Digital technologies and the nature and routine intensity of work

Evidence from Hungarian manufacturing subsidiaries

Andrea Szalavetz

Working Paper 2021.01

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Brussels, 2021
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Print: ETUI Printshop, Brussels

D/2021/10.574/08
ISSN: 1994-4446 (print version)
ISSN: 1994-4454 (electronic version)

The ETUI is financially supported by the European Union. The European Union is not responsible for any use made of the information contained in this publication.

Contents

Abstract

This paper explores the impact of digital technologies on the nature and routine intensity of shopfloor work, the ways in which digital technologies exert their effects and the factors moderating the outcomes of digitalisation in respect of work.

The effect of technology cannot be limited to a dichotomy of increasing versus decreasing degrees of routine. Instead, there are basic scenarios as far as the routine content of activities is concerned: a) no change in routine; b) increased routine; c) transformed routine; d) reduced routine.

More specifically, drawing on data from Hungarian companies, we discuss the multiple ways that technology affects the nature and routineness of work. These include (i) workload and intensity of work; (ii) the degree to which tasks can be explicitly defined, measured and codified; (iii) task spectrum, i.e. the variability, complexity and diversity of work tasks; (iv) the composition and amount of skills required for task execution; (v) the importance of experience or tacit knowledge for task execution; and (vi) the value added of work tasks.

Evidence indicates that the qualitative enrichment of shopfloor work and digital technology-induced reduction in the routine content of job tasks apply only to relatively skilled employees, albeit not exclusively in high-level shopfloor functions. It is argued that the beneficial effects of digital technologies materialise only if employees are skilled enough to be upskilled and become engaged not only in digitally-assisted but also in digitally-augmented, high-value activities.

Finally, positive developments in the nature of work require that employees' work tasks be reorganised, work design and work practices modified and employees upskilled: thus, they are contingent on conscious organisational and human resources management.

Without these intentional managerial interventions, digital technology implementation entails deskilling and/or technological unemployment rather than providing richer dimensions to shopfloor work.

1. Introduction

Digital technologies have been praised for improving the nature of work at all skill levels and making the task content of occupations more interesting by reducing the share of routine tasks (e.g. Acemoglu and Autor 2010; Autor and Dorn 2013; Brynjolffson and McAfee 2014). In manufacturing units, for example, digital technologies relieve operators of physically demanding, repetitive and dangerous tasks. Supported by smart digital solutions and working alongside smart machines, shopfloor workers carry out fewer manual tasks than previously. They are expected, rather, to monitor and interpret the signals of production equipment, supervise production, solve problems and make decisions if troubleshooting is required (Leyer *et al.* 2019; Pfeiffer 2017; Waschull *et al.* 2017). Shopfloor work will thus undergo 'qualitative enrichment'. Since tasks involving problem solving require greater autonomy and decision-making authority than tasks performed according to work instructions, digital technologies will entail 'employee empowerment' (Kaasinen *et al.* 2019; Leyer *et al.* 2019; Martišková 2020).

Digital technologies would thus convey new work practices, involving higher-value and more diversified tasks than previously, and changed forms of control allowing for more self-determined work activities.

By contrast, other scholars predict an expansion of precarious work practices enabled by digital technologies. Instead of an alleged smart machine-enabled reduction of workload, Gaddi (2020) documents a machine-dictated intensification of work processes. Indeed, if software drives manufacturing processes, human idle time is dramatically reduced. Additionally, digitally-enabled workplace surveillance enables a continuous monitoring and real-time traceability of workers' actions (Pfeiffer 2017).

Moreover, in line with classical labour process theory relating technological progress to deskilling and the progressive routinisation of the workforce, and considering this mechanism a general tendency of capitalist development (Bravermann 1974), some labour economists contend that, instead of skill-biased and routine-replacing technological change, digitalisation will engender deskilling, standardisation and the increased routinisation of tasks (Dörrenbächer *et al.* 2018; Krzywdzinski 2017). In certain work tasks and at certain hierarchical levels, the deployment of digital technologies is autonomy-reducing – employees would passively carry out the system's directives (Gerten *et al.* 2019, Jarrahi 2019).

Other, more nuanced studies argue that the specific impact of new technologies on the nature of work depends on the tasks undertaken by the given employees. Technology is a substitute for routine, codifiable tasks but it complements activities requiring problem solving and creativity (Autor 2015). Furthermore, the impact of technology is moderated by several factors. Hirsch-Kreinsen (2016) considers that industrial relations, cultural factors and management choices can moderate the impact of technology on work. Krzywdzinski (2017) complements this list, highlighting that the role of individual business units within the value chain – as reflected by the labour use strategies of lead companies – is also an important moderating factor. Consequently, there is little evidence of one single direction of change in terms of the nature of work (Gallie 2017).

Other scholars warn that most of the papers predicting any of the aforementioned developments focus on the experiences of advanced economies. However, there might be non-negligible differences across countries with different development levels and factor endowments in the nature of work and the routine task content of 'identical' occupations (Dicarlo *et al.* 2016; Hardy *et al.* 2018). For example, Dörrenbächer *et al.* (2018) and Krzywdzinski *et al.* (2018) argue that, instead of upskilling and empowering workers, digital technology implementation in central and eastern Europe (CEE) might lead to a kind of digital Taylorism; that is, to an increasing standardisation of processes and deskilling. Keister and Lewandowski (2017) highlight that, in contrast to advanced economies experiencing routine-replacing technical change, routine-intensive employment kept growing in CEE in the 2010s, particularly in the manufacturing sector.[1]

However, except for some surveys assessing skill use in the workplace and the distribution of routine and non-routine work (e.g. Hardy *et al.* 2018; Marcolin *et al.* 2016), there is a dearth of studies exploring digital technologies-induced changes in the nature of work in 'factory economies' specialised in labour-intensive activities[2] (Dörrenbächer *et al.* 2018; Krzywdzinski 2017; Krzywdzinski *et al.* 2018).

Additionally, although it is safe to acknowledge the existence of a strong relation between digitalisation and changes in the nature and routine intensity of work, little is known about the mechanisms involved.[3] Analyses of digitalisation-induced changes in the routine intensity of work are concerned mainly with the direction of change; that is, whether the routine intensity of occupations is reduced or enhanced as a consequence of digital technology implementation. How the impact of digital technologies on the nature and routine intensity of work unfolds remains unexplored: this process is regarded as a 'black box'.

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1. One explanation is that country-level routine intensity is influenced by globalisation, specifically by the movement of routine-intensive activities to locations characterised by a relatively low wage level (Consoli *et al.* 2016; Goos *et al.* 2014; Hardy *et al.* 2018). In contrast, Cortes and Morris (2018) found that the number of routine-intensive manual jobs has declined in Mexico, a key offshoring destination of US companies. These authors conclude that technological change dwarfs the impact of task offshoring on changes in employment patterns. Analysing panel data from 37 advanced and emerging countries, Reijnders and de Vries (2018) come to a similar conclusion.

2. Baldwin (2013) distinguishes two types of countries according to the activities in which local economic actors specialise. Accordingly, there are 'headquarter economies' and 'factory economies' in international production networks. Economic actors in headquarter economies are specialised in headquarter-specific activities: the coordination and governance of the production network, business development and other high value added, intangible business functions and activities. Actors in factory economies 'provide the labour', performing predominantly labour-intensive activities.

3. This paper uses digitalisation in a broad sense, referring to digital technologies transforming business processes. In selected contexts, however, the term will simply refer to the automation of work processes.

This paper addresses these knowledge gaps by exploring the impact of digitalisation on the nature and routine intensity of shopfloor work in a sample of Hungarian manufacturing companies.
Specifically, it seeks to answer the following research questions:

Q1 How does the nature and routine intensity of shopfloor work change as a result of digital technology implementation?
Q2 How do digital technologies exert their effects on the nature and routineness of work? Which occupational features are affected?
Q3 Under what conditions can digital technologies exert a beneficial effect on the nature of shopfloor work?

The case of Hungary is considered a model setting for the investigation. Hungary is a factory economy, highly specialised in industries such as automotive, industrial machinery and electronics that were the pioneers of, and are still leading the way in, the adoption of digital technologies. These industries are dominated by foreign-controlled, export-oriented manufacturing units (e.g. Pavlínek 2017 for the automotive industry; and Sass 2015 for electronics) in which local subsidiaries are able to harness their global owners' investments in digitalising their local manufacturing facilities. Moreover, evidence obtained in the course of past investigations by the author of this study (Szalavetz 2017; 2019a; 2020) and by the authors of other studies (e.g. Demeter *et al.* 2019) indicates that the Hungarian manufacturing subsidiaries of global companies are often selected to become pilot factories of their parent companies in terms of experimenting with new technologies or with new organisational and work practices. Outcomes and lessons are carefully analysed before the given solutions are rolled out to other subsidiaries. Consequently, analysis of the Hungarian setting promises to yield insights of great relevance to the research questions of this study.

This paper differs from prior research in two respects. First, in contrast to the quantitative approach characterising the dominant majority of analyses discussing routine-biased technical change, we apply qualitative techniques. We explore 'the subtleties of human experience' (Zuboff 1988: xi) regarding the impact of digital technologies on the nature of work by drawing on interview-based investigation (Eisenhardt and Graebner 2007). Second, we focus on the shopfloor to study within-occupation changes both in terms of automation and augmentation. The experiences of production workers and employees in selected production-related support functions such as production logistics, quality control, production scheduling and maintenance are investigated to find out whether and to what extent the solutions deployed in sample companies augment the skills of their users or deskill them. By contrast, the existing literature tends to consider these two effects of advanced manufacturing technologies separately: automation and substitution on the shopfloor; and augmentation in occupations requiring high qualifications (Jarrahi 2019; Moniz and Krings 2016).

The key contribution of this paper is that it opens the 'black box' regarding the impact of digital technologies on the nature and routine intensity of shopfloor work and provides evidence for the multifaceted nature of digitalisation-induced changes.

The study proceeds as follows. First, selecting from various streams of the related interdisciplinary literature, we briefly review some relevant studies (section 2). Based on this review, in section 3 we present a number of propositions on how the nature and routine intensity of shopfloor work might change following the implementation of digital technologies. Following a section describing the research design, the sample of our interviewees and the data analysis (section 4), we present the results of our empirical investigations (section 5). Section 6 contains a discussion of the empirical results, provides some concluding remarks and elaborates on the implications and limitations of our findings.

2. Theoretical background

Investigating the impact of digital technologies on the routine intensity of shopfloor work, our research is closely related to studies analysing the impact of new technologies on work practices and the nature and skill intensity of work (e.g. Acemoglu and Restrepo 2018, 2019; Atalay *et al.* 2020; Bisello *et al.* 2019).

Prior research on the impact of ICT adoption (e.g. Autor *et al.* 1998; Bresnahan *et al.* 2002) has shown that technology is not neutral to skills. A widespread consensus has emerged among academics that overall demand for low-skilled, routine task inputs – i.e. for repetitive and well-codified tasks – decreases whereas demand for non-routine tasks increases as a result of the introduction of ICT-related technologies (e.g. Arntz *et al.* 2016; Autor *et al.* 2003).

Coined as routine-biased technological change (Autor *et al.* 2003), these developments have continued to intensify with progress in digital technologies (Brynjolffson and McAfee 2014; Frey and Osborne 2017; Goos *et al.* 2019; Manyika *et al.* 2017). Digital technologies have evolved progressively to carry out tasks previously considered professional and tacit knowledge-intensive, raising the question of how the rest of the tasks that constitute the given occupations will be transformed.

A classical study trying to answer this question by discussing the impact of information technology on work practices and the nature of work is Zuboff's (1988) Smart Machine. Her theory, centred around the distinction between technology 'automating' or 'informating' work, is still relevant today, thirty years after the first publication of her book (Kallinikos 2011). Automation, in Zuboff's conceptualisation, is about streamlining, simplifying, speeding up and increasing the efficiency of work. In contrast, information technology can also be used to enrich work and give rise to 'better jobs'. Workers, developing new (intellectual) skills in order to interact with smart systems, are enabled to adopt a more informed perspective of their work since information technology allows for greater transparency of the organisation and work processes. This latter effect of information technology is referred to by Zuboff as technology 'informating' workers.

Thirty years later, scholars discussing the implications of digital technology implementation for work still conduct their analyses along the same lines and conclude that digital technologies either augment the skills of their users in the workplace or deskill them. Augmentation takes place if technologies amplify users' skills and improve their existing competencies. By contrast, certain digital technologies make users' skills, competencies and tacit knowledge redundant. These twin effects of technology often prompt sharp differences in scholars' predictions and conclusions concerning the outcome of digitalisation-induced changes in the content and quality of work.

For example, numerous papers discuss the ways digital technologies support production workers: 'operators 4.0' (see surveys by Romero *et al.* 2016; Ruppert *et al.* 2018). Supported by collaborative robots undertaking physically demanding, ergonomically challenging and/or repetitive tasks that require high precision, operators 4.0 are relieved of an increasing number of routine tasks. More importantly, they receive instructions that support their work tasks in a user-friendly manner, e.g. through smart visualisation. Assembly workers are supported by augmented reality solutions that project contextualised information to operators' visual field; that is, to the point at which the tasks requiring this kind of information are performed (Romero *et al.* 2016). Warehouse picking is facilitated by indoor positioning systems and/or mixed-reality glasses. Digital technologies engineer human error out of the production system and enable shopfloor employees to perform their respective tasks in an improved and more efficient manner (Lazarevic *et al.* 2019). Embedded applications provide continuous feedback about successful task execution (Longo *et al.* 2017) and/or about the status of the production process (Zhou *et al.* 2019).[4]

By contrast, Moore (2019) elaborates on the nature of digitalised work in the context of agility and precarity where digital technologies, specifically worker monitoring and tracking tools, empower advanced control mechanisms. Another adverse effect of digital technology implementation is the intensification of work. Moore maintains that smart technologies 'accelerate the labour process to the cliff edge of what is possible to endure' (2019: 140). Work intensification originates in that digital technologies both allow for and require the enhancement of lean practices as well as the optimising and standardising of work (Buer *et al.* 2018, Wagner *et al.* 2017).

4. Employees in production support functions are assisted by digital solutions that automate non value adding activities, such as filling out time sheets or reporting. Digital technologies support decision-making in shopfloor activities by making the right information available at the right time. Plant managers and line managers are informed by enterprise resource tracking technologies providing information about the location and utilisation of assets. The real-time status of overall equipment effectiveness and order fulfilment is displayed on dashboards, together with a variety of other performance indicators. Decision-making for production planners and schedulers is supported by smart algorithms integrated in the cyber-physical production systems (Colledani *et al.* 2014) that perform real-time optimisation. Accordingly, the shopfloor engineers engaged in process optimisation, who used to rely on accumulated experiences and tacit knowledge to identify and eliminate bottlenecks and other process vulnerabilities, now rely on machine learning-powered process management algorithms that identify the best procedural approaches and recommend actions (D'Addona *et al.* 2018; Romero *et al.* 2016; Zhou *et al.* 2019).

Investigating operators' perceptions of changes in the nature of their work following the deployment of new automation solutions, Wurhofer *et al.* (2018) argue that automated systems such as digital work instructions are associated with a decrease in mental effort.[5] Digital assistance systems have a deskilling effect and convey a loss of know-how. Furthermore, routine cognitive work, involving a passive monitoring of the robots that perform the work tasks, lead to boredom and reduce operators' job satisfaction. In a similar vein, Jarrahi (2019) draws attention to the threat of cognitive complacency, when workers mindlessly follow the instructions of the system.

In sharp contrast to this view, Pfeiffer (2016) stresses that assembly operators' qualitative role has even increased with automation. Such workers do not passively monitor machines but are expected to intervene to fix failures, addressing difficult and complex problems and unexpected situations. Kagermann (2015: 35) claims that 'rather than simply being employed to operate machines, workers [in the digital workplace] will increasingly act as experts, decision-makers, and coordinators. This will make their work more varied and interesting.'

This assessment is supported also by Holm (2018) who conducted interviews with manufacturing managers, human resources specialists and future shopfloor workers (students) in Sweden. Holm conjectures that operators' tasks will be less repetitive and more diverse as a result of digital technology implementation. Operators will have to learn new workflows, become comfortable with new tools and applications, interact with smart machines and work in a more information-intensive and technology-rich environment than previously. Operators' responsibility thus grows: in addition to performing technologically-enhanced production tasks, they are required to take process-related decisions and are encouraged to generate ideas for process improvement.

In summary, while this review confirms the relevance of Zuboff's (1988) framing of the twin role of technologies in transforming work, it highlights that neither the magnitude nor the direction of change in the routine content of work tasks is straightforward.

A related stream of research underscores the importance of managerial and organisational practices, the level and composition of employees' skills and corporate strategy; that is, the non-technological factors shaping the impact of digital technologies on work (Brynjolfsson and McElheran 2016; Hirsch-Kreinsen 2016; Krzywdzinski 2017). Accordingly, the organisational context and the ways in which digital technologies are used can significantly influence their impact on the nature of work; that is, whether the deployment of smart assistive solutions augments the skills of shopfloor employees or rather deskills them. A quote by Zysman and Kenney (2017: 331) is illuminating here: '[The specifics of

5. In the interpretation of Attaran *et al.* (2020), employees needn't cope with information overload: they can obtain the right information whenever needed. These authors document a dramatic reduction in the amount of time dedicated to searching for information – not only at high hierarchical levels in companies but across practically all shopfloor functions.

technology] deployment will depend on whether firms [...] view workers *as assets to be augmented* or simple costs' (emphasis added).

3. The relation between digital technologies on the shopfloor and the routine intensity of employees' work

From a shopfloor perspective, the routine intensity of work in manufacturing facilities has been shaped by two developments working in opposite directions. On the one hand, shorter product life cycles, rapidly changing and highly varied demand, and short production runs increase the non-routine content of work both in production and in production support functions. In line with the requirements of mass customisation, manufacturing plants are frequently reconfigured and production lines redesigned (Váncza *et al.* 2011). This increases both the complexity of the management of operations and the diversity of work tasks in all shopfloor functions.

On the other hand, an array of computational tools and smart user assistance solutions are at hand, tailored to the skills of users. Deployed to prevent errors, offer guidance and make the right information available at the right time to the right people, these assistive solutions rationalise and simplify complex activities. Accordingly, the mix of manual and/or cognitive activities becomes transformed. However, the overall degree of routine does not necessarily change. Technologically enhanced employees at all skill levels and in all functions may rather develop new routines, aligned with the specifics and the requirements of the newly deployed digital solutions.

These new routines are indispensable from the additional point of view of keeping up with the increased pace of work, given that digital technologies not only assist but also intensify work, allowing for inefficiencies to be systematically eliminated.

Taken together, the impact of digital technologies on the routine intensity of work cannot be limited to a dichotomy of increasing versus decreasing degrees of routine. Routine may become completely transformed without any meaningful change in the share of routine activities in total. Some routine and non-routine tasks may be eliminated, replaced by other routine and non-routine ones, and complemented with new tasks. The overall outcome of change might differ even within individual occupational categories, depending on the moderating factors outlined in the introductory section.

We propose, therefore, four basic scenarios for digital technologies-induced change in the routine content of activities: a) no change in routine; b) increased routine; c) transformed routine; and d) reduced routine.

As for the mechanisms that induce these scenarios, we propose that – in a direct or indirect manner – digital technologies affect several variables used as proxies for measuring the nature and routineness of work. These include:

- The intensity of work;
- The degree to which tasks can be explicitly defined, measured and codified;
- The variability, complexity and diversity of work tasks;
- The composition and amount of skills required for task execution;
- The importance of experience and tacit knowledge in task execution;
- The importance of interactions and peer-to-peer communication in task execution;
- The degree to which abstract reasoning, creativity and intuition is required for task execution;
- The value added of work tasks.

Finally, in accordance with labour economists pointing out the paramount importance of non-technological factors, moderating the relation between technology and the nature of work (e.g. Brynjolfsson and McElheran 2016; Hirsch-Kreinsen 2016; Krzywdzinski 2017), we propose that the level and composition of employees' skills, managerial practices and organisational complementarities exert strong influences on the outcomes of digital technologies on the nature of shopfloor work, moderating their effects.

4. Method

To investigate the specifics of digital technologies-induced changes in the nature and routine intensity of work in the context of Hungarian manufacturing companies, we developed an exploratory research design. Research involved qualitative data collection from semi-structured interviews (Patton 2002) with a sample of key informants: those behind digital technology implementation on the shopfloors of manufacturing companies as well as informed observers. Data were collected on the 'everyday realities' of work life regarding the impact of digital technologies on work.

Striving to obtain rich details of context-specific changes in work practices (Doz 2011), we used insights from the field, gained from interviews with operators and managers, as well as workplace observation and analysis of corporate videos uploaded by sample companies on YouTube for employee attraction and marketing purposes.

In order to reinforce the trustworthiness of our qualitative research, we devised research variables that are indirectly related to routine intensity. Rather than asking our informants to evaluate the impact of digital technologies on the routine intensity of their work, we asked them about technology-related changes in workload, task spectrum, skill requirements, value added and aspects of work practices. These concepts are 'suggestive', evoking the phenomenon investigated in this study only indirectly (Burgelman 2011). Table 1 summarises the research variables employed in this study.

Table 1 **Research variables**

Topic	Keywords mentioned during the interviews
Workload	Changes in work intensity, speed of work and idle time
Codifiability	Measurement and standardisation of work tasks and procedures, explicit work instructions
Task spectrum	Multitasking; task variety; specialisation
Skill requirements	New skills required and skills becoming redundant; changes in occupational features such as interaction-intensity and abstract reasoning and in the related skills requirements
Experience and tacit knowledge	Changes in the importance of experience and tacit knowledge
Work practices	Use of teamwork; multiskilling of operators; job rotation; feedback about performance; involvement of employees in continuous improvement

We started our interviews with inquiries about the particularities of the digital technologies recently deployed in the given companies (see Appendix B for the interview template). Next, we asked some related, open, 'how is it to work with'-type questions, tailored to the solutions mentioned by the firms.

Next, we inquired about the resulting changes in the features of work and working conditions: workload and complexity; task spectrum (specialisation or multitasking); skill requirements; and the role of tacit knowledge and experience. Another group of questions addressed changes in work tasks and work practices.

As summary questions, utilised to provide opportunity for interviewees to return to aspects deemed crucially important, we asked our informants to summarise the overall impact of digital technologies on work. We also asked them to identify the most important complementary investment(s) accompanying digital technology implementation that were deemed necessary to capture the expected benefits, e.g. the productivity potential of the newly deployed solutions.

In interviews with operators, this summary question was replaced by a question inquiring about operators' overall perceptions regarding digital technologies-induced changes in working conditions.

Our initial aim was to make the sample of interviewees as heterogeneous as possible regarding industries, level of digital maturity and interviewees' positions and work tasks. Before engaging in the collection of field data and observations, we conducted expert interviews to gain orientation about the most recent advances in digital technologies, the characteristics of the Hungarian market for advanced manufacturing technologies and the solutions with which some leading companies in Hungary are currently experimenting. We interviewed an expert representing a robotics technology provider and three researchers engaged in digital solutions provision for business companies. Additionally, we conducted an interview with a representative of a human resources management services provider (a recruitment and temporary personnel agency), who proved to be a source of valuable information about recent changes in manufacturing companies' demand for skills.

These expert interviews guided our choice of industries since they all emphasised that smart manufacturing technologies are concentrated in specific industries (automotive, electronics, and rubber and plastics industries). Accordingly, we decided to focus on three industries instead of adopting a maximum variation sampling approach. The companies in the sample were recommended by experts and/or were selected on the basis of the author's previous experience, gained in the course of earlier investigations.

Our sample consists of six automotive,[6] three electronics and five machinery companies. The basic data of the companies in the sample are summarised in the Appendix.

Apart from conducting interviews with executives in the C-suite (managing directors, a plant manager and a business unit head – four interviews), we gained access to managers directly involved in the digitalisation of the shopfloor (responsible for industrial strategy, corporate planning and IT, process improvement, IT and digitalisation, and operations – eight interviews). In order to capture diverse perspectives, including viewpoints that are rarely obtained by researchers concerned with the impact of new technology adoption, we conducted three interviews with shopfloor operators and additionally interviewed a representative of the Metalworkers' Federation representing members in several companies in the automotive and electronics sectors. In this way, we managed to obtain multiple views on the issues listed in Table 1 which not only contributed to validating the emerging conclusions but also to reducing single-respondent bias (Eisenhardt and Graebner 2007).

Altogether the data used in this study consists of 20 interviews (including four expert interviews) conducted in the first half of 2020. Interviews lasted sixty to ninety minutes and were not recorded although we took detailed notes including word-by-word quotes. In order to triangulate the findings, we have supplemented interview information with data from multiple sources including press releases, corporate websites, business press articles, company reports, notes to the financial statements and YouTube videos (in the case of eight companies).

Interviews with operators, workplace observation and analysis of the videos did, to some extent, challenge the overall picture obtained from interviews with managers. While these latter laid emphasis on the augmentation effects of digital technologies and argued that work has become more varied, more interesting or at least easier, the accounts of shopfloor workers were rather centred around the intensification of work and the authoritarian behaviour of employees at higher hierarchical levels. On the other hand, videos and workplace observation indicated that shopfloor work tasks involved a high level of routine and repetition, irrespective of a smart work environment, and that operators were using smart devices and tools for work. Having also considered these perspectives, we

6. Automotive is considered in the broad sense, encompassing suppliers that belong to other industries such as manufacturers of plastic or metal components.

managed to control for social desirability bias (Podsakoff *et al.* 2003) and increase the trustworthiness of our conclusions.

The sample firms are large, export-oriented and, with the exception of two companies, foreign-owned.[7] Similarities in size and ownership notwithstanding, there are non-negligible disparities between these firms in terms of the breadth and depth of the utilisation of various digital technologies.

One of the fourteen case companies, a Hungarian-owned automotive supplier, has barely progressed beyond Industry 3.0. Its production system is characterised predominantly by industrial automation solutions combined with manual work tasks. The first steps of advanced manufacturing technology implementation involved the robotisation of certain tasks – both caged and uncaged robots have been implemented – and the deployment of a smart quality control solution. Isolated IT solutions control selected shopfloor processes while vintage machines (without a digital interface) coexist with newer machinery incorporating embedded smart sensors and digital interfaces.

Three companies have already progressed further along the digitalisation roadmap, introducing smart IoT (internet of things) applications and advanced visualisation solutions (dashboards displaying the real-time status of key performance indicators). They have achieved connectivity on the shopfloor and are progressing towards a fully-fledged manufacturing execution system (MES).

In addition to these solutions, the production systems of seven companies have seen the deployment (or piloting) of various advanced digital solutions, including big data analytics and digital twin factory models used for virtual commissioning and/or process improvement. These companies are progressing towards data-driven decision-making regarding a wide variety of decisions.

The rest of the sample consists of three companies that have already laid the groundwork for being able to pilot with machine learning solutions to determine whether production malfunctions are imminent. These companies have not only implemented an integrated shopfloor IT system (MES) but have also accomplished the bridging of the shopfloor with the IT systems controlling higher-level enterprise functions.

Our data analysis aimed at (i) establishing a connection between the specifics of the digital technologies deployed and the changes in the nature and routineness of work; (ii) identifying how digital technologies exert their effect on different occupational features; and (iii) identifying the factors moderating this connection.

Aiming to obtain a contextualised understanding of digital technologies-induced changes in the nature and routineness of work, our data analysis drew on the

7. The average number of employees was 1,976 in 2019 (or the latest year available). Average turnover amounted to €885.4 million and the average share of exports in total sales was 85.5 per cent (one firm was predominantly domestic market-oriented with a share of exports of just 11 per cent).

interpretivist tradition (Stake 1995; Welch *et al.* 2011), allowing for a detailed representation of interviewees' experiences in the form of quotes (Gioia *et al.* 2013). Accordingly, data analysis involved analysing interviewees' narratives in a broad, holistic manner, i.e. trying to embrace the micro-context of their accounts. We have structured the analysis around the research variables listed in Table 1.

The first draft of this paper was sent to all our informants asking for comments, corrections or approval. Their focused feedback helped us enhance the cross-sectional validity of our arguments.

5. Results

Our initial interview questions were aimed at collecting data about the specifics of the digital technologies implemented in the companies in the sample. These data helped us put the changes in the nature of work described by our informants into context. The technical particularities of digital technology implementation are summarised in Appendix C.

5.1 The impact of digital technologies on workload, measurement and the standardisation of work

The first observation crystallised from the interviews is that, compared to our previous investigations (Szalavetz 2017; 2019a; 2019b; 2020), robots have become more prevalent. They are employed mainly in handling and palletising – relieving humans of tasks involving pure physical strength. Robots perform pick and place tasks, load and unload components and feed the production machinery. Other robotic applications target direct processing tasks such as assembly, painting, welding and screwing. In some companies these tasks are partially performed by collaborative robots.

> 'In safety critical places, where multiple screws should be tightened at the same time, we have installed cobots for screwing. Our operators work alongside the robots. Both humans and robots perform their own duties' (manufacturing engineering manager, automotive company).

The robotic replacement of physically demanding, dirty and dangerous human work has clearly improved average working conditions.[8] Workers now perform relatively easier tasks. As explained by the managing director of an automotive company:

> 'Using robotic handling is useful not only because the parts are heavy: this kind of repetitive work is a chore!'

8. For example, in one of the automotive companies in the sample robots are used to pour liquid metal into the moulds and robots that withstand heat and dirt handle the pieces in waterjet cleaning cells.

However, robots have failed to improve another component of working conditions: the intensity of work. On the contrary, workload and work intensity have increased in practically all companies in the sample. The reason is that the implementation of digital technologies requires a reorganisation of work processes, the optimisation of material flows and the standardisation of work tasks. One digital solutions provider commented:

> 'We usually have intense discussions with clients, trying to convince them that before installing robots they should first improve and standardise their processes. It is hard to make them accept that they should reorganise their work processes first and not stick to their traditional procedures. If this homework is done properly, they would need far fewer robots than originally calculated.'

In line with this reasoning, investments in digital technologies were, in most of the companies in the sample, both preceded as well as accompanied by projects addressing the design of work. The flipside is, however, the intensification of work. The head of the industrial engineering team of an automotive company commented:

> 'Before installing robots, our process engineers performed a thorough analysis of the given tasks. They sliced operators' activities into motions and analysed every motion to determine which ones are superfluous – to be eliminated – and which ones can be performed better and quicker.[9] Accordingly, the process has become more simplified and suitable for being automated. Work efficiency increased even in those cases when we decided not to robotise the given task since, as a result of this analysis, we managed to develop better practices and reduce or eliminate unnecessary movements.'

Taken together, the investments preceding and complementing the deployment of all kinds of digital solutions (not only robots) can be described with four keywords: measure, analyse, improve and standardise. They are illustrated by the account of a business unit manager of an electronics company, summarised in Figure 1.

> 'You know, if workers are told that they should manufacture, say, fifty pieces of a given product, they start executing the task at their leisure. You have to tell them how much time they have for that and what to do next. Accordingly, first we had to measure how long it takes to perform each task [mounting process].
>
> Next, we optimised task accomplishment. Previously, our operators performed individual tasks according to their intuition and experience. In order to optimise the processes and eliminate wasteful movements, we first

9. Nowadays, since an analysis relying on process developers' observation of work processes is not only time consuming but also has several disadvantages such as the subjective character of human measurement, the poor traceability of specific movements and the unavoidable impact of the presence of an observer on operators' work, firms would rather use digital technologies, for example RFID-based task time analysis, to capture the specifics of work tasks.

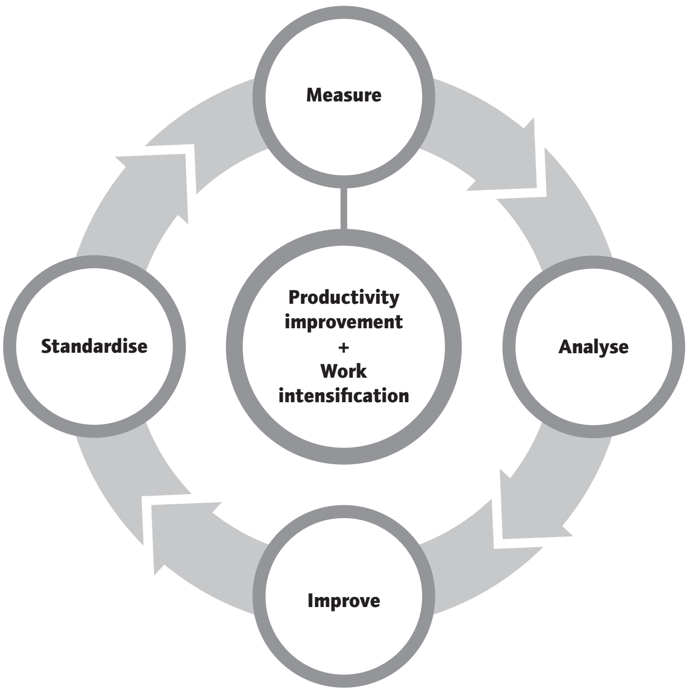
defined each process. In the case of welding, for example, we specified the temperature, the position, which side to weld from, how to finish it and so forth. We also paid attention to the ergonomic positioning of tools and parts.

In relation, we had to improve the delivery of raw materials, parts and tools to workstations and upgrade the organisation of work so that operators do not wait for the line manager to tell them what to do next. Once these reorganisation steps were completed, we determined the standard times of the individual work tasks and provided extensive training to operators who learned, internalised and mastered these standardised processes.

At the beginning of each working day, each operator received his or her daily duties in printed form which also established how much time they had to implement the particular work tasks. They have to provide hourly progress reports and indicate whether they have managed to execute the plan. In the case of any delays, they have to indicate the reason. It's not an essay that they are expected to write, just to tick the reasons from a predetermined menu of possible choices. This latter management innovation, alone, has increased productivity by ten per cent.

We initiated an overarching digitalisation project, the implementation of a manufacturing execution system, only when these processes had been standardised and were running smoothly. Operators now receive their work instructions in digital form and, since the MES measures task accomplishment, they no longer have to submit progress reports.'

Figure 1 **Investments addressing the design of work**



Source: Author's elaboration.

These reorganisation initiatives have contributed to a non-negligible increase in workers' productivity. The subsequent implementation of digital technologies has further improved the efficiency of work processes, resulting in increased throughput and reduced variations in cycle times. The obvious consequence for operators – as mentioned in interviews – is reduced idle time and the intensification of work (see also Meszmann 2019). Workers were quick to recognise that the better organisation of work leads to its added intensity.

Regarding the impact of investments in digitalisation on work efficiency, the managers interviewed were unanimous in placing the highest emphasis not on robots but on the tools and techniques enabling data acquisition, processing and analytics. Investments in developing cyber-physical production systems, for example, laid the foundation for introducing basic use cases such as the measurement of the idle time of the machinery. Data allowed for a granular-level analysis of the production cycle and ensured reliable knowledge of processing times and idle time, which is the foundation for any process optimisation exercise. The director of operations at a machinery company noted:

> 'Data-driven manufacturing, that's just a nice word. In reality, imagine a great number, really a huge number of tiny improvements. You would hardly notice any impact of the individual steps on performance but, together, these tiny adjustments in process design have increased the productivity of the forging and surface treatment processes by more than 20 per cent.'

Digital work measurement techniques are used in the sample companies additionally for balancing production lines. In a high mix, low volume environment, where assembly tasks continuously vary, operators may occasionally face backlogs because certain tasks require more labour input than others. If lines are not properly balanced – that is, the distribution of work tasks is inappropriate – certain operators face a higher than average workload which would turn into a bottleneck in the assembly process. One of the electronics companies in the sample decided to implement a shopfloor task scheduling algorithm measuring task-related labour input. If the line threatens to become unbalanced, because of an improper sequence of the workpieces arriving on the conveyor, the system intervenes, rearranging tasks in real time.

> 'Improved balancing has in itself contributed to increased productivity. Whether it is interpreted as "better adapting the pace of work to the speed of the equipment" and thus "intensifying work", or as "adapting workflows and equipment to operators' capabilities" and thus "reducing their stress", is subject to observers' personal judgement' (representative of the digital solutions provider describing the digitalisation of an assembly process).

5.2 Changes in production workers' task spectrum and skill requirements

Expressing their views about the medium to long-term impact of digital technologies on skills, all the managers interviewed claimed that job tasks requiring elementary physical or cognitive skills will gradually disappear. However, notwithstanding the exposure of elementary physical tasks to the substitution effect of advanced automation technologies, sample firms' operators, displaced by tasks that had been automated, were not fired but deployed to other manual activities requiring similar repetitive movements and elementary skills. Consequently, their cases elicited changes neither in the required skills nor in the routineness of work.[10]

In other instances, although operators were found to perform similar unit tasks as previously, their task spectrum exhibited greater complexity and variability. The account of a process improvement leader of a machinery company makes clear that multitasking, involving a reduction in routine, is by no means an automatic development:

> 'In parallel to investments aiming to digitalise and streamline certain processes we provided a series of training programmes to machine operators to make them able to learn new processes and serve more machines at the same time.'

We encountered a number of cases, however, where the diversification of production workers' tasks was not the outcome of an organic process involving a systematic accumulation of capability but rather one reflecting the constant nature of change in the production environment. Our informants pointed out that current assembly processes change much more frequently than previously. High product variety coupled with reduced cycle time requirements makes today's assembly work hard to compare with that of previous eras. The changes are so fast that it makes no sense for production workers to learn the specifics of new products; and neither do they have any time to gain a deep understanding of the system and the process of which their rapidly changing work tasks are a part.

Coping with mounting requirements in terms of variability and speed is aided by a number of digital solutions supporting shopfloor workers. The managing director of a machinery company provided some details:

> 'Visual work instructions help assembly line workers figure out what has to be assembled next and how this needs to be done. Supportive information

10. The trade union representative interviewed drew attention to a rarely considered aspect of worker redeployment. 'Since automation usually eliminates the most strenuous and dangerous work tasks, observers equate automation-induced worker redeployment with improved working conditions. However, this is not necessarily the case. For example, an automotive company with members in our Federation completed an automation project, automating a task requiring human dexterity, precision and concentration. Workers were redeployed to perform relatively easier tasks. When I inquired how they viewed their new tasks, several workers complained, highlighting that working conditions had deteriorated. It turned out that the workstation where previous high-precision work was performed was better designed ergonomically, being better lit and ventilated. As operators put it, everything was simply more convenient to use. Moreover their prior workplace was equipped with several kinds of welfare facilities that were badly missed at the new site. It was simply their sense of well-being that was lost. Or, consider another automation-induced redeployment case I recently encountered: redeployed workers, whose prior tasks had been automated, had to accept rotating shifts in a three-shift system that was not the case at their previous site.'

> should be provided in the form that is the easiest to grasp. Workers have no time to read lengthy instructions and check manuals or printed material again and again. Moreover, if information is not easy to understand, they just ignore it and trust either their own experiences or their peers' advice – this latter is not necessarily better.'

In other companies, assembly tasks are supported by integrated digital sensor- or visual system-enabled error-proofing devices. These solutions prevent operators from assembling wrong parts or omitting assembly steps. Yet another assembly company uses a pick-to-light system, where blinking lights guide assemblers to pick the parts in the correct sequence.

In these cases, digital solutions had made some existing skills redundant. Increased efficiency was achieved by deskilling workers and converting them into 'robots' that are simple 'extensions of the production equipment'. Employees 'assisted' by these solutions do not need to learn the logic of the assembly process, develop tacit knowledge about the layout of the warehouse and/or learn the tricks that allow for effective and rapid assembly. Instead, they simply 'follow the lights'.

The converse of this process is that operators' technical literacy, e.g. the ability to use the tools and devices developed for advanced manufacturing applications and to become quickly familiar with the logic of the supporting applications, has eventually become paramount. The trade union representative interviewed explained in which sense the infusion of digital technology in the production process requires new skills:

> 'I wouldn't limit it [novelty in the nature of work] to operators working faster and more precisely than before. I would rather say they work in a much more information-intensive environment. Interfaces have become more complex, containing not only two or three buttons to press as in traditional machine control units.'

Regarding the impact of digital assistance solutions on routines, empirical evidence indicates that they often entail a scenario of 'increased routine'. Digital assistance solutions reduce the mental effort required to execute work tasks, improving operational excellence and enabling increased productivity. Operators perform tasks according to simple and precisely defined instructions and develop new routines to keep up with the increased pace of work.

5.3 Changes in the task spectrum and skill requirements of employees in production support functions

At operator level, the impact of advanced automation technologies and digital assistance solutions is mainly perceived in terms of work intensification and occasional multitasking, and not necessarily as a transformation of the required skill mix. This latter impact is, however, prevalent among relatively higher skilled operators and employees in production support functions. The following two interview excerpts, describing changes in the execution of quality inspection tasks, highlight the twin faces of change: digital assistance and the resulting reduction of mental effort and intensification of work on the one hand; and the 'intellectification of work' (Jarrahi 2019) on the other:

> 'Visual work instructions are used to assist quality checking. Since the pieces arriving on the conveyor are heterogeneous, every time the inspector has to check different parameters. The arriving pieces are equipped with a radio frequency identification tag (RFID) which is one of the key components of the dynamic visual work instruction system. Sensing the arrival and the specifics of the new work piece, the points to be checked by the inspector will be automatically displayed on a screen placed in front' (industrial strategy manager, automotive company).

> 'Operators have to perform a second check, which is indispensable in the case of safety critical products. Human workers would, however, be unable to handle all pieces with the same precision. Reassured by the "green light" decision of robots, quality checks are much easier. At the same time, they have to check the pieces that have been deemed defective. This latter is a more intellectual task, involving "problem solving", since they have to find out the primary reason for the defects. Is it because of a wrong set-up of the machine? Is it simply because the vision-based inspection system could not cope with changing light, for instance when sunshine disappeared because of sudden rainfall? Are the defects caused by inadequately placed pieces? Of course, operators are not required to identify the causes alone: we have line managers, technicians and quality inspection engineers to contribute to solving quality problems. However, working directly with the pieces in question, operators often have good ideas.'

Changes in line managers' task mixes exemplify how complex is the transformation of the task spectrum, even beyond the automation of some of their tasks such as reporting, filling time sheets and checking the status of production. The two interview excerpts below, obtained from interviewees representing automotive companies, provide an illustration of this:

> 'Before we established a real-time interconnection between the production lines and the warehouse, from time to time the line managers would go and check whether a sufficient amount of parts and components was available at the production lines. If they noticed that assemblers were bound to run out of components, they would mark this in their notebooks and make a phone call to signal the need to warehouse staff or walk to the warehouse with the list and ask the warehouse pickers to collect the necessary items and dispatch a delivery. This was one of the first tasks of line managers to get automated.'

> 'With digital work shift management and automatic shift handover reports, our line managers have been relieved of immensely time-consuming and boring administrative tasks. The duties they perform now correspond more to what one would imagine that a line manager does: they direct and coordinate the activities of operators; interpret job orders; explain procedures to workers; and resolve workers' problems and complaints.

> Line managers have thus genuinely become 'managers', engaged mainly in management tasks. Of course, as a result of these changes we do not need one line manager for ten operators: one line manager can supervise fifty operators. Superfluous line managers can be employed to train operators or they can be retrained to become quality technicians. The best new career path for them is related to 'quality' and 'process engineering', since now they have more time for higher-value tasks such as recommending measures to improve production methods and equipment performance. If a line manager is talented at streamlining production and has good ideas, this should be recognised and the opportunity for a new career path offered.'

Furthermore, line managers – the first persons to be alerted to production disturbances – could harness advanced digital solutions to enhance the effectiveness of how such disturbances can be addressed. For example, smart glasses containing built-in cameras to enable maintenance technicians and line managers to provide remote assistance to operators allow for virtual troubleshooting assistance or, at least, the diagnosis of problems to arrive much more quickly than previously. Other companies have introduced SmartLight towers and other plant-specific messaging applications (smartphone- or tablet-based applications or on-site computer terminals) to establish a digital interconnection enabling the exchange of information between operators and line managers or maintenance staff.

Elaborating on digitalisation-induced changes in employees' task spectrum, a process improvement leader of a machinery company highlighted how changes in the task mix lead to new skill requirements associated with a given occupation.

> 'Our materials planners work closely together with customer relationship management and collaborate with suppliers, production units, distribution and logistics. Their work spans departmental boundaries, they have to organise work starting from the processing of incoming orders and ending with delivery to customers. With the digitalisation of materials planning-related workflows, the skills required to perform their work have thoroughly changed. Previously, good communication, organisation and time management abilities were among the key requirements. Now, when order processing has become automated, and data about suppliers' deliveries, the status of production, outbound deliveries and payments are all available, performing work requires data analytics skills. Instead of communicating with colleagues in production management and inventory management, and collaborating with colleagues in procurement, logistics and customer relationship management, materials planners control databases, process, check inconsistencies in, and update data. This involves significant changes in the nature of their work and in the skills to be developed and applied. For example, they are expected to be familiar with new IT tools. As a matter of fact, some of our materials planners were unhappy with these changes. We tried to compensate them by involving talented people in the ongoing improvement of our processes, so as to increase the diversity of their work tasks.'

A similar transformation can be observed in the task mixes of production schedulers. Since their job tasks used to involve a substantial amount of communication, they required not only programming skills but good communications and organisation skills. Schedulers used to be always on the phone, requesting information about new orders and the status of production and inventories, while watching out for disturbances that required the adaptation of production schedules or the preparation of new ones. Real-time information about the status of orders, inventories and production has eliminated the need for such interactions. Moreover, sophisticated production scheduling algorithms enable production schedulers to generate new schedules with a few clicks. In contrast, schedulers have been involved in improving the flexibility and efficiency of scheduling algorithms through building simulation-based models.

5.4 Changes in the importance of experience and tacit knowledge

The accounts of the managers interviewed highlight a typical race-against-the-machine situation (Brynjolfsson and McAfee 2011) regarding the importance of experience and tacit knowledge. On the one hand, operators' ability to detect malfunctions and to notice, for example, unusual sounds or the excessive vibration of machines in operation is deemed indispensable. An industrial strategy manager of an automotive company commented:

> 'Irrespective of the prevalence of sensor-based, smart process control solutions, operators' experience is and will remain indispensable. For example, with advanced data collection and analysis, our production control system is really highly sophisticated. We measure more and more parameters, are able to predict a great number of malfunctions and apply preventive maintenance to eliminate them before they happen. We cannot measure everything, however! Consider the case of a car: you have sensors to measure oil pressure and the pressure in tyres; you have sensors for coolants, for fuel temperature; you monitor the rotating speed of the crankshaft; and so forth. However, since you cannot measure everything, there are still accidents because of technical reasons. The situation is the same here, although we try to measure as much as we can, operators' tacit knowledge is indispensable: they are the ones who would sometimes discover the first signs of malfunctions.'

However, given the time constraints and the other pressures that operators face during their daily duties, they would sometimes ignore (i.e. not act upon) the perceived informal signals of the machinery.[11] Being aware of the cognitive

11. Observers may recall Kahneman's (2011) theory about fast and slow information processing. In fast information processing mode (Kahneman's System 1), 'unnecessary information' is filtered out and decision-making is fast and intuitive. In contrast, information processing in System 2 mode is slower and more reflective. Choices are made more rationally, also considering the longer-term consequences. When operators are facing time pressures in executing the plan, fast information processing will determine their behaviour and prevent them from acting in accordance with the company's longer-term and general objective of overload faced by operators, companies continue to invest in digital solutions, trying to measure as many parameters as possible. Advanced IoT solutions would not only improve the quality of process control but also reduce reliance on tacit human knowledge regarding alerts in the case of production disturbances. As a business unit manager at an electronics company noted:

> 'We have a well-determined escalation policy, trying to make sure that incidents are resolved properly. An operator noticing an unusual sound should examine what happened and call the line manager if the problem cannot be immediately resolved. The line manager examines the issue and notifies the maintenance technicians if necessary. If maintenance technicians cannot resolve the problem either, they should ask the engineers for assistance. However, it turns out, from time to time, that operators just do not care and fail to alert line managers. So we decided to develop a sensor-based solution that measures and analyses the sounds of the machinery – not only within-equipment sounds but also on-site sounds, the sounds of the production line environment. Combined with a machine-learning solution, the system will be able to detect unusual sounds – in the same way as operators working there would, if they were paying attention – and sound automatic alerts.'

Although they were not developed specifically to achieve such an objective, certain digital assistance solutions reduce the value of tacit knowledge and experience in that they contribute to this becoming explicit and standardised. For example, dynamically changing visual work instructions assisting quality inspectors make their experiential knowledge matter less. Similarly, equipment maintenance databases[12] make it possible for novice maintenance workers or existing ones, who had not had to repair a given machine previously, to obtain immediate information about its past problems (previously recorded defects) and weak points (machine-specific functionalities that need to be double-checked when inspecting or repairing it). This reduces the value of maintenance workers' previously accumulated experience and routine.

A reduction in the value of experience has been 'formally quantified' in one automotive company, as illustrated by the telling comment of the plant manager:

> 'How is it, to work with a cobot? Well, you know, we classify our welders into four categories according to their capabilities and experience. Workers

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keeping production lines running smoothly. Digital solutions allowing for easy and immediate communication such as the aforementioned SmartLight towers and other plant-specific messaging applications are, in this respect, considered appropriate nudging techniques. A nudge is defined here as a small modification in operators' environment that influences their choices or behaviour (Weinmann *et al.* 2016). Simple and smart messaging solutions facilitate operators in taking the company's longer-term requirements into consideration by alerting maintenance staff if they notice something unusual.

12. Two companies in the sample have introduced a digital platform to assist troubleshooting and maintenance. These projects started with the systematic development of a database documenting all kinds of problems with the functioning of each component of the production equipment. Failures, defects and repair and maintenance actions have been registered. In this way, the platform can be used as a search engine since the database contains detailed information about the machinery and previous problems.

who have just left vocational school belong to category one, whereas highly skilled workers with more than twenty years of experience belong to category four. By using a cobot for welding, a category 1 welder can perform tasks that require higher skills and experience than what he has: tasks that were previously allowed to be performed only by category 2 or category 3 welders.'

5.5 High performance work practices

At the time of our research, selected components of high performance work practices (HPWP; e.g. Pil and MacDuffie 1996; Posthuma *et al.* 2013)[13] were prevalent across the surveyed companies. Elaborating on the design of work, the managers interviewed argued that digital technology implementation has reinforced ongoing developments that had started far earlier in the surveyed companies. These include advanced performance management and regular feedback,[14] the use of teamwork, the involvement of employees in continuous improvement and operator multiskilling. Operators were being increasingly rotated among workstations so as to make them capable of working under a flexible task assignment system. Old-new work practices, such as mapping skills and designing competency matrices, were revived and digitised. Experienced operators have been increasingly involved in training their peers.

The advanced functionalities of digital solutions facilitate the enhancement of some of these 'traditional' practices. In particular, advanced automation and digital technologies have contributed to operators' increased multitasking. Relieved of selected strenuous or repetitive work tasks, operators have instead been assigned a more diverse set of tasks such as quality control, basic maintenance and aspects of process control. In other instances, they have become responsible for supervising and working with an increased number of machines.

Operators participating in process improvement is an issue mentioned recurrently during the interviews. In practice this was, however, not necessarily related to digitalisation: being introduced much earlier, it was rather considered a traditional component of production systems in the sample companies.

One-third of the managers interviewed emphasised the importance of employee involvement with respect to digital technology implementation. These companies started small, usually with pilot projects, and have systematically requested employee feedback on the individual solutions before rolling them out to other production lines within the plant.

One component of HPWP that has apparently gained momentum with digitalisation is teamwork involving cross-functional collaboration. Formal teams including

13. The evolution of work practices in Hungarian manufacturing firms is discussed in comparative perspective in Makó 2005 and Makó *et al.* 2011.

14. Digital performance management solutions, for example dashboards providing real-time feedback on operator or team performance, have contributed to the upgrading of companies' existing performance management systems.

production engineers, robot programmers, maintenance workers, quality control staff, logistics employees and operators have been set up for problem solving and continuous improvement.

> 'Digital technologies helped us further improve the organisational setting we have been refining for a couple of years now. Ever since we redesigned our processes according to value stream principles, we have been improving and refining the new organisational structure. Instead of traditional production lines, we connected product-related core and support processes: production, intralogistics, quality, maintenance and so forth. We bundled the necessary competencies which means that, instead of a traditional functional hierarchy, we moved to a process-oriented set-up. Our value stream-based teams encompass not only production operators and their team leaders but also employees responsible for logistics, quality and maintenance related to the given product family. Furthermore, we have process engineers, IT experts and lean experts in these teams: these employees are all on the shopfloor, not in separate offices! Team members' connectedness – that is, their access to all relevant data in the electronic shift-book coupled with the real-time visualisation of key performance indicators – have enabled the smooth functioning of the new organisational set-up' (chief information officer, automotive plant).

Further, team-based organisational set-ups have led to a reshaping of traditional authority levels.

> 'Digitalisation was necessary but insufficient: it turned out that our traditional hierarchical structure with well delineated responsibilities was not appropriate anymore. We tried to leverage digital interconnection for a project-based configuration of teams. However, interconnection alone failed to induce a change in employees' mindset. Previously they used to execute the tasks assigned to them by a couple of colleagues at higher hierarchical levels in the same department. It was difficult for them to get accustomed to a practice in which requests can arrive from any colleague' (plant manager of an automotive firm).

Most of our informants in firms where cross-functional teamwork was relevant (half of the firms in the sample) reported that this type of flexible work organisation was not new and was not specifically related to digitalisation. The plant manager of the same automotive firm was, however, of a different opinion – more in line with the view of the author of this study:

> 'It is no coincidence that we have been progressively embracing cross-functional collaboration and setting up project-based teams. Both our production runs and the required delivery times are much shorter today than previously. Consequently, we have to reconfigure our production lines and launch new products much more frequently than previously. These are complex tasks that require the collaboration of multiple departments, going beyond the authority and expertise of our production engineering staff. When it comes to ramping up the production of new products, process

> engineers have to collaborate with quality control staff, logistics managers, IT and a variety of colleagues responsible for organising production resources. Digital technologies enable both a horizontal and a vertical interconnection of functions and activities, and are indispensable to information sharing.'

This reported case demonstrates that, while the relation between digitalisation and the adoption of HPWP is co-evolutionary rather than causal, technology affordances have certainly facilitated the progress towards HPWP of sample companies.

Taken together, apart from working out a new division of labour through redistributing work tasks between humans and machines, managers have also had to devise new forms of integrating work. They have experimented with operating models and organisational set-ups that have eventually become effective alternatives to hierarchical forms of organisation.

5.6 Increased value added

One of the most straightforward outcomes of digital technology implementation is an increase in the average value added per unit of work. A general reason underlying this phenomenon is that plants equipped with advanced manufacturing technologies require fewer, albeit more qualified employees.

> 'As a rule of thumb, newer generations of production lines require ten to fifteen per cent fewer employees. We leveraged employee churn to improve the average quality of the workforce. Since our processes are highly automated, our operators' tasks involve observing the equipment in operation and ensuring that pieces are manufactured without any disturbances. Easy as it may sound, this requires experienced operators with adequate training in procedures, best practice and troubleshooting. The most important task of the operators is incident management: they take actions in case of errors. In these cases, they may regain manual control of the system, which requires higher skills than what a simple blue collar operator would have. Accordingly, our operators cannot be labelled as real blue collar workers: they are 'specialists', often with tertiary educational attainment' (chief information officer, automotive company).

As for digital technology-enabled within-occupation increases in value added, two mechanisms acting in opposite directions have been observed: (i) task diversification, in terms of employees taking on additional (and often higher value) tasks; and (ii) specialisation in higher value activities. The account of the business unit manager of an electronics company illustrates the first development.

> 'Having progressively streamlined and digitalised maintenance-related activities, our maintenance team could take up tasks that were previously

> performed by the engineering department.[15] We progressively shifted to total productive maintenance, covering an ever-larger scope of maintenance areas, including the building of a database for maintenance. This latter is indispensable since we have about one thousand machines to maintain. Our team has undertaken even those activities that were previously outsourced to external services providers.'

Although task diversification, i.e. the taking up of additional, high value tasks, is the most conspicuous manifestation of a digitalisation-driven increase in value added, sometimes it is rather specialisation, i.e. a streamlined task spectrum, that has enhanced the value added of work tasks.

This development is furthermore illustrated by the experiences of maintenance workers who are reported to have increased the share of 'maintenance' within their activity mix. Non value added activities such as retrieving information from manuals previously accounted for a significant share of their working hours. Carrying out regular and often unnecessary checks and inspections of the tools and the machinery was an additional time-consuming exercise in which the value added was low. While sensor-based continuous monitoring and algorithms-based analysis of asset conditions have reduced the need for and the time requirement of this latter exercise, smart supportive solutions (maintenance databases and augmented reality solutions) have addressed the former type of 'waste'. Maintenance has thus become more efficient and generates higher value added than previously.

5.7 Conditions moderating digitalisation's outcomes for work

Interview findings confirm the consensus view among industrial sociology and labour economics scholars (Brynjolfsson and McElheran 2016; Hirsch-Kreinsen 2016; Krzywdzinski 2017) that the impact of digital technology deployment is non-deterministic. If digitalisation engendered the allocation of new tasks to related employees, these are, in some instances, indeed more diverse, more complex and/or higher value adding. In other contexts, new tasks are as similarly elementary and routine-intensive as previously. Positive outcomes, in terms of reduced routine and enriched work, are contingent on employees' skill level and on the direction and effectiveness of managerial interventions redesigning work, introducing advanced work practices and enacting some necessary organisational transformations.

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15. Note that this account illustrates Holm's (2018) argument that digital technologies blur the difference between blue collar and white collar responsibilities. Today's shopfloor teams, encompassing skilled production and maintenance workers, process engineers and other representatives of relatively high-level functions, have taken on many of the engineering duties formerly carried out only by white collar employees. This development also substantiates Szalavetz (2019b) who argues that digital manufacturing technologies transform the content and the nature of 'production capability' since this concept has come to include some capabilities classified previously as 'technological'.

As a definite commonality in these observed heterogeneous developments, we found that the higher the level of employees' initial skills, the more likely was a scenario involving a reduction in the routine intensity of their activities. For relatively low-skilled employees, the routine content of work activities did not diminish. On the contrary, routine increased in a number of instances in which digital technology implementation engendered deskilling.

Accordingly, we found that it is barely possible to establish an unambiguous relation between the types of digital technologies and their impact on work in terms of deskilling and increased routine, or skills augmentation and reduced routine. Visualisation solutions constitute a good example. The real-time visualisation of the status of production and of key performance indicators, such as overall equipment efficiency, 'informate' line managers (Zuboff 2018), who dedicate less working time to information search and may instead focus on higher value activities. In contrast, visual work instructions or pick-to-light visualisation solutions, assisting assembly workers, result in deskilling and increased routine. The visualisation embedded in augmented reality solutions, assisting maintenance workers, convey the erosion of the value of their tacit knowledge. However, once the more effective resulting task execution among maintenance workers had engendered the assignment of additional and relatively more skill-intensive tasks, i.e. led to an increase in their task spectrum, the same visual solutions bring about an augmentation of skills.

In relation to this, empirical evidence indicates that managerial interventions envisaging the augmentation of work and an increase in company-level (subsidiary-level) value added is a strong condition of positive outcomes.

It is managers' responsibility to 'direct the impact' of digital technology implementation through the reorganisation of work and to ensure that employees perform more varied, higher value and more interesting work tasks. The comments of a managing director of an automotive company provide an illustration of managers' cardinal role in ensuring an overall positive outcome of digitalisation.

> 'Every time we introduce a new digital solution, we can observe the same developments. Employees try to prove it is useless, or at least it functions only if the input of their tacit knowledge makes the system work. For example, we have digitalised controlling. Preparing regular business activity reports was automated. When realising that in real-time, standard analyses were available with a few clicks and controllers were particularly worried about their jobs. Previously it took two days for them to collect data, copy them into Excel files, rearrange them for analysis and finally copy them into another Excel file. Standard analyses are now done in seconds: real-time activity reports are available. Controllers' first reaction was to overrule the system and try to find deficiencies in its functioning. Shortly afterwards, however, new tasks have been assigned to them: now they participate in the analysis of price quotes and calculate returns. This task is more interesting and produces higher value added: consequently they have stopped trying to interfere with the automated processes.

> We had a similar story with employees in procurement: with the introduction of automatic workflows, their previous work tasks involving preparing and sending purchase orders to suppliers, checking whether inventory quantities were sufficient, preparing purchasing reports and comparing suppliers' invoices with purchase orders have been automated. First, they were very worried but they soon realised that the tasks that were newly assigned to them, involving negotiations about prices and the management of complaints about late deliveries and other, non-quality problems, are more interesting and challenging. Interactions with suppliers and problem solving requires much more creativity than working with standard documents and according to standard procedures. In my view, it's up to the management to find more interesting and higher value tasks for employees instead of the repetitive analyses that had become automated. Of course, changes in the work tasks of procurement clerks proved beneficial also for the company: we have eliminated low-value activities and introduced higher value ones instead … while salaries remained unchanged.'

6. Discussion and conclusions

This paper has investigated the impact of digital technologies on the nature and routine intensity of shopfloor work, the ways in which digital technologies exert their effects and the conditions which moderate digitalisation's outcomes for work.

Drawing on qualitative data, we found that, in a within-occupation context, digitalisation does not necessarily involve routine-replacing change. Observational and interview data provided ample evidence for the scenarios involving no change in routine or, definitely, increases in routine. A common feature of the surveyed context-specific changes in the nature of work was that employees develop new routines aligned with the specifics and the requirements of the digitally enhanced work environment.

In other instances, instead of changes in the degree of routine, we rather found a transformation of routine, specifically in cases when advanced automation solutions reduce the amount of manual labour input on the shopfloor. Instead of performing direct production activities, production operators embark on monitoring the control panels of the equipment and adjusting the machinery if necessary. Although these tasks require more routine cognitive labour input than previously, the routineness of work has not necessarily changed.

Obviously, we also came across cases characterised by a digital technology-induced reduction in the routine content of work. The reduction of routine was driven by multitasking or was manifest in a reduced share of routine tasks within the overall task bundle.

We found that a digital technology-induced reduction in the routine content of work applies only to relatively skilled employees, albeit not exclusively in high-level shopfloor functions.

One of the most conspicuous ways in which digital technologies exert their effect on the nature and routineness of work is by enabling a precise measurement of a number of work parameters. Our empirical data highlight a strong association between digital technology deployment and the measurement, codification and standardisation of work tasks. Measurement allows for the optimisation of both the individual tasks and the work processes. As set out in Figure 1, optimisation is followed by standardisation and results in the intensification of shopfloor work which, in turn, requires new routines to cope with the increased pace of work.

The second essential mechanism conveys technology-induced changes in the composition and amount of skills required for task execution. The direction of change is, however, far from straightforward as is demonstrated by examples of digital technologies contributing to the deskilling of manual workers and/or reducing the importance of experience and tacit knowledge in several functions.

According to the third mechanism, digital technology implementation impinges on occupational features such as the importance of peer-to-peer communication or abstract reasoning for task execution as well as the variability, diversity and complexity of work tasks.

A conspicuous commonality of digitalisation-driven changes in occupational features is their context-specificity or, otherwise, the lack of commonalities. As we pointed out briefly in section 5.7, it was rarely possible to establish a causal relation between a particular digital technology implemented and its ultimate outcomes in terms of changes in the nature and routineness of work. Causal power can rather be ascribed to managerial intentionality and, to some extent, to the initial conditions: skill structures and organisational structure. This highlights the importance of moderating factors and confirms the non-deterministic impact of technology on work.

This heterogeneity of developments in the nature and routine intensity of work tasks in various shopfloor functions suggests two non-trivial conclusions.

Firstly, we conclude that, all else being equal, digital technology implementation simplifies work and increases routine on the shopfloor. Without intentional managerial interventions envisaging the augmentation of skills required for work, the automation and deskilling effects of digital technologies will prevail over augmentation. Augmentation requires that employees' work tasks be reorganised, work design and work practices modified and employees upskilled. Positive developments are thus contingent on conscious organisational and human resources management. Without these managerial interventions, digital technology implementation will – in line with Braverman (1974) – contribute to deskilling and/or technological unemployment rather than provide richer dimensions to shopfloor work.

The good news in this respect is that market forces are progressing in this direction, too. It is in the interest of companies to redesign workflows and work practices to ensure a (higher) return on investment in digital technologies.

The second conclusion is that the widely-hailed beneficial effects of digital technologies on the nature of work become apparent only if employees are sufficiently competent to be upskilled and become engaged not only in digitally-assisted but also in digitally-augmented, high value activities.

These results confirm our conjecture about the paramount importance of the level and composition of employees' skills at the time of digitalisation projects. Digitalisation can, indeed, foster a better utilisation of human skills. However, since upskilling is a slow and gradual process and skills gaps should not jeopardise ongoing operations, digital solutions are usually more or less tailored to users' skills. Consider a commonly used metaphor to illustrate the difficulties of updating the production system amidst ongoing production: it is said that this task is like changing tyres while the car is moving. The same applies to addressing gaps with respect to 'future of work' competencies.

Our findings have an important implication that goes beyond the common policy recommendation about the imperative of addressing skills gaps. An equally important, albeit even more difficult to implement, implication is the requirement to raise local managers' awareness of their roles and responsibilities in configuring socially sustainable work designs. Managers should act consciously when reorganising the task bundles of employees to turn digitalisation into collective benefit. As is well known at least since Zuboff (1988), technology can both enable and enslave workers. Digital technologies can be used as a means of controlling, instigating and disciplining 'imperfect humans' – if not completely removing them from the production process. Positive outcomes require 'catalysts for progress' in the form of managerial vision and a conscious approach to technology.

Although the findings of this study contribute to a more fine-grained understanding of the ways in which the impact of digital technologies unfolds on the nature and routine intensity of work, the study is not without limitations. On one hand, the usual limitations apply in terms of a small number of interviews, industries and shopfloor functions. Another concern is the bias of the sample towards the managerial view: frontline workers and trade unions are underrepresented. At the same time, an important limitation is the bias introduced by the specifics of the research context. The explored Hungarian setting exhibits a number of similarities to foreign-owned manufacturing companies in other factory economies but, in terms of activity specialisation within global value chains, as well as digital maturity and the impact of technology deployment on the nature of work, these similarities might conceal important differences across a number of dimensions. Examples include the lower than average performance of the Hungarian vocational education system in terms of keeping up with the requirements posed by technological progress in manufacturing; low and declining investments in education and training (Fazekas 2020); the lower than average prevalence of lifelong learning; and race-to-the-bottom labour market regulations (Artner 2020; Köllő 2019). These Hungarian specifics influence both the motivations and the outcomes of firms' investments in digital technologies.

Two other factors need to be acknowledged here. First, the study captures a snapshot view of the impact of digital technologies on the nature and routine intensity of shopfloor work while developments in this field are dynamically changing. This calls for longitudinal research and an extension of the scope of the issues investigated. Second, the complexity and multifaceted character of the topic calls for further research to gain further evidence regarding the effects across distinct types of technologies and adoption contexts.

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All links were checked on 29 January 2021.

Appendix A
Basic data of companies in the sample[16]

No.	Employment	Turnover (€ million)	Share of exports (%)	Industry	Interviewees
1	358	18.2	11.0	automotive	managing director
2	13,096	8,561.1	99.5	automotive	digital officer; operator
3	976	489.8	100.0	electronics	manager responsible for corporate planning and IT
4	808	59.3	99.8	automotive	plant manager
5	1,058	125.0	99.6	machinery	managing director
6	1,016	580.1	98.9	automotive	chief information officer
7	1,890	781.4	80.0	automotive	head of industrial engineering; operator
8	581	89.4	92.4	machinery	managing director of operations; operator
9	890	92.1	92.1	electronics	business unit manager
10	1,121	171.8	98.7	machinery	process improvement leader
11	1,612	532.2	64.3	electronics	trade union representative
12	832	106.0	99.0	automotive	industrial strategy manager
13	614	73.1	84.9	machinery	director of operations
14	2,807	716.3	76.1	machinery	manufacturing engineering manager

16. 2019 or the latest year available.

Appendix B
Interview template

Introduction – A company-specific or interviewee-specific question, developed on the basis of business press articles and other information sources that sets the context.

Examples: 1) I read in X about recent investment in XX. Can you tell me what this new solution changed in your company? 2) I read you recently introduced collaborative robots. How is it to work with them? What was the experience of the operators? 3) You are the process improvement leader/digital officer at X. Please tell me some words about this kind of occupation. What kind of tasks does it comprise in your case?

Investments in digital solutions on the shopfloor – Details are asked about automation solutions, worker augmenting technologies, solutions for employees in support functions (e.g. dashboards, remote assistance solutions, smart process control solutions, MES).

Impact of digital solutions – in terms of workload, work intensity, performance demand, task spectrum (multitasking versus specialisation), new tasks requiring new skills, changes in the value added of work.

Novelties in the nature of work – evolving responsibility? autonomy? importance of experience, tacit knowledge, incidence of digital control, incidence and examples of problem solving and less clearly defined tasks. (Are these novelties related to digital technology implementation?)

New work practices – incidence of and details about process standardisation, simplification of work, teamwork, job rotation and employee involvement e.g. in continuous improvement. (Are these novelties related to digital technology implementation?)

Summary questions – In summary, has digitalisation brought about the qualitative improvement of work? If yes, in which respects? Are there any differences among employees with respect to the impact of digitalisation? Were any complementary investments (accompanying digital technology implementation) necessary to capture the expected benefits?

In interviews with operators: Altogether, was digital technology implementation beneficial for you? Did the new technologies improve your working conditions?

Appendix C
Summary of the results

No.	Investments in digital technologies mentioned during the interviews*	Summary of changes regarding the research variables*
1	Industrial automation (fully electric injection moulding machines); industrial robots for handling and packaging; digital quality control solution	Increased productivity; increased automation ratio; increased process standardisation; no changes in skill requirements
2	Industrial robots and collaborative robots; rapidly progressing automation and digitalisation of all business processes; RPA solutions; smart cameras for digital quality control; digital process control solutions; worker augmenting technologies (VR, tablets, maintenance database); digital error-proof solutions; smart visualisation; introduction of AI-powered solutions	High performance work practices; multiskilling of operators and multitasking; increased use of teamwork (teams comprise employees from heterogeneous occupations working together on the shopfloor); involvement of employees in continuous improvement; increased work intensity; increased task complexity in some occupations (e.g. maintenance); higher value added of work
3	MES; digital quality control solution; fenced robots; RPA solutions; digital error-proof solutions	Increased automation ratio; increased share of working time dedicated to monitoring the machinery; new tasks for IT staff requiring higher skills; no changes in skill requirements for production operators; productivity improvement
4	Development of CPS; industrial automation; smart visualisation solutions; development of data-driven maintenance; MES; RPA of controlling, administration tasks and reporting; introduction of a digital procurement solution; AI-powered business intelligence solutions for management Planned: automation of in-plant deliveries;	Increased complexity of production processes; increased importance of technical skills (interpreting information); smart machines require increased attention and precision from operators; increased standardisation of work; personalised employee feedback; operators increasingly shift to monitoring the machinery (at the expense of physical actions); increased responsibility for technicians; reorganisation of shopfloor support functions into teamwork
5	Connection of workstations and maintenance/engineering staff through webcameras and other messaging solutions; collaborative robots; tool data management solution; document management solution; real-time OEE calculation through IoT solutions; RPA for various business functions; product data management solution; connection of various shopfloor IT solutions; 3D scanner for quality control; digital twin for new product development; pilot use case: smart glasses	Increased diversity of work, requiring higher creativity for relatively higher-skilled employees in production support functions; smart solutions automate a number of work tasks which requires employee retraining and upskilling; working with numerous new digital solutions requires continuous learning; delegation of relatively advanced tasks to lower-level functions; increased skill requirements at all levels, especially regarding IT-related technical skills; collaborative robots assist relatively low-skilled welders
6	Industrial automation; special-purpose machinery; smart error-proof and other worker assistance solutions; smart visualisation; digitalisation of shopfloor processes (quality control, process control, reporting); automation of in-plant logistics; connection of MES and ERP; corporate chatbot (for HRM issues); interconnection of international production databases	The average skill level of frontline workers increased; increased share of working time dedicated to monitoring the machinery but, at the same time, multitasking and increased task complexity; high performance work practices, e.g. increased use of teamwork; value stream-specific organisation of teams; higher value added work
7	Advanced digitalisation of the shopfloor (CPS); rapidly progressing digitalisation of production support and other business functions (real-time interconnection of functions); industrial robots and collaborative robots; improvement of IT infrastructure; continuous development of MES; AGVs and automation of plant logistics; extensive business intelligence solutions; 3D printers; RPA (e.g. of administration); digital twins to simulate production environment; augmented reality pilot use cases: smart glasses; digitalisation of employee training.	Increased worker responsibility and autonomy at all levels; multitasking; teamwork; involvement of employees in continuous improvement and support for bottom-up digitalisation initiatives; training and upskilling to meet increased skill requirements (e.g. related to abstract reasoning); more emphasis on creativity; bottom-up initiatives (albeit not at the level of frontline workers)
8	Industrial special-purpose machinery; welding robots; robots for material handling; worker assistance solutions; smart solutions for product testing	Increased efficiency and productivity; agile redeployment of workers; substitution of robots for skilled welders; delegation of some relatively advanced tasks to lower-level functions (e.g. basic programming of robots); new, more creative tasks for engineers

No.	Investments in digital technologies mentioned during the interviews*	Summary of changes regarding the research variables*
9	Industrial automation; digitalisation of the factory floor (CPS); analysis of production data; MES deployment; industrial and collaborative robots; worker assistance solutions; SmartLight tower; maintenance database; digital twins for training new employees	Comprehensive reorganisation of work practices according to the principles of lean manufacturing; increased process standardisation; multi-skilling of operators and multitasking; higher workload and work complexity; improvement of efficiency and productivity; introduction of new tasks for employees in a number of production support functions; higher value added work.
10	Digitalisation of material planning; creation of a customer service eStore solution; digital connection of processes related to material planning such as procurement, order management and accounting, controlling, logistics, administration and CRM; investment in new data analytics and business intelligence solutions	Reorganisation of processes related to material planning, involving process standardisation and a thorough transformation of the content of work and related skills; introduction of new tasks but reduced task diversity; increased abstract reasoning (data analysis); reduced communication and interaction; increased speed and efficiency of task execution; reduced error ratio; new teams, new jobs related to the same function; employee retraining; upskilling.
11	Algorithmic control (for line balancing); dynamic work instructions (IoT-based); smart visualisation; industrial robots; pick-to-light solutions; remote assistance solutions (assisting shopfloor processes); real-time location system; real-time OEE calculation through IoT solutions	More personalised work allocation; better work organisation (process optimisation); reduced error ratio; increased work efficiency; easier task execution for technicians
12	Industrial robots and collaborative robots; extension of big data collection and analytics to new processes; digital AI-powered assistance for quality control; digitalisation of quality control and maintenance functions; automation of inbound logistics (AGVs) for in-plant deliveries; smart glasses assisting warehouse workers; smart traceability solutions	Increased use of teamwork for shopfloor support functions; creation of new teams e.g. for continuous improvement; increased speed of spare parts deliveries from the warehouse; increased accountability of production workers; increased value added work at all levels
13	Industrial robots; IoT: data collection and real-time OEE calculation; big data and data analytics for data-driven decision-making in shopfloor processes, e.g. process optimisation, root cause analysis, smart visualisation of production status	Multiskilling of operators; multitasking (prompted by the increased share of machine observation within total working time); operators are increasingly rotated between workstations; process standardisation; more explicit and user-friendly work instructions; sharply reduced instances of strenuous work; upskilling for technicians and maintenance workers in response to increased skill requirements
14	Industrial automation; industrial robots; traceability solutions; IoT solutions; big data for OEE; digital quality monitoring; digital process control; smart worker assistance solutions (visualisation of assembly tasks and of production status); smartphones for employees in shopfloor support functions used for job-specific information provision	Standardisation of work; work instructions are more detailed and explicit; training and upskilling of IT staff; overall continuous development of technical competences in relatively higher-level functions; optimisation of shopfloor work (higher work intensity); organisational development to establish a more intensive collaboration between IT and engineering staff

Notes: AGV = automated guided vehicles; AI = artificial intelligence; CPS = cyber-physical production system; CRM = customer relationship management; HRM = human resources management; IoT = Internet of Things; IT = information technology; MES = manufacturing execution system; OEE = overall equipment effectiveness; RPA = robotic process automation; VR = virtual reality.

* = May not be exhaustive

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D/2021/10.574/08
ISSN: 1994-4446 (print version)
ISSN: 1994-4454 (electronic version)

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