analytics*: they use the analytics for process optimization and shop floor control. Requirements: sensors, cloud, big data, internet.

We can identify the majority of I4.0 technologies in the applications of the case factory. We could not find AR/VR (it is in experimental phase in a US factory only), and it has only plan to adopt machine learning in some equipment.

Some of the *design principles* are already working at the case factory. Upgrading of machines was among the first steps of the digital journey which is the basis for *virtualization*. Digitalization is also used in the support processes, e.g. e-QCPC is the virtualization of a previously paper-based system. Data collected by sensors are the main input for the *decentralized decision making*. *Real-time information* is used mainly for monitoring (dashboard) and escalation (andon). Although machines are connected and monitored, their interconnectivity is not beyond yet (e.g. machines cannot self-compare, prioritize and optimize or reconfigure themselves). Nevertheless, the implementation of MIRs in the internal logistics processes will rely on the interoperability of machines and systems, which can take the factory to the next level of maturity. *Modularity* and *service orientation* are not in focus yet.

Vision and objectives

The vision of the initiatives is to build a flexible factory. They have made steps to make the factory more flexible and agile.

The main reason behind this visionary factory concept is that the factory has experienced a slow but continuous change in the demand: customers require smaller volumes and higher varieties. It led to a reduction in the batch sizes at the shop floor level, reducing the company's profit margins. Nevertheless, the company must provide the same level of service (i.e. operations measures) for their clients. The clear dominant objective is cost reduction while sustaining and possibly improving other measures (Table 3.).

Type of innovation, integration

They have moved into the direction of personalized production, but they are still far from that. The company is still a "pure" manufacturing firm, as we could not identify additional services in the product portfolio.

I4.0 at the factory is dominated by development efforts related to the production system. The production system centred approach at the corporation is reflected by the fact that the lean departments were actively involved during the digital transformation from the very beginning within the regional automotive division.

Minor changes have started in the organization. At the division level, a Chief Digital Officer (CDO) is appointed and he has regional accelerators responsible for spreading the policies of the digital transformation and the knowledge of specific technologies. At the case factory, the head of the lean department is appointed as the digital factory manager. The factory is also in the process of creating local accelerator positions.

Vertical integration was in the centre from the beginning of the digital transformation. Links between human resources and operations were resolved by OLMS; digital andon implies closer cooperation of maintenance and operations; the installation of MIRs connects logistics and operations. Considering the factory's responsibilities in the internal network (produce products based on central orders and deliver them into the distribution centre), we expect that the vertical integration will remain at the forefront of digital developments.

Table 3.

Perspectives of I4.0 at the case factory

Layer	*Case factory experience*
Technologies	Cloud, IoT, Big data analytics, 3D printing, Advanced industrial robotics (MIR)
Applications	Digital andon, digital dashboard, e-QCPC, OLMS, predictive maintenance (pilot), 3D printing, Mobile Industrial Robots, real-time analytics, plant simulation
Design principles	Interoperability of machines (only connection and conversion), virtualization of paper-based systems, decentralized data acquisition, real-time information
Vision	Flexible factory able to handle smaller batch sizes, while keeping the same service level.
Competitiveness, measures	Dominantly cost focus. Indirectly quality and flexibility are also addressed.
Type of innovation	Mainly core manufacturing processes, plus some supporting ones (e.g. OLMS, predictive maintenance). Minor modifications in the organization (CDO, accelerators)
Type of integration	80-85% of machines are connected, which means some level of vertical integration. No projects for changes in the supply chain. Other measures (sustainability) are not in the focus.
Maturity	Connection/monitor/visibility phase

Source: own compilation

Maturity

The innovation of the production system is in the focal point of efforts both at the corporate and factory level. To assess the factory's maturity, the factory focused model (Schuh et al., 2017) is appropriate. According to that classification, the factory is between the visibility and transparency levels. This is also confirmed by the current level of design principles.

The strategic importance of the digital factory is underlined by the internal audit system as well. The business unit assigns stars to each factory annually based on the yearly operations audit performance. The operations audit is built around the business unit level multi-plant improvement program (Netland & Aspelund, 2014), that merges six sigma and lean. As we have already noted, the appearance of digital tools in the daily operations has impacted the lean departments from the beginning. The corporation has also modified the operations audit system and incorporated digital aspects as a separate item, added to the 12 existing items. Factories get 1 to 5 stars (5 is the highest) for each item. The lowest item ("the bottleneck") determines the overall performance of the factory. Due to the novel nature of the digital item, it can get one level lower than the overall performance (e.g. if each item is 4 or higher, and the digital item is only 3, the overall performance still can be 4 stars). Therefore, considerable digital efforts are required to get the usual audit performance (4 out the 5 stars).

The framework for the case factory

The advantage of our framework is that going through the perspectives a detailed picture of an organization can be obtained, connecting the business and technology sides of I4.0. Even if the perspectives are closely related sometimes, still each has its own logic and provides specific insights into the digital transformation. Furthermore, the perspectives also help to see in which directions the company has a shortage or might have opportunities.

Based on our multi-perspective framework we have shown that the case factory has deep experience and can rely on accumulated knowledge gained by the deployment of traditional industrial robots. It works heavily on interoperability of machines and real-time capability. Most of the applications are digitally dominant solutions, but the factory also uses 3D printing, and just started with advanced robotics. The efforts focus on vertical integration. Considering the technologies and the level of integration the factory is at the visibility/monitoring level. Business-wise, their dominant objective is to sustain – and if possible, to improve – operational performance, mainly the cost position; business level performance measures and sustainability issues are secondary (but certainly not neglectable). The I4.0 investments at the case factory serve to improve the core processes both directly and indirectly (i.e. transparency, quicker feedbacks).

To summarize, the factory uses many technologies, but the level of integration is still low. Currently, there are islands of digitalization in the daily operations. Due to their position in the corporation network probably they will not able to change their production and cost focus, even if opportunities would be there. The business and the technology side seem to fit each other.

Summary

Our study highlights that there are many perspectives around Industry 4.0, as it is usual in every newly emerging management initiative. We have selected several seminal perspectives that are widely discussed in relation to Industry 4.0 in (operations) management literature. We are convinced that based on our case-illustrated description of perspectives researchers could and should make a much clearer stance on their approach to I4.0. In our view, the type of innovation pursued by the available technologies is the most distinctive factor. The case factory level efforts are focused on the production system and a matching audit system is developed (see Schuh et al., 2017). Expected improvements (operations measures) and related fields (lean management) are emerging accordingly (Buer, Strandhagen, & Chan, 2018; Tortorella, Giglio, & van Dun, 2019). As our comprehensive approach indicates, alongside these perspectives even the behaviour of a disruptor firm (e.g. Tesla), which builds a completely new business ecosystem, can also be described.

We acknowledge that there are several shortcomings of our study. First, we do claim that this list of perspectives is not comprehensive. Considering the background of the authors, this "patch" is proposed to be the most useful for production plant managers, for manufacturing experts, and even for general and academic audiences. There are further crucial perspectives at the firm level, such as managing the digital transformation process itself, the role of IT, the development of organization and people etc. (Liao et al., 2017), that are not covered in the paper. Second, our case factory's experience is limited to the production system (core process) innovation. This level of analysis is not necessarily in the focus of wider interest related to digital transformation. Nosalska et al. (2019) claim that business reports and government documentations emphasize business model changes disproportionally more frequently than scientific articles. Promising future research could examine the link among these different types of innovations in the I4.0 context. Finally, there are crucial factors beyond the firms' boundaries, namely legislation, education, infrastructure, industrial policies and social acceptance which were not considered. These factors with many unintended consequences require structural changes (Kovács, 2017) (Kovács, 2018), and only their successful restructuring could accelerate the organizational efforts.

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