Industry 4.0 in practice: a case-study based analysis from Central and Eastern Europe

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Abstract

Recently digital solutions and novel industrial technologies started to become widespread in manufacturing. There are many different approaches to assess the so called Industry 4.0 transition of national economies (macro) and of individual companies (micro) as well. Our paper elaborates a framework that enables the assessment of Industry 4.0 at sector (meso) level. Relying on the proposed methodology we compare the (evolution of) Industry 4.0 readiness of four manufacturing sectors in EU28. We conclude that the aggregated sector of computer and vehicle manufacturing is the most advanced in I4.0. A deeper analysis of this sector has revealed that countries with top starting performance in the transition in 2014 (SWE, DE, AT) have presented the greatest progress between 2014-2017. While there are expectations that I4.0 could strengthen the relative importance of manufacturing in terms of value added, we did not found evidence for it.

Keywords: Digitalisation, Industry 4.0, Sector

Introduction

Digitalisation has become the most recent buzzword in many field of business and management. In the service domain, a few years ago the emergence of social media that enables customized marketing has totally restructured the sales activities of companies. Today, the digitalisation trend also includes the appearance of Industry 4.0 (I4.0) in the manufacturing context (Lasi, et al., 2014) (Valenduc & Vendramin, 2016). However, in practice, I4.0 goes well beyond the adoption of digitally based business innovations; novel and/or renewed physical technologies are also integrated in its core. In its vision, I4.0 exploits cyber-physical technologies to offer customized products with digitally enriched service content that is delivered by a reengineered value chain (horizontal integration) within a restructured supply chain (vertical integration) in which all participants are interconnected and share information with each other (Schlechtendahl, et al., 2015) (Brettel, et al., 2014).

Although, there are many conceptual works on key I4.0 technologies and well-documented empirical findings about specific I4.0 applications, current literature offers only rather superficial empirical findings about organisation-wide I4.0 transformations. **Our objective is to provide a complex framework for I4.0 implementation and discuss three case studies based on the developed framework**. Our framework synthetizes the common dimensions of company level I4.0 maturity models (Fettermann, et al., 2018) (Geissbauer, et al., 2016) (Viharos, et al., 2017). It covers strategy formulation and deployment, classification of I4.0 technologies (e.g., maturity, human impact), and touches upon changes in the organisation. Given the current state of knowledge, case-study based research bears the potential of a notable contribution for both researchers and practitioners to better understand the phenomenon.

Industry 4.0 in the digital economy

Technologies in Industry 4.0

The emergence of the Industry 4.0 concept shows that the development and adoption of digital and physical innovations has reached a critical mass in manufacturing context. In *Table 1* we highlight nine of the core I4.0 technologies. *Table 1* is structured according to Schwab (2016) who has grouped the technologies into digitally and physically dominated categories. As *Table 1* indicates, authors with very different backgrounds and target audiences usually refer to the same core I4.0 technologies.

In our opinion, these technologies are the building blocks of I4.0 efforts and the practical applications generally implement a specific technology (e.g., 3D printing) and/or the combination of technologies (e.g., digital quality management, digital performance management, real-time yield optimization, predictive maintenance, real-time supply chain optimization, human-robot collaboration) (Goran, et al., 2017).

Table 1 – Core technologies of Industry 4.0

Appear-ance	**Industry 4.0 technology**	**Description**	**Target audience**		
			Top managers	**Policy**	**Researchers**
			(Rüssmann, et al., 2015)	(Davies, 2015)	(Fettermann, et al., 2018)
Digital world	Internet of Things (IoT)	Network of physical items which connect and exchange data.	**X**		**X**
	Cloud computing	Users are able to access software and applications from wherever they need, while they are being hosted by an outside party.			

			X	X	X
	Big Data (analytics)	Large volume, large variety, real time data, which can be used for advanced simulations and automatic inquiries.	X	X	X
	Simulation and modelling		X	X	X
	Virtual and augmented reality	Virtual reality offers a digital recreation of a real-life setting; augmented reality delivers virtual elements as an overlay to the real world.	X	X	X
"Glue"	Sensors	Collect and transmit data, more intelligent ones are also capable of self-calibration or sending warning signals.			
Physical world	Global positioning systems (GPS)	A global navigation satellite system that provides geolocation and time information to a GPS receiver anywhere on the Earth.			
	Additive manufacturing (3D printing)	Material is joined or solidified under computer control to create a three-dimensional object, with material being added together.	X	X	X
	Automation and Industrial Robotics	Machines that can substitute for humans.	X	X	X

The articles in the table are illustrative. Important criteria for the selection were that they cover the whole topic of I4.0 and they are frequently used by their target audiences. Looking at the wide community of I4.0 stakeholders, much confusion can be seen on the technologies. For example, overall terms appear in specific applications, like digital twin or cyber-physical system. Within data-based technologies the kind of data created a new term, semantic technologies. AI is still usually not on the lists (although the Gartner 2018 report already contains it showing a long path ahead). Cybersecurity is more a precondition than a specific technology. Blockchain is an innovation, but is it a new technology?

Literature review

The literature review is organized around the topics of strategy, technology and organization.

Strategy

The fact that the adoption of new technologies and strategic change go hand in hand in organizations is not surprising. Indeed, several papers from different literature streams argue that a shift in strategic orientation is required to drive a more effective implementation of new technologies (Stock and McDermott, 2001; Lewis and Boyer, 2002), or that at least adoption strategies and firm-level business strategies need to be aligned for the successful implementation of any new technology (Kotha and Swamidass, 2000; Pires and Aisbett, 2003). Nevertheless, some recent findings suggest that this issue requires further verification, as the link between strategy and technology adoption is not always straightforward (Lucianetti et al., 2018). This is especially true in the case of the newly emerging I4.0 technologies and methods.

When introducing important changes on the operational level, especially changes that require the application of new technologies, two important issues are discussed in the literature. The first aspect concerns whether the strategic planning is proactive or reactive in nature (King and Teo, 2000). Proactive strategies imply that the company takes an active role in strategic innovation, seeking to introduce new processes or products ahead of competitors with the aim to seize arising opportunities and obtain a competitive advantage on the market. On the other hand, reactive strategies mean that a company takes a passive role in strategic innovation, changing its strategic behaviour to comply with external pressures, react to the changes observed in the environment or to respond to challenges posed by its competitors (Chen et al., 2012).

Another aspect related to the strategic implications of new technology adoption concerns the extent to which a strategic planning process is formal or informal (O'Regan and Ghobadian, 2002). Formal strategic planning represents an iterative, comprehensive and systemic approach by which the management of the company analytically determines a strategic direction for the organization as a whole (Galbraith, 2010). On the other hand, informal planning relies only on the past experience and intuition of an organization to make decision regarding the future. Informal planning implies that firms do not systematically plan ahead their strategies, and that strategic actions and adaptations emerge from the experience of the company when it is facing a strategic decision (Mintzberg, 1985). This distinction is closely related to the top-down and the bottom-up nature of operations strategy formulation. The top-down approach implies that functional strategies (including the technology strategy) are derived from clearly stated corporate and business strategies, while in the case of the bottom-up perspective argues that strategic decisions are shaped over time and are based on the day-to-day practical experience of the organization. Thus, top-down strategies are a result of a formal, hierarchical planning process, while bottom-up strategies are a result of the knowledge accumulated with the daily activities of an organization (Slack et al., 2010).

Thus, in order to classify strategic approaches to I4.0 implementation, at least two aspects need to be taken into consideration: (1) the reactive or proactive nature of strategic planning, and (2) the formality of strategic planning which is closely linked to the top-down or bottom-up nature of strategy formation.

Classification of technologies

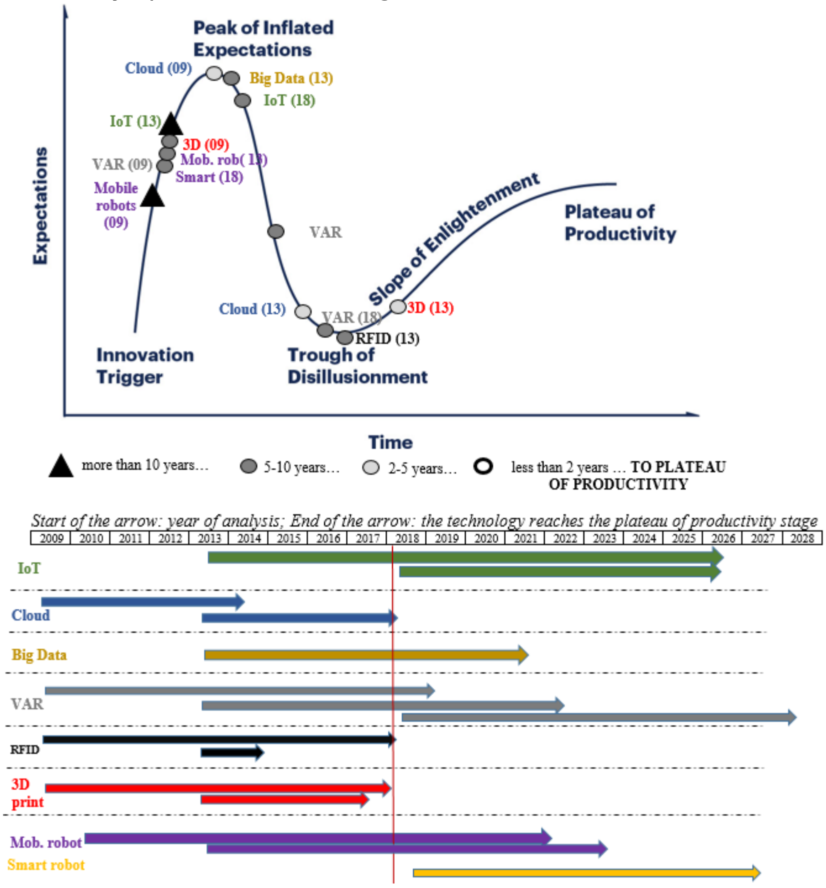
The actual aim of the use of I4.0 technologies and the focus of I4.0-related efforts at company level can vary significantly. Hereby, we introduce three different approaches to classify technologies.

The maturity of the technologies

Since sporadic application of I4.0 technologies will not lead to an organisational renewal, it is usually suggested to develop a strategy which builds on the interplay of many core I4.0 technologies (Ghobakhloo, 2018). However, core I4.0 technologies are at different stages of maturity and that impacts the potential attitude and access to them. There are technologies with "boxed product" applications (e.g., robots), while others are still in the experimental phase (e.g., big data analytics).

We assess the maturity of the core technologies based on the hype cycle of emerging technologies by Gartner (Gartner, dátum nélk.). The annual hype cycle defines the actual stage of many emerging technologies alongside the following phases of a "life cycle": innovation trigger, peak of inflated expectations, trough of disillusionment, slope of enlightenment, plateau of productivity. Furthermore, the analysis also predicts the time horizon when the specific technology arrives at the plateau of productivity phase. To assess the maturity of the nine I4.0 technologies we have reviewed the Gartner analyses on emerging technologies for three selected years: 2009 (Hutch, 2009), 2013 (Gartner, 2013), and 2018 (Panetta, 2018) (Figure 1).

Figure 1 – Maturity of core I4.0 technologies – assessment based on Gartner's hype cycle



Source: (Hutch, 2009) (Gartner, 2013) (Panetta, 2018)

To assess a specific technology, we have looked at its appearance (yes/no), the date of appearance and the predicted year of arriving at the plateau phase. The nine technologies can be classified into four groups:

1. Long history and well-known technologies: simulation and modelling and sensor technologies were not mentioned on the hype cycle at all. While these technologies have long history, in our opinion, other I4.0 technologies (e.g. IoT, big data) can leverage the applicability of them. IoT enables to collect data on large scale and use them as input for simulations.
2. Mature I4.0 technologies have appeared a decade ago and are predicted (by different analyses) to have already arrived at plateau phase. Cloud, 3D and RFID belong to this group.
3. Several well-known technologies (IoT, VAR, smart robots) belong to the emerging group that will arrive at the plateau stage in the long term.
4. Big Data lies between the latter two groups. Despite its shorter history, it is predicted to be productive application at the start of the next decade.

The implication of technology on work force

Based on the implication of technology on work force Acemoglu (2016) (2017) differentiates replacing and enabling technologies. Enabling technologies are conceptualized as "*augmenting the capabilities of some workers and enabling them to perform new functions, increasing their productivity*" (Acemoglu, 2017, p. 4), e.g., based on big data analytics a process monitoring system improves managers' decisions on capacity improvements. Replacing technologies are "*explicitly replacing labor in some*

tasks" (Acemoglu, 2017, p. 5). Robots usually impact repetitive tasks both in manual (industrial robot) and in cognitive (automatic order management) settings. On the long run, the promise of AI is that it might replace creative cognitive tasks.
In our opinion this differentiation leads also to distinct assessment of return. For example, in the case of replacing technology (robot) short term direct return can be calculated. An enabling tool like the current data collection system (MES) usually leads to reactive interventions (eg., quality improvements) which can lead to direct (lower scrap rate) and indirect benefits (transparency), however the calculation of return is not evident.

Type of innovation boosted by I4.0
Different types of innovation can be boosted by I4.0. The most complex change is organised around business model innovation. The business model innovation considerably reshapes the relations with stakeholders, and it can also lead to the development of completely new modus operandi (eg., new processes, new competitors) in a particular industry. It necessarily relies on smart products or services that we regard as the second type of innovation. Finally, the exploitation of I4.0 in process innovation is also a viable adoption strategy. In this case the main (exclusive) aim is to make, usually internal processes of, the value chain more efficient. Although, we can identify cases in which new value propositions and business models were developed, manufacturing companies usually look for internal process integration and better operational performance (López-Gómez, et al., 2018). The process innovation approach means a quite narrow interpretation of the I4.0 phenomenon.

Organisation and new organisational structure
Successful implementation of I4.0 can contribute to a long-term competitive advantage for international manufacturing networks (Gilchrist, 2016). This is the reason, why the technology-organization-environment (TOE) fit of the manufacturing companies is more important today, then ever before. Tornatzky and Fleischer (1990) developed the TOE framework, which explains on the organization-level that three different elements of a firm's context influence adoption decisions and process. These three elements are the technological context, the organizational context, and the environmental context. All three are posited to influence technological innovation, which impacts directly the long-term profitability of a company (Gilchrist, 2016).

Operations management (OM) literature has researched both the technological level, and the environmental level, while we have little knowledge on the organizational perspective (Baker, 2012). Andersson and Tuddenham (2014) claim that organizational structures are rigid, therefore cannot change as fast as the digitalization process would make it necessary. They argue that digitalization should be part of a reinvented IT function, as it changes the demands on IT in three ways: (1) digitalization requires increasingly sophisticated technology, (2) greater IT-delivery performance is needed across the board, and (3) digitalization means that IT must prepare for higher engagement form senior management, because the value at stake is higher than before. The IT function is not anymore just a cost center, it developed to a profit center, as IT solutions (e.g. I4.0) have an impact also on revenues (Choudhary & Vithayathil, 2013).

These changes highlight the need for a new organizational governance in which the digitalization has a greater role. While this has regularly been claimed in the context of discussions on IT's strategic value in firms, it is seldom achieved (Legner et al., 2017; Andersson & Tuddenham, 2014).

Legner et al. (2017) claim that many firm level digital transformation success stories are often directly supported by CEOs, while some companies employ dedicated Chief

Digital Officers (Horlacher, 2016) to foster digital transformation. Thus, a companywide successful digitalization project is driven by the CEO and business leaders, who consider it as one of their top priorities and not just as an "IT effort" (Andersson & Tuddenham, 2014). However, the implication of the management is a necessary but not sufficient condition for the organizational digital transformation. In order to meet the challenges of digitalization, the IT function must undergo a "change that comprises new models of internal organization as well as new forms of collaboration and alignment with business departments" (Legner et al., 2017, p. 307).

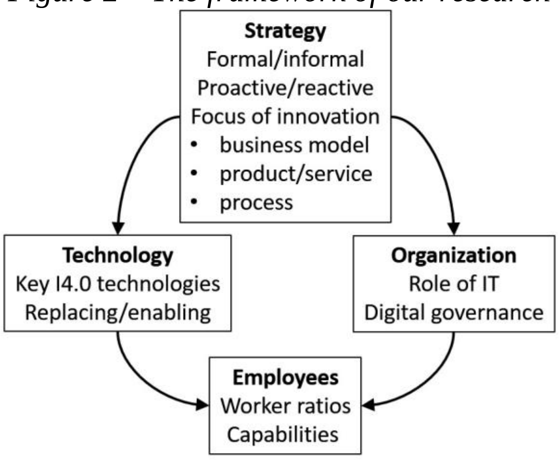
Nonetheless there is no relevant OM literature how to implement digitalization on a plant level, and how to adopt the plant's organizational structure for the digital transformation. The business information system literature relied on the concepts of co-location and cross-functional digital teams, which could enable the digital transformation process by switching the IT function from service provider to enabler and innovator. Cross-functional teams and employees who have formal or informal links to other departments or to other value chain partners are the enablers of I4.0 implementation.

More broadly, organic and decentralized organizational structures are associated with effective digital transformation (Andersson & Tuddenham, 2014). Manufacturing plants with these types of structures, have a degree of fluidity in responsibilities for employees, and promote lateral communication in addition to communication along reporting lines (Baker, 2012). Other research on organizational structure indicates that while organic and decentralized structures may be best suited to the adoption phase of the innovation process, mechanistic (rather than organic) structures, with their emphasis on formal reporting relationships, centralized decision-making, and clearly defined roles for employees, may be best-suited to the implementation phase of the innovation process (Zaltman et al. 1973). If the organizational condition of the IT function, as an enabler is met, digitalization could bring competitive advantages for the firm, and for the plant.

The research framework

Based on the literature review we developed a framework to grasp the key issues in an I4.0 transition.

Figure 2 – The framework of our research



Research methodology

We collected data from three companies in Hungary working in the automotive and electronics industry based on a uniform case study protocol. We chose these industries because they are ahead in I4.0 adoptions (Demeter et. al., 2018). Companies were selected by convenience and based on their commitment to I4.0. To assess the I4.0 transformation we collected data on company and plant level changes, and gained deep understanding of two I4.0 projects (application).

Our interviewees were managers (manager of digital department (if applicable), senior manager, project managers) who could provide detailed information on these topics. Interviews were recorded and transcribed for further analysis. We have also processed publicly available information, student works and company documents.

Table 2: The sources of data

	Company 1	**Company 2**	**Company 3**
Interviewees	4	3*	1
Department responsible for digital project	yes, this responsibility is integrated into lean department	no (it is supported by engineering)	yes, lean department has been integrated into digital engineering department
Plant visit	YES	YES	Planned in future
Public documents	YES	YES	YES
Supervisory work of the co-authors at company / previous research project at the company	YES / YES	NO / YES	YES / NO

* 5 additional interviews at other subsidiaries of the company.

We apply the developed framework for single case analysis, and then we synthetize the information gained in the cross-case analysis to identify the specific characteristics of I4.0.

Case descriptions

All three case units' main business activity is to assemble different kinds of electronic parts for the automotive companies in TIER1/2/3 positions. The business measures of the case units have improved considerably in recent years due to the following factors: (1) soaring production volumes in the European car markets, (2) accelerating offshoring towards Eastern European countries in the automotive industry, and (3) the share of electronic parts have become more important to comfort and safety innovations.

Company 1

The subsidiary is part of a market leader global company with American roots that is currently headquartered in Switzerland. The global company produces half a million different precision products in approximately 100 plants, with 70,000 employees worldwide. The company's products are available in 150 countries. The subsidiary operates with 1500 employees in North Hungary in the transportation solution business line that belongs to the automotive division and the EMEA region. The product variety (2800 active products), size differences (from nanotechnology to 10 m long) and volumes (millions per product) are all at a high level in the plant.

The subsidiary started its first experiments with I4.0 in 2012-2013 with the lead of its lean department. They placed thousands of sensors, actuators and videos in the plant to increase the machine connectivity level. Their first projects were the electronic andon and the digital dashboard in the production area. In 2014 the automotive division in the EMEA region had a workshop, where they collected the potential processes to improve, 160 processes altogether. The clear objective was to address process efficiency and costs. The Hungarian subsidiary became one of the two pilot plants due to its ambitious lean manager. They have received money and started new projects, such as the digital operator learning platform (operator learning management system, OLMS) to provide on the job online training for operators, the e-QCPC (electronic quality control process chart) by digitizing and enhancing the existing QCPC system. The lean department has employed some IT experts to support these developments. They also have had pilots in predictive maintenance, collecting big data, but achieving limited progress so far. They received a 3D printer for metal products with the idea to produce products for the aftermarket on this machine. The company has its own internal cloud, due to security reasons they have not outsourced yet. After spending a lot of money and having many experiments the global company decided to organize a 6 weeks strategic meeting with the help of a big consulting company to prepare the digital strategy for the company, with a roadmap and a digital governance model.

Under the digital governance model, the global division has a digital leader directing the so-called regional champions. Champions work with regional accelerators, 3 in the EMEA region, each of them is an expert in an I4.0 technology. At plant level there are a) subject matter experts (SMEs), knowing the area (technology) of intervention, b) local accelerators, familiar with the digital technologies and have data analytic skills (if there is no such person, the regional accelerator can substitute), and c) there is a person responsible for the implementation project, usually someone from the lean department. The subsidiary provides data analysis and SCRUM training for experts and project managers. Above these three people there is a local digital champion, who represents the management, and coordinate the work of the three experts.

The key success factor of project implementations is people. 5% is the technical solution and 95% to train and persuade people to use it. They involve employees as much as possible into the developments (e.g. they can participate in designing the screen for the dashboards), provide online trainings, give rewards for ideas and contribution. The I4.0 applications support decision making (dashboard, eQCPC) and training (OLMS), increase visibility and transparency (dashboard), and hopefully will reduce costs in the future (predictive maintenance, 3D printing for small batches). All these efforts currently need more employees, especially engineers and IT experts, so the number of employees has not reduced yet.

Company 2

Company 2 is a Hungarian headquartered electronic manufacturing services company. This company is listed on the Manufacturing Market Inside' (MMI) EMS TOP50 list. The company's turnover was around 300 million Euros in 2018. Almost half of the turnover comes from the automotive segment, its one third from industrial applications, and its fifth from household appliances. In the last few years, the automotive and industrial appliances segments have considerable improved their relative share in the turnover. The company have many subsidiaries. These subsidiaries, even if the they supply for the same markets (eg., automotive), are run by independent top managers with strong control from the HQ. At the company, we have investigated two large subsidiaries (1000+ employees respectively), the automotive and the household appliances factories. In this paper we describe the experiences of the automotive subsidiary.

Regarding process innovations, the company is (and its larger factories are also) committed to lean management and recently to I4.0. However, given that subsidiaries have high degree of independence, no formal strategy or coordination exists for the deployment process. Until now, one meeting for top managers at the HQ was organized around I4.0 in 2018. The managers at all levels of the company share a "conservative" investment policy. It means that investments are usually triggered by specific customer request and that short-term returns are expected.

The automotive subsidiary is in TIER2/3 position in the supply chain. It has doubled its turnover in the last few years. High variety and low volume products give the majority of the product portfolio. The related production processes rely largely on manual work. Only a few products are assembled in large volumes that are produced on automated production lines.

The subsidiary started its traceability system on a specific customer request several years ago. For today, this system has turned into a basic MES system. It’s a monitoring system that covers automated processes and machine-based workstations in the assembly. However, there are still stand-alone stations that are not connected to it. In the future the subsidiary could resolve the interconnectedness of machines and the integration of further internal functions (e.g., logistics). The subsidiary has developed the system on its own due to cost and independency/flexibility considerations exploiting internal programming know-how. Although, the initial trigger has come from a buyer, the upgrading of MES has been continuous due to functional managers’ and supervisors’ needs.

A few years ago the subsidiary launched an assembly robot on a high runner work station with the support of an integrator supplier. The robot assembles an electronic device and replaces two operators per shift. It also runs quality and conformity checks on the assembled electronic device. Relying on M2M communication the assembly robot arm orders the next robot arm to select the scrap. At the subsidiary this assembly robot is regarded as “automation” project instead of I4.0-minded application.

At the subsidiary level there is no specific department that is exclusively responsible for digital projects. Regarding the engineering content of such developments the engineering department manages the I4.0-minded projects. This department is led by the chief engineer and by the head of new product introduction group. The robot project was an occasional project without any previous experience. The installation of the robot has delayed considerably despite having an integrator supplier. The potential installation of further robots is constrained by the product portfolio (low proportion of high runners) and in the case of some product the tolerance levels of input materials and shortcomings of product developments cause also difficulties. Altogether, changes alongside the supply chain (e.g., product development designed for robots, stricter standards for suppliers) could accelerate the diffusion of I4.0-minded technologies.

Company 3

This case unit is a subsidiary of a large Western European automotive supplier. The Hungarian factory is in TIER 1 and in TIER 2 positions at the same time with different electronic products. The subsidiary has more than 1000 employees and a turnover more than 500 million Euros. Its short-term plan is to double the turnover without further increase the number of employees and hence they have to fully exploit the potential of the digital factory concept. Since it is an assembly unit it devotes its efforts to process innovation.

The company developed a division-wide Industry 4.0 strategy (digital factory concept). The digital factory is embedded into a high-tech IT context and it also assume experts with proper digital skills. KPIs are developed to motivate and to measure the advancement of the I4.0 applications.

The strategy differentiates the I4.0 technologies and applications based on the proposed roll-out period. Robots (cobots, AGVs), additive manufacturing, shop floor management and reporting systems have been integral parts of operations for the recent years. The subsidiary has installed dozens of robots. While at the beginning it has worked with integrator, for today the unit has the installation competence. 3D printers (more than 10) are in daily use for non-production materials within the unit everywhere. Digital reporting system utilize the data collected by an extended MES system that covers production and logistics and integrates also information of other business functions (e.g., HR, development plans). The company has several centres of excellence that act as internal consultancy units. These units develop and test specific applications and then help the company-wide roll-out process. Beside the central initiatives there are minor I4.0-minded experimental pilot projects in the preparation phase (e.g., drone, gloves).

The deployment of the central I4.0 strategy is supported by a new department (digital engineering). The department has more than 20 employees and it has integrated the lean group as well. As described earlier, different applications are in use. The digital department' main focus is on robot technology. Digital solutions directly help the work of lean expert as well, e.g., new product introduction and related processes are simulated in advance. IT department also has a crucial role in digital transformation, e.g., it has developed the MES system, the basis for reporting and BI.

The widespread impact of digital transformation has necessary influence on employees. The assumption is that successful digitalization strategy relies foremost on people. Training materials have been developed and skill matrix is also extended to digital competences.

Cross-case analysis

In order to compare our cases, we organized the key information into Table 3.

Our case companies use different strategies. While C1 started informal and bottom up, today they have a formal digital transformation strategy with a mixture of bottom up and top down approaches, C2 does not have formal digital strategy yet (but they already have plans for it) and C3 uses formal and top down approach (we have no information about their start). So far, each company has focused their efforts on process development in manufacturing and material flow. Altogether, based on the three cases, we suppose that companies need some preliminary experience with I4.0 before forming their digital strategy.

The targeted technologies and developed applications are very different. C1 developed its basic infrastructure to increase machine connectivity, and mainly focus on data provided opportunities. For C2 return on investment is crucial, so they follow a very conservative innovation strategy, usually led by customer requests. C3 invest into applications, which can pay off fast. They do have limited opportunity for experiments, get knowledge and instructions from the headquarter. Based on the cases the issue of return on investment influence the path companies follow. It is easier to calculate and expect return from replacing technologies, where direct costs of employees provide clear basis of comparison. The advantages of enabling technologies are mostly indirect and difficult to quantify.

Regarding the organization, again, different solutions can be identified. C1 has a digital governance model, having roles at local, regional and global level, as well. At many units of C1, including our case company, I4.0 is driven by the lean department staff. At C2 the engineering and New Product Innovation (NPI) department is responsible for I4.0 efforts. At C3 there is a local industrial engineering group, dealing with robots and lean. The global company assign a pilot to a unit depending on their capabilities and create a center of excellence there. That center has global responsibilities in the given technology. To sum up, the bigger the effort, the more sophisticated and separated the organization dedicated to I4.0. It seems that lean knowledge and organization provides a good basis for I4.0 efforts.

Finally, no clear sign of reduction in the number of employees. It can be partly because of the level of development (affect only small part of the business), the increasing level of sales, or, like in C1, because enabling technologies will not replace people but need more engineering and IT staff.

Table 3 – Key I4.0 related information from case companies

Aspects	Company 1	Company 2	Company 3
Strategy	Start: informal, bottom up, Now: formalized, mixed	No formal strategy	Now: formalized top down
Type of innovation	Process improvement in manufacturing	Process improvement in manufacturing	Process improvement in manufacturing and internal material flow
Technologies	*Mainly enabling* Sensors, partial IoT, own cloud, (big) data solutions (dashboard, OLMS, eQCPC) and pilots (predictive maintenance), 3D printing	*Enabling and replacing* MES, robot	*Mainly replacing* Robot, simulation, drone (pilot)
Organisation	Start: loose network of unit's (experiments) Middle: coordinated efforts bw plants (pilot factories, roll-outs) Now: global and local digital governance (digital strategy and deployment)	Engineering department and NPI	Now: Digital department at the unit Center of excellence group (central digital strategy with KPIs)
Implication on the workforce (*type of task impacted*)	*Cognitive/manual, repetitive* (eQCPC, dashboard) *Cognitive, creative* (big data) No reduction in workforce Capability development (OLMS, SCRUM, data analysis)	*Cognitive, repetitive* (MES) *Manual, repetitive* (robot) Very limited impact	*Manual, repetitive* (robot) *Cognitive/manual, creative/repetitive* (simulation) Capability development (enlarged skill matrix, robot programming)

Discussion and conclusions

In our paper we developed a framework to grasp the main features of I4.0 transitions through three case studies. Based on our experiences we can draw some conclusions.

First, we found a limited approach towards I4.0 technologies, focusing only on process development in manufacturing and material flow similarly to López-Gómez, et al. (2018). It does not support the predictions made by consultancy reports (e.g. Rüssmann et al., 2015). This fact might be due to the positions of case companies in the supply chain (assemblers), which is also highlighted by the integration of lean and digital groups.

Second, all the efforts companies make are not about competitive advantage. This is more about staying in competition and searching for opportunities for improvement. Even the best companies can only be considered as early adopters, small experiments are started everywhere. Competitive advantage would be related more to product innovation or new business models, but the factories we saw serve the low-cost direction. It might be a context specific result and Western European companies – even within the network of our case companies – follow different path.

Third, consistently with the second finding, mainly mature technologies are in use, and there are only some limited experiments with others. High runner products are in focus. MES system and IoT could be the basis of Big data analytics serving better decisions, but they aren't yet. The lack of technology standards is a big constraint in this matter.

Fourth, digitalisation is "integrated" into business as usual operations, no radical changes yet, adjustments were made to provide the fit; but it did not transform the culture.

Companies develop digital global and local governance structure that fits into the existing structure. It does not bring a considerable shift, it is "just" a new department. The level of structural change is made according to the level of changes on the field. Less change (C2) does not require even a new department, bigger change (C1) gradually results in new structures.

Fifth, replacing technologies bring good and easy to estimate returns (wages!), while for enabling technologies business cases should be developed. However, enabling technologies bear the potential to transform from reactive to a proactive unit (predictions in manufacturing, maintenance) and can provide real productivity increase (Acemoglu, 2016, 2017).

Sixth, our case companies developed cooperation with technology providers and consultancy agencies, acquired start-ups if needed to get access to knowledge and develop their own capabilities. For small companies it is not an option.

Since we are currently in the data collection phase, it is still too early to formulate deeper conclusions. Nevertheless, it seems already clear that companies need a lot of financial and human resources for successful implementation; template factories and pilot projects are typical to make experiments without necessarily expecting short term returns on investment. Efforts are focused on internal developments, much less on supplier-customer related ones.

Furthermore, beside technology, the most important barriers of implementation are related to human resources, including the skills of employees to understand and use the most recent digital solutions (Goran, et al., 2017).

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