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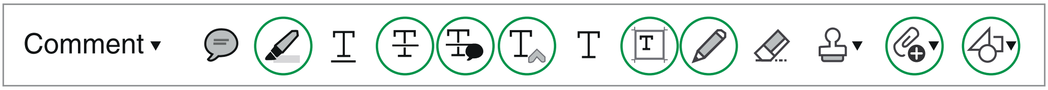

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Competition & Change

Competition & Change
2022, Vol. 0(0) 1–25

DOI: 10.1177/10245294221107489
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Digital technologies shaping the nature and routine intensity of shopfloor work

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Abstract
Drawing on data from Hungarian manufacturing companies, this paper aims to explore the ways in which digital technologies affect the nature and routineness of work. It concludes that digital technologies impinge on some defining features of occupations, such as workload and intensity of work; the degree to which the tasks can be explicitly defined, measured and codified; composition and amount of skills required for task execution; and the importance of experience or tacit knowledge for task execution. Non-technological factors, such as managerial approach to technology and work design moderate outcomes. Evidence indicates that a reduction in the routine content of job tasks applies only to relatively skilled employees. For low-skilled employees, certain digital assistance solutions increase routine and engender deskilling. We conclude that a qualitative enrichment of shopfloor work becomes apparent only if (1) employees are skilled enough to become upskilled – and thus engaged not only in digitally enabled but also in digitally augmented, high-value activities; (2) employees' work tasks are reorganised, work design and work practices modified, and employees upskilled. Without appropriate managerial interventions envisaging the augmentation of work, digital technology implementation entails deskilling and/or technological unemployment, rather than providing richer dimensions to shopfloor work.

Keywords
digitalisation, routine-intensity, nature of work, deskilling, work practices, hungary

Introduction

Emerging digital technologies portend further contraction in the share of routine tasks and changes in the kinds of skills jobs require. Several scholars assume that occupational transitions will bring about substantial improvement in the nature of work (Autor and Dorn, 2013;

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Brynjolffson and McAfee, 2014; Handel, 2020). For example, in manufacturing units, 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, 2016). Since tasks involving problem solving require greater autonomy and decision authority than tasks performed according to work instructions, digital technologies will entail 'employee empowerment' (Kaasinen et al., 2019; Leyer et al., 2019; Martišková, 2020).

Altogether, there are many scholars who expect that digital technologies convey new work practices, engender changed forms of control, allow for more self-determined work activities, and involve higher value and more diversified tasks than previously.

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 (Delfanti and Frey, 2020; Pfeiffer, 2017).

Moreover, in line with the 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 leads to deskilling. Production work (and work in production support functions) becomes increasingly standardised and engenders a further routinisation of tasks (Dörrenbächer et al., 2018). 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). Moreover, 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; Kopp et al., 2019).

Whilst most of the papers predicting any of the aforementioned developments focus on the experiences of advanced economies, there might be non-negligible differences across countries of different development levels and factor endowments in the nature of work and the routine task content of jobs having the same occupational title (Hardy et al., 2018; Krzywdzinski, 2017). 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.

These latter insightful studies notwithstanding, there is a dearth of studies exploring digital technologies-induced changes the nature of work in 'factory economies' specialised in labour-intensive activities.[1] Additionally, although it is safe to acknowledge the existence of a strong relation between digitalisation[2] and changes in the nature and routine intensity of work, little is known about the mechanisms involved in this relation. Analyses of digitalisation-induced changes in the routine intensity of work are concerned mainly with the direction of change, 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 the routine intensity of work unfolds, remains unexplored: this process is regarded a black box.

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

Q1 How does the nature and the routine intensity of shopfloor work change as a result of digital technology implementation?
Q2 How do digital technologies exert their effect 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 adopting digital technologies.[3] These industries are dominated by foreign-controlled, export-oriented manufacturing units (see e.g. Pavlínek, 2017 for the automotive and Sass, 2015 for the electronics industries). Whilst on one hand, this indicates a dependent market economy status, that is the exposure of Hungary's economic performance to efficiency-seeking FDI in manufacturing (Farkas, 2011), on the other hand, local subsidiaries can harness their global owners' investments in digitalising their local manufacturing facilities.

Hungary is an interesting example also in terms of the low performance of local vocational institutions and weakness of employee representation bodies. The low and declining investments in education and training (Neumann and Mészáros, 2019), coupled with race-to-the-bottom type labour market regulations (Artner, 2020; Köllő, 2019) and increasingly pressing labour shortages affect global companies' local labour-use strategies. These institutional factors influence the motivations and shape the outcomes of firms' investments in digital technologies (Krzywdzinski, 2017). Taken together, 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. Firstly, in contrast to the quantitative approach characterising the majority of analyses discussing routine-biased technical change, we apply qualitative techniques. We explore 'the subtleties of human experience' (Zuboff, 1988: p. xi) regarding the impact of digital technologies on the nature of work by drawing on interview-based investigation (Eisenhardt and Graebner, 2007). Secondly, by capturing the perspectives of middle and lower-level managers and some operators, this paper is intended to open the black box regarding the impact of digital technologies on the nature and the routine intensity of shopfloor work. We study within-occupation change both in terms of automation and augmentation. Extant 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). Our focus is uniquely on the shopfloor: we provide evidence for the multifaceted nature of digitalisation-induced changes and show that both automation and augmentation are present.

The study proceeds as follows. We begin with a brief review of the related interdisciplinary literature including approaches by labour economists, scientists specialised in operations research AQ1 and technology assessment, and industrial sociologists (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.

Related work

Labour economists on the impact of digitalisation

Investigating the impact of digital technologies on the routine intensity of shopfloor work, our research is closely related to labour economics studies analysing the expected net impact of these technologies on employment (Acemoglu and Restrepo, 2018; Brynjolffson and McAfee, 2014; Frey and Osborne, 2017).

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 – that is for repetitive and well-codified tasks – decreases, whereas demand for non-routine tasks increases because of ICT-related technologies (Arntz et al., 2016; Autor et al., 2003). Accordingly, technological progress induces changes in countries' occupational structure: it creates and destroys jobs and drives employment reallocation both across and within firms (Acemoglu and Restrepo, 2019; Autor and Dorn, 2013).

Coined as routine-biased technological change (Autor et al., 2003), these developments kept intensifying with progress in digital technologies (Brynjolffson and McAfee, 2014; Frey and Osborne, 2017; Manyika et al., 2017). Digital technologies have been evolving and progressively carrying out tasks that previously were considered professional and tacit knowledge-intensive.

This raised the question how job content is restructured once part of the tasks that constitute a given occupation is automated. Accordingly, scholarly interest has increasingly shifted to the within-component of the structural change in employment (Acemoglu and Restrepo, 2019; Bisello et al., 2019; Nedelkoska and Quintini, 2018). Atalay et al. (2020) analysed the texts of job advertisements over a period of six decades (1940–2000) to identify changes in tasks, technologies and skill requirements. They show that most of the individual occupations have undergone substantial change, specifically, the share of non-routine analytic and non-routine interactive tasks increased at the expense of routine ones. Similarly, Nedelkoska and Quintini (2018) found that in the 2010s, jobs across countries have become more intensive in less automatable tasks – both within and between occupations.

These observations and findings were questioned by Eurofound's recent survey of European working conditions. Based on survey evidence, Bisello et al. (2019) report a marked increase in the degree of repetitiveness and standardisation of work tasks, across EU15 countries, between

1995 and 2015. Since these variables measure routine intensity, the cited authors concluded that within-occupation developments (increased repetitiveness and standardisation) have more than offset compositional developments in overall employment. This is in accordance with the widely documented fact (Dörrenbächer et al., 2018; Goos et al., 2019) that digital technologies require the standardisation of work procedures.

In summary, apart from transforming the composition of employment, digital technologies have a meaningful impact on the bundles of tasks associated with individual occupations and the skills required to perform specific work tasks. However, neither the magnitude nor the direction of change in the routine content of work tasks is straightforward in the literature.

Operations research and industrial sociology on the impact of digitalisation on shopfloor work

Apart from labour economics scholars, the impact of technology on work practices and the nature of work has received ample attention in industrial sociology studies. A classical study is Zuboff's (1988) '*Smart Machine*'. Her theory, centred around the distinction between technology 'automating' or 'informating' work, is still relevant today, 30 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. By contrast, information technology can also be used to enrich work and give rise to 'better jobs'. Smart systems enable workers to gain a more informed perspective of their own activities. 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, conduct their analyses along the same lines, and conclude that digital technologies augment or deskill their users at the workplace. 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 operations research and technology assessment studies focus on the ways digital technologies support production workers. Digitalisation gave birth to a new concept called 'operator 4.0' (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, for example through smart visualisation. Assembly workers are supported by augmented reality solutions that project contextualised information to operators' visual field, that is to the point in space where 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.

Employees in production support functions are also 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 by the right time. 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.

Whilst operations research is concerned with describing the augmentation effect of technology, a well-known strand of industrial sociology literature elaborates on the nature of digitalised work in the context of agility and precarity (Moore, 2019). In this context, 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' (p. 140). Work intensification is the outcome of 'digitally reinvigorated lean', since digital technologies both require and allow for enhancing lean practices, optimising and standardising work (Buer et al., 2018; Dörrenbächer et al., 2018).

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. Digital assistance systems have a deskilling effect and convey a loss of know-how. Furthermore, routine cognitive work involving a passive monitoring of robots that perform the work tasks causes boredom and has a negative impact on 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 the *qualitative role* of assembly operators has even increased with automation. These workers do not passively monitor machines but are expected to intervene to prevent technical incidents and/or address unexpected malfunctions. In line with this latter assessment, Holm (2018) conjectures that operators' tasks will be less repetitive and more diverse as a result of digital technology implementation. They 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, whilst this review confirms the relevance of the twin role of technologies in transforming work (Zuboff, 1988), 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, corporate strategy, and industrial relations, that is, non-technological factors shaping the impact of digital technologies on work (Hirsch-Kreinsen, 2016; Krzywdzinski 2017). Several contributions in this stream stress the importance human-centric work design – associated with a good use of employees' skills and operators' autonomy/responsibility to control automated systems and intervene in emergent complex situations (Fantini et al., 2020; Pinzone et al., 2020). Since evidence (surveyed by Parker and Grote, 2020) has been accumulating to suggest that a human-centric work design is likely to entail better organisational performance than a pure technocentric approach, managers' proactive efforts to put human-in-the-loop principles into practice are of cardinal importance (Waschull et al., 2020). A quote by Zysman and Kenney (2017, p. 331) is illuminating in this respect: [The specifics of technology] 'Deployment will depend on whether firms […] view workers *as assets to be augmented* or simple costs'. (Italics added)

However, as demonstrated persuasively in Krzywdzinski (2017) managerial liberty in shaping various dimensions of work is constrained by multiple factors, such as the availability of adequately skilled workforce, owners' strategies, the power of trade unions and labour market regulations.

The relation between digital technologies on the shop floor and the routine intensity of employees' work

From a shopfloor perspective, the routine intensity of work at manufacturing facilities has been shaped by multiple developments working in opposite directions. On 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). Digital technologies and advanced manufacturing solutions embedded in firms' production systems are paramount for meeting these requirements. At the same time, they transform the mix of manual and/or cognitive activities within individual occupations and exert a significant impact on task-related skill requirements. In a nutshell, the increased complexity of operations and diversity of work tasks in all shopfloor functions may increase the diversity of the required skills and *reduce the routine content of work*.

On the other hand, an array of smart user assistance solutions is 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 work tasks, and … *increase the routineness* of activities. Developing new routines is often indispensable since 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 with or without a 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. Technologically enhanced employees may develop new routines, aligned with the specifics and the requirements of the newly deployed digital solutions. The overall outcome of change might differ even within individual occupational categories.

We propose, therefore, four basic scenarios of 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 (i) the intensity of work; (ii) the degree to which the tasks can be explicitly defined, measured and codified; (iii) the composition and amount of skills required for task execution; (iv) the importance of experience and tacit knowledge for task execution and (v) other features, such as task complexity and importance of independent decision-making and interactions with peers for task execution.

Besides the direct and indirect effects of technology, these features of work are significantly influenced also by managerial practices, in terms of choice of technology, skill use strategy and work design (Parker and Grote, 2020; Waschull et al., 2020). Managers may reorganise work by grouping the remaining, non-automated work tasks into jobs in a way that jobs become more diverse and engaging. Positive outcomes are particularly strong if managers allocate as much decision-making authority to lower-level functions as possible. In contrast, managers may favour task simplification, standardisation and even substitution wherever possible. Advanced digital technologies may be used for supervisory control over the production and support processes. Managers' choices are influenced by task-specific features of work and other factors, such as corporate culture and competitive strategy (Hirsch-Kreinsen, 2016; Krzywdzinski, 2017). Additionally, these choices are enabled – albeit often rather constrained – by the level and composition of current employees' skills. Consequently, the overall outcome of change might differ even within individual occupational categories.

These arguments are used as guidelines for our empirical research of digitalisation-induced changes in the nature and routineness of shopfloor work. We limited our scrutiny to the first four variables and touched upon the issues listed in (v) only superficially (cf. Appendix B). Since the surveyed literature makes it clear that technology itself does not determine outcomes, we also explored the moderating role of managers by way of scrutinising technology-induced new work practices.

Method

Research design and data

To investigate the specifics of digital technologies-triggered changes in the nature and the 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 shopfloor of manufacturing companies and informed observers (Westney and Van Maanen, 2011). Data have been collected on the 'everyday realities' of work life: on 'the subtleties of human experience' (Zuboff, 1988: p. xi) regarding the impact of digital technologies on the nature of 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 observations 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 various features of work. The research variables we employed to guide our interviews (Table 1) are 'suggestive', evoking the phenomenon investigated in this study only indirectly (Burgelman, 2011).

To set the context, we started our interviews with inquiries about the particularities of the digital technologies recently deployed at the given companies. Next, we asked some related, open, 'how is it to work with'-type questions, tailored to the solutions mentioned by the firms. The subsequent group of questions addressed the resulting changes in the features of work and working conditions: workload, codifiablity (measurement and standardisation), changes in skill requirements and the role of tacit knowledge and experience. Another bundle of questions addressed changes in work practices.

As summary questions, utilised to provide opportunity for the 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

Table 1. Research variables.

Topic	Keywords mentioned during the interviews
Work intensity	Changes in work intensity, speed of work and idle time
Standardisation	Measurement and standardisation of work tasks and procedures, explicit work instructions
Skill requirements	New skills required and skills becoming redundant
Experience and tacit knowledge	Changes in the importance of experience and tacit knowledge
Work practices	Use of teamwork, multiskilling of operators, multitasking, job rotation, personal feedback, involvement of employees in continuous improvement

investment(s) accompanying digital technology implementation that were deemed necessary to capture the expected benefits, for example 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-triggered 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 researchers engaged in digital solutions provision for business companies. Additionally, we conducted an interview with a representative of a recruitment and temporary personnel agency, who proved to be a source of valuable information about recent changes in manufacturing companies' demand for skills.

The experts interviewed pointed out that industrial robots are concentrated in specific industries.[4] They also stressed that besides industry, firm size and foreign ownership are important determinants of digital technology adoption.

Accordingly, we decided to focus on three industries instead of adopting a maximum variation sampling approach. Our sample consists of six automotive, two electronics and five machinery companies. Sample firms are large, export-oriented, and with the exception of two companies, foreign-owned.[5] The basic data of the companies in the sample are summarised in Table A in the Appendix.

When selecting the companies, we have followed the principle of purposeful sampling, and chose companies representing illuminative cases from the point of view of implementing digital manufacturing technologies (Patton, 2002). Accordingly, the companies in the sample have been recommended by the experts and/or have been selected on the basis of the author's previous experience, gained in the course of earlier investigations.

Apart from conducting interviews with executives in the C-suite (managing directors, plant managers), we gained access to managers directly involved in the digitalisation of the shopfloor (responsible for operations, process improvement, IT and digitalisation). Managing directors provided a broad overview of how the nature of work was changing at their companies, assessed the potential of digital technologies to drive performance in different arenas, and evaluated the necessary organisational complementarities supporting the introduction of digital technologies. Since they were the ones deciding about investments in smart worker assistance solutions, they were remarkable knowledgeable also about shopfloor-level developments and problems. The lower-level managers interviewed provided rich descriptive insights about changes in the nature of work for frontline workers, the ways they transformed job designs, and the particularities of human-machine interaction.

In order to capture diverse perspectives and reduce the single-respondent bias (Eisenhardt and Graebner, 2007), we conducted interviews with three shopfloor operators and interviewed a representative of the Metalworkers' Federation representing several companies in the automotive and electronics sectors. The accounts of shopfloor workers were centred around the intensification of work, and social problems on the shopfloor, such as line managers' authoritarian behaviour and unequal treatment of certain colleagues.

Interviews with operators, workplace observations and the analysis of videos have to some extent challenged the overall picture obtained from the interviews with managers. Whilst 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, operators' accounts, videos and workplace observations 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 considered also these perspectives, we attempted to control for the social desirability bias (Stockemer, 2019) and increase the trustworthiness of our conclusions.

Altogether, the data used in this study consist of 20 interviews (13 managers, three operators, a trade union representative and three expert interviews), conducted in the first half of 2020. Interviews lasted 60 to 90 minutes. 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 corporate videos.

Data analysis

For data analysis, we applied the interpretivist methods of analysis, the point of departure of which is the paramount importance of context (Stake, 1995; Welch et al., 2011). Although an ethnographic method, involving observations to reveal actual practices, would have been better suited for studying the nature of work, after the first three interviews the COVID-19 pandemic prevented us from visiting the other firms and taking factory tours to observe work practices. Accordingly, we carried on our research interviews by conducting interviews by phone or other remote communication platforms and relied on corporate videos to obtain an insight about the nature of work at the given companies. This data collection method allowed for an interpretivist approach involving a detailed representation of informants' perceptions and experience.

Our data analysis has also employed certain constituents of grounded theorising (Glaser and Strauss, 1967) since we applied the methods of constant comparison. The comparison of the narratives helped us detect a number of inconsistencies in outcomes, which called for caution in establishing causality. This made us decide for applying process analysis (Hall, 2006), starting from observations, comparing them, and identifying the context-specific mechanisms behind them.

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.

Results

Our initial interview questions were aimed at collecting data about the specifics of 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. Examples of technology-related changes in the research variables are summarised in Appendix B.

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

The first observation crystallised from the interviews is that, compared to our previous investigations (Szalavetz, 2019a, 2020b), robots, relieving humans from tasks involving pure physical strength, have become more prevalent. Notwithstanding, 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.

Accordingly, investments in digital technologies were both preceded and accompanied by projects addressing the design of work. These latter projects can be described with four keywords: measure, analyse, improve and standardise – as illustrated with two interview excerpts:

> "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 one is superfluous – to be eliminated – and which one can be performed better and quicker. Accordingly, the process has become more simplified and suitable for being automated." (head of the industrial engineering team, No. 7)

> "To optimise task accomplishment, we first defined the way in which tasks must be performed. In the case of welding, for example, we specified the temperature, the position, which side to weld from, and determined the related time standards. Consequently, our operators stopped performing tasks according to their intuition and experience: they used the prescribed methods. We improved the delivery of raw material, parts, and tools to workstations and upgraded the organisation of work so that operators do not wait for input material or for the line manager to tell them what to do next. We initiated a digitalisation project and implemented a manufacturing execution system only when these processes had been standardised and were running smoothly. (plant manager, No. 4)

These reorganisation initiatives have significantly increased 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 intensification of work. 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 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.

Changes in skill requirements and importance of experience and tacit knowledge

In this section, interviewees' accounts are analysed from the perspective of digitalisation-induced changes in the skill-intensity and routine content of work. Relatedly, some illustrative examples of the influence of digital technologies on the value of experience and tacit knowledge are presented.

Interviewees unanimously stated that although some of the simplest manual tasks had been replaced by automation technologies, a number of other tasks remained that require similar repetitive movements and elementary skills. Since companies face pressing labour shortages, operators, displaced in tasks that had been automated, were usually not fired but deployed to perform other manual activities.[6] Consequently, as several managers interviewed (No. 1, 3, 8, 12 and 13) claimed, their cases elicited changes neither in the required skills nor in the routineness of work.

In other instances, the automation of specific work tasks was accompanied by a thorough re-organisation of work and training provision to manual workers. This enabled operators to engage in multitasking. Although the skills required for the execution of individual tasks remained the same, task diversity increased, since operators executed different tasks at several – partially automated – workstations. Whilst the managers of No. 4, 8 and 9 stressed that this kind of multitasking involves a reduction in the routineness of work, two operators interviewed (2 and 7) were rather of the opinion that reduced routine characterises only the initial weeks that follow the reorganised work activities. Once they had developed new routines, the overall degree of routine was perceived to be the same as previously.

Regarding the impact of smart visualisation solutions, there was a general agreement among interviewees that although, indeed they enable faster execution of work tasks and reduce assembly-related errors, they have a deskilling effect. As an explanation, both the digital solution providers interviewed and several other informants (No. 3, 8 and 9) pointed out that today's assembly processes would change much more frequently than previously. High product variety coupled with reduced cycle time requirements makes current assembly work hard to compare with that of previous eras. Changes are so fast that it makes no sense for production workers to learn the specifics of new products. Easy-to grasp visual work instructions and integrated digital error-proofing devices prevent operators from assembling wrong parts or omitting assembly steps. In this way, operators work faster and more precisely than before. Managers (No. 1 and 13) and experts acknowledged, however, that certain digital assistance technologies may turn assembly operators into 'extended workbenches': they perform tasks according to simple and precisely defined instructions. The following quotes illustrate these arguments:

> "Visual work instructions simply help operators figure out what has to be assembled in the next moment and how this needs to be done." (expert interview, digital solution provider)

> *"The processes need to be adapted to operators' capabilities. Operators do not have time to read lengthy instructions or check the manuals or the printed material. Moreover, if information is not easy to understand, they just ignore it and rely on their intuition."* (operations manager, No. 8)

> *"Some testing tasks have predetermined time standards: operators mustn't finish the given task earlier than prescribed. Operators should count how long they inspect a given part, for example, for 40 seconds. Since fatigue is unavoidable, after a couple of hours it becomes increasingly difficult to keep the required*

time. Operators would try to finish earlier and move on to the next piece. We have installed a digital control that provides feedback to operators showing how much time has elapsed." (process engineering manager, No. 13)

At operator level, the impact of advanced digital assistance solutions was mainly perceived in terms of work intensification and occasional multitasking, and not necessarily as a transformation of the required skill mix. Nevertheless some 'intellectification of work' (Jarrahi, 2019) does occur – at least, this is how the transformation was interpreted by the plant manager of No. 4:

"Operators have to check the pieces that have been deemed defective by the robotic system. This is an intellectual task, involving 'problem solving', since they have to find out the primary reason for the defects. Is it because of a wrong setup of the machine? Are the defects caused by inadequately placed pieces? Of course, not only the operators are required to identify the causes: 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."

The managers interviewed were not unanimous in stating that monitoring the machinery instead of – or rather along with – performing physical tasks refers to a reduction in the routineness of work or just to a changing content of occupational tasks. Nevertheless, experts and managers in No. 4, 6, 7 and 9 acknowledged that this kind of activity requires relatively higher information processing abilities, and operators' technical literacy, for example the ability to use the tools and devices developed for advanced manufacturing applications and become quickly familiar with the logic of the supporting applications, has become paramount. Operators work in a much more information-intensive environment than before. Relatedly, advanced manufacturing technologies demand fewer, albeit more qualified employees.

"As a rule of thumb, newer generations of production lines require ten to fifteen per cent fewer employees. Since our processes have become highly automated, our operators' tasks involve observing the equipment and taking actions in case of errors. This kind of incident management 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, No. 6)

"Interfaces have become more complex, containing not only two or three buttons or switches as in traditional machine control units. Being familiar with all the buttons on the control panels or being able to navigate through the menu of a touch screen are competencies developed through several months of work experience." (expert interview: trade union representative)

Digitalisation-induced upskilling and the transformation of the required skill mix were more straightforward for employees in production supporting functions. Digitally augmented employees may experience a significant transformation of the composition of their tasks, involving, for instance increased diversity, interaction-intensity, and mental demand: these are proxies of reduced routine and improved nature of work. The interview excerpt below (No. 4) illustrates the case of increased interaction-intensity.

"With digital work shift management and automatic shift handover reports, our line managers have been relieved from 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."

A digitalisation-induced transformation of work involving increased mental demand is exemplified by the case of maintenance workers. As reported by No. 2, 9 and 11, retrieving information from manuals previously accounted for a significant share of maintenance workers' 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. Whilst 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'. Consequently, the share of 'maintenance' increased within the activity mix of maintenance employees, and as argued by the business unit leader of No. 9, by taking up new and relatively higher value activities instead of the ones they had disposed of, their work has become more engaging and interesting.

The flipside of the coin is that smart technologies reduced the value of maintenance workers' previously accumulated experience. Equipment maintenance databases made it possible for maintenance workers, who had no experience with a given machine, 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). Reduction in the value of experience was reported also with respect to other activities, such as quality control or welding, as illustrated by the following quotes.

> "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 will be automatically displayed on the screen, placed in front of the inspector." (industrial strategy manager, automotive company, No. 11)

> "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 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."

Conditions moderating the outcome of digitalisation for work

Interview findings have confirmed the consensus view of industrial sociology and labour economics scholars (Hirsch-Kreinsen, 2016; Krzywdzinski, 2017; Parker and Grote, 2020; Waschull et al., 2020) that the impact of digital technology deployment is non-deterministic. If digitalisation engendered the allocation of new tasks to individual employees, these are, in some instances, indeed more diverse, more complex, and higher value adding. In other contexts, new tasks are as 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.

At the time of our research, components of high-performance work practices (Makó, 2005; Pil and MacDuffie, 1996; Posthuma et al., 2013), such as advanced performance management, teamwork, involvement of employees in continuous improvement were already prevalent across the surveyed companies. The advanced functionalities of digital solutions allowed for enhancing some of these practices.

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 digitalisation projects, and have systematically requested employee feedback about the individual solutions before rolling it out to other production lines within the plant. Employee involvement did not affect the eventual impact of technology on the nature of work, but it definitely promoted the acceptance of the given solutions and thus, indirectly, it enabled these firms to achieve the expected performance improvements.

Teamwork involving cross-functional collaboration was also a recurrent topic (cases No. 2–12) in the accounts detailing general changes in the nature of work. Team-based organisational setups 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, No. 4)

Accordingly, apart from working out a new *division of labour* through redistributing work tasks between humans and machines, managers also had to devise new forms of *integrating work.* They were experimenting with new organisational setups that have eventually become effective alternatives to hierarchical organising.

In summary, 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 for work. Managers' conscious approach to technology has unquestionably improved the nature of work by increasing task diversity, even in those cases where digital support reduced the importance of experience and tacit knowledge. Obviously, the purpose of managerial interventions was to ensure that the deployment of advanced manufacturing technologies delivers upon expectations. Nevertheless, the emergence of more desirable scenarios, involving a (somewhat) reduced routine was in some instances more than a simple beneficial side effect. As pointed out by two informants (No. 4 and 9), in an era marked by formidable labour shortages, offering interesting, digitally assisted work opportunities is a means of employee attraction and retention. On the other hand, for higher skilled employees, digitally augmented work enables a more effective use of their skills.

Discussion and conclusions

This paper investigated the impact of digital technologies on the nature and routine intensity of shop-floor work, the ways in which digital technologies exert their effects, and the conditions moderating the outcome of digitalisation 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 scenarios involving no change in routine, or, definitely, increased 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 less routine manual and 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 manifested in a reduced share of routine tasks within the overall task bundle.

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

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 section 5.1, optimisation is followed by standardisation and results in the intensification of shop-floor 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.

A conspicuous commonality of digitalisation-driven changes in occupational features was their context-specificity, or otherwise, the lack of commonalities. The observed heterogeneity of changes 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 shop floor. Plant managers, however, can to some extent '*direct the impact'* of digital technology implementation towards enrichment by redesigning workflows so that employees could perform more varied, higher value, and more interesting work tasks. Without intentional managerial interventions envisaging the augmentation of 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 technology unemployment, rather than provide richer dimensions to shopfloor work.

The second conclusion is that the widely hailed beneficial effects of digital technologies on the nature of work become apparent 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. This is particularly important in the Hungarian context, characterised by low and declining investments in education, a lower-than average prevalence of lifelong learning (EC, 2020), and a lower-than-average performance of the vocational education system in terms of keeping up with the requirements posed by technological progress in manufacturing.[7]

Over and beyond the common policy recommendations about addressing skill gaps and improving the efficiency of vocational education, our findings indicate that local managers need to be aware 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 conscious approach to technology.

We believe that this study contributes to existing research by offering a more fine-grained understanding of the ways in which the impact of digital technologies on the nature and the routine intensity of work unfolds. It integrates three key approaches (labour economics, technology assessment, and industrial sociology) to studying the opportunities, challenges, and risks of digital technologies for work, and offers insights from the workplace in an under-researched context: that of a 'factory economy' specialised in labour-intensive activities.

The study is, however, not without limitations. On one hand, the usual limitations apply, in terms of a small number of interviews, industries, and shop-floor functions. Another concern is the bias of the sample towards the managerial view: frontline workers and trade unions are underrepresented. Furthermore, the sample is biased towards high-performing flagship manufacturing subsidiaries that have been present and undergoing continuous expansion and upgrading for more than a decade (more than half of the sample companies). These subsidiaries are among the largest ones of their owners' production facilities, which again, strongly influences their owners' investment decisions.

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

Acknowledgement

Research support by the European Trade Union Institute is gratefully acknowledged.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study is supported by European Trade Union Institute.

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Notes

1. Baldwin (2013) distinguished two types of countries according to the activities performed by local economic actors. Accordingly, there are 'headquarter economies' and 'factory economies' in international production networks. Economic actors in headquarter economies are specialised in headquarter-specific activities: 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.
2. This paper uses digitalisation in a broad sense, referring to digital technologies transforming business processes. In specific contexts, however, the term will simply refer to the automation of work processes.
3. The flipside of the coin is that apart from a few high-flying foreign-owned manufacturing companies, digital technology adoption leaves a lot to be desired in Hungary. According to the data of the Digital Economy and Society Index (DESI, 2020) Hungary scores the second lowest in terms of business digitisation in EU28, trailed only by Bulgaria.
4. According to World Robotics data, the density of industrial robots in Hungary is lower than the European average: 84 vs 114, in 2018. Industrial robots are concentrated in the automotive industry. Here, robot density is 369 (per 10,000 employees), whereas the average in all other manufacturing sectors is 46.
5. The average number of employees was 2224 in 2019 (or the latest year available). The average turnover amounted to EUR 912.6 million, and the average share of exports in total sales was 87.1% (one firm was predominantly domestic market-oriented, with a share of exports of a mere 11%). These data, as well as the data in the Appendix apply to single plants in Hungary or in two cases, consolidate the turnover and employment of multiple plants in Hungary.
6. Instead of firing employees, the companies in the sample have rather relied on employee churn to improve the average quality of the workforce.
7. In 2016, the majority of vocational training school graduates was employed in unskilled jobs, and only 43% were employed in activities that required skilled labour (Köllő, 2017). This is no surprise since the instruction time of Hungarian students participating in vocational education comprises far fewer classes dedicated to general education subjects such as foreign languages, mathematics, sciences, or literature, than that of their German peers (Hermann et al., 2020). Over and beyond the particularly serious problems in terms of the availability and quality of the workforce, the local race-to-the-bottom type labour market regulations and the weakness of trade unions (Artner, 2020) may also influence managers' technology choice and skill use approaches.

References

Acemoglu D and Restrepo P (2018) The race between man and machine: Implications of technology for growth, factor shares, and employment. *American Economic Review* 108(6): 1488–1542.

Acemoglu D and Restrepo P (2019) Automation and new tasks: how technology displaces and reinstates labor. *Journal of Economic Perspectives* 33(2): 3–30.

Arntz M, Gregory T and Zierahn U (2016) *The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis*. Washington, DC: OECD Social, Employment, and Migration Working Papers.

Artner A (2020) Workfare Society in Action – The Hungarian Labour Market and Social Conditions in European Comparison. *Romanian Journal of European Affairs* 20(1): 109–128.

Atalay E, Phongthiengtham P, Sotelo S, et al. (2020) The evolution of work in the United States. *American Economic Journal: Applied Economics* 12(2): 1–34.

Autor DH (2015) Why are there still so many jobs? The history and future of workplace automation. *The Journal of Economic Perspectives* 29(3): 3–30.

Autor DH and Dorn D (2013) The growth of low-skill service jobs and the polarization of the US labor market. *American Economic Review* 103(5): 1553–1597.

Autor DH, Levy F and Murnane RJ (2003) The skill content of recent technological change: An empirical exploration. *The Quarterly Journal of Economics* 118(4): 1279–1333.

Baldwin R (2013) Global supply chains: Why they emerged, why they matter, and where they are going. In: Elms DK and Low P (eds), *Global value chains in a changing world*. Geneva: Fung Global Institute, Nanyang Technology University and WTO, pp. 13–60.

Bisello M, Peruffo E, Fernandez-Macias E, et al. (2019) How Computerisation Is Transforming Jobs: Evidence From the Eurofound's European Working Conditions Survey. JRC Working Papers Series on Labour, Education and Technology.

Braverman H (1974) *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century*. New York, NY: Monthly Review Press.

Bresnahan TF, Brynjolfsson E and Hitt LM (2002) Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence. *The Quarterly Journal of Economics* 117(1): 339–376.

Brynjolfsson E and Hitt LM (2000) Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives* 14(4): 23–48.

Brynjolfsson E and McAfee A (2014) *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York and London: WW Norton & Company.

Buer SV, Strandhagen JO and Chan FT (2018) The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International Journal of Production Research* 56(8): 2924–2940.

Burgelman RA (2011) Bridging history and reductionism: A key role for longitudinal qualitative research. *Journal of International Business Studies* 42(5): 591–601.

Cimini C, Pirola F, Pinto R, et al. (2020) A human-in-the-loop manufacturing control architecture for the next generation of production systems. *Journal of Manufacturing Systems* 54: 258–271.

Colledani M, Tolio T, Fischer A, et al. (2014) Design and management of manufacturing systems for production quality. *CIRP Annals-Manufacturing Technology* 63(2): 773–796.

Consoli D, Vona F and Rentocchini F (2016) That was then, this is now: Skills and Routinization in the 2000s. *Industrial and Corporate Change* 25(5): 847–866.

Cortes GM and Morris DM (2019) *Evidence from Changes in the Occupational Structure of Employment in the US and Mexico*. Rimini Centre for Economic Analysis Working Paper.

Dai HN, Wang H, Xu G, et al. (2020) Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies. *Enterprise Information Systems* 14(9–10): 1279–1303.

Delfanti A and Frey B (2020) Humanly extended automation or the future of work seen through Amazon patents. *Science, Technology, & Human Values* 46: 655–682. in press. DOI: 10.1177/0162243920943665

DESI (2020) *Digital Economy and society Index Report, 2020. Integration of digital Technology*. Available at: https://ec.europa.eu/digital-single-market/en/integration-digital-technology-enterprises

Doz Y (2011) Qualitative research for international business. *Journal of International Business Studies* 42(5): 582–590.

Dörrenbächer C, Geppert M, Pastuh D, et al. (2018) *ETUI Research Report*. Brussels: European Trade Union Institute. Cross-border standardisation and reorganisation in European multinational companies.

Drahokoupil J and Piasna A (2018) What is behind low wages in central and eastern Europe? *Post-Communist Economies* 30(4): 421–439.

EC (2020) *Education and Training Monitor 2020 – Hungary*. European Commission, Available at: https://op.europa.eu/webpub/eac/education-and-training-monitor-2020/countries/hungary.html#one

Eisenhardt KM and Graebner ME (2007) Theory building from cases: Opportunities and challenges. *Academy of Management Journal* 50(1): 25–32.

Fantini P, Pinzone M and Taisch M (2020) Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems. *Computers & Industrial Engineering* 139: 105058.

Farkas B (2011) The Central and Eastern European model of capitalism. *Post-Communist Economies* 23(1): 15–34.

Frey CB and Osborne M (2017) The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change* 114: 254–280.

Gaddi M (2020) Technological and organisational innovation under Industry 4.0 – Impact on working conditions in the Italian automotive supply sector. In: Drahokoupil J (ed), *The challenge of digital transformation in the automotive industry. Jobs, upgrading and the prospects for development*. Brussels: European Trade Union Institute, pp. 127–152.

Gallie D (2017) The quality of work in a changing labour market. *Social Policy & Administration* 51(2): 226–243.

Gerten E, Beckmann M and Bellmann L (2019) Controlling working crowds: The impact of digitalization on worker autonomy and monitoring across hierarchical levels. *Jahrbücher für Nationalökonomie und Statistik* 239(3): 441–481.

Glaser BG and Strauss A (1967) *Discovery of Grounded Theory*. Chicago, IL: Aldine Transaction.

Goos M, Arntz M, Zierahn U, et al. (2019) *The impact of technological innovation on the future of work*. JRC Working Papers Series on Labour, Education and Technology.

Hall PA (2006) Systematic process analysis: when and how to use it. *European Management Review* 3(1): 24–31.

Handel MJ (2020) *Job Skill Requirements: Levels and Trends*. MIT Work of the Future Working Paper.

Hardy W, Lewandowski P, Park A, et al. (2018) *The Global Distribution of Routine and Non-routine Work*. IBS Working Paper.

Hermann Z, Horn D and Tordai D (2019) The effect of the 2013 vocational education reform on student achievement, In *The Hungarian Labour Market, 2019*. Budapest: KRTK. Available at: https://kti.krtk.hu/wp-content/uploads/2020/07/LMYB2019_InFocus_2_4.pdf

Hirsch-Kreinsen H (2016) Digitization of industrial work: development paths and prospects. *Journal for Labour Market Research* 49(1): 1–14.

Holm M (2018) The future shop-floor operators, demands, requirements and interpretations. *Journal of Manufacturing Systems* 47: 35–42.

Jarrahi MH (2019) In the age of the smart artificial intelligence: AI's dual capacities for automating and informating work. *Business Information Review* 36(4): 178–187.

Kaasinen E, Schmalfuß F, Özturk C, et al. (2019) *Empowering and Engaging Industrial Workers with Operator 4.0 Solutions*. Computers & Industrial Engineering.

Kallinikos J (2011) *The "Age of Smart Machine": A 21st Century View*. Encyclopedia Software EngineeringTaylor & Francis, pp. 1–7. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.708.1279&rep=rep1&type=pdf

Keister R and Lewandowski P (2017) A routine transition in the digital era? The rise of routine work in Central and Eastern Europe. *Transfer: European Review of Labour and Research* 23(3): 263–279.

Köllő J (2017) *Munkaerőhiány és szakképzés.Munkaerőpiaci Tükör 2016*, MTA-KRTK. Available at: https://www.mtakti.hu/wp-content/uploads/2017/12/MunkaeropiaciTukor2016.pdf

Köllő J (2019) Toward a "Work-Based Society". In: Kovács JM and Trencsényi B (eds), *Brave New Hungary: Mapping the "system of National Cooperation*. Lanham: Lexington Books, pp. 139–158.

Kopp R, Dhondt S, Hirsch-Kreinsen H, et al. (2019) Sociotechnical perspectives on digitalisation and Industry 4.0. *International Journal of Technology Transfer and Commercialisation* 16(3): 290–309.

Krzywdzinski M (2017) Automation, skill requirements and labour-use strategies: high-wage and low-wage approaches to high-tech manufacturing in the automotive industry. *New Technology, Work and Employment* 32(3): 247–267.

Krzywdzinski M, Gerber C and Evers M (2018) The Social Consequences of the Digital revolution. In: Basso P and Chiaretti G (eds), *Le grandi questioni sociali del nostro tempo: a partire da Luciano Gallino*. Venezia: Edizioni Ca' Foscari, pp. 101–120.

Lazarevic M, Mandic J, Sremcev N, et al. (2019) A systematic literature review of Poka-Yoke and novel approach to theoretical aspects. *Journal of Mechanical Engineering* 65(7–8): 454–467.

Leyer M, Richter A and Steinhüser M (2019) Power to the workers" Empowering shop floor workers with worker-centric digital designs. *International Journal of Operations & Production Management* 39(1): 24–42.

Longo F, Nicoletti L and Padovano A (2017) Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers & Industrial Engineering* 113: 144–159.

Makó C (2005) Neo-instead of post-Fordism: the transformation of labour processes in Hungary. *The International Journal of Human Resource Management* 16(2): 277–289.

Manyika J, Chui M, Miremadi M, et al. (2017) *A Future that Works: Automation, Employment, and Productivity*. McKinsey Global Institute.

Martišková M (2020) The transformation of jobs and working conditions: towards a policy response. In: Drahokoupil J (ed), *The challenge of digital transformation in the automotive industry: jobs, upgrading and the prospects for development*. Brussels: ETUI, pp. 153–175.

Moniz AB and Krings BJ (2016) Robots working with humans or humans working with robots? Searching for social dimensions in new human-robot interaction in industry. *Societies* 6(3): 23.

Moore PV (2019) E(a)ffective Precarity, Control and Resistance in the Digitalised Workplace. In: Chandler D and Fuchs C (eds), *Digital Objects, Digital Subjects: Interdisciplinary Perspectives on Capitalism, Labour and Politics in the Age of Big Data*. London: University of Westminster Press, pp. 125–144.

Nedelkoska L and Quintini G (2018) *OECD Social, Employment and Migration Working Papers, No. 202*. Paris: OECD Publishing.

Neumann E and Mészáros G (2019) From public education to national public upbringing: the neoconservative turn of Hungarian education after 2010. In: Traianou A and Jones K (eds), *Austerity and the Remaking of European Education*. London: Bloomsbury Academic, pp. 117–146.

Parker SK and Grote G (2020) Automation, algorithms, and beyond: Why work design matters more than ever in a digital world. *Applied Psychology*: apps.12241. DOI: 10.1111/apps.12241

Patton MQ (2002) *Qualitative Research and Evaluation Methods*. 3rd ed. Thousand Oaks: Sage.

Pfeiffer S (2016) Robots, Industry 4.0 and humans, or why assembly work is more than routine work. *Societies* 6(2): 16.

Pfeiffer S (2017) Industrie 4.0 in the Making. Discourse Patterns and the Rise of Digital Despotism. In: Briken K, Chillas S, Krzywdzinski M, et al. (eds), *The new digital workplace: how new technologies revolutionise work*. London: Palgrave, pp. 21–41.

Pil FK and MacDuffie JP (1996) The adoption of high-involvement work practices. *Industrial Relations: A Journal of Economy and Society* 35(3): 423–455.

Pinzone M, Albe F, Orlandelli D, et al. (2020) A framework for operative and social sustainability functionalities in Human-Centric Cyber-Physical Production Systems. *Computers & Industrial Engineering* 139: 105132.

Posthuma RA, Campion MC, Masimova M, et al. (2013) A high performance work practices taxonomy: Integrating the literature and directing future research. *Journal of Management* 39(5): 1184–1220.

Romero D, Stahre J, Wuest T, et al. (2016) *Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies*. Tianjin China.

Ruppert T, Jaskó S, Holczinger T, et al. (2018) Enabling technologies for operator 4.0: A survey. *Applied Sciences* 8(9): 1650–1719.

Sass M (2015) FDI trends and pattern in electronics. In: Galgóczi B, Drahokoupil J and Bernaciak M (eds), *Foreign investment in eastern and southern Europe after 2008.: Still a lever of growth?* Brussels: ETUI, pp. 257–295.

Stake RE (1995) *The Art of Case Study Research*. Thousand Oaks: Sage.

Stockemer D (2019) *Quantitative Methods for the Social Sciences, A Practical Introduction with Examples in SPSS and Stata*. Cham: Springer.

Szalavetz A (2019a) Industry 4.0 and capability development in manufacturing subsidiaries. *Technological Forecasting and Social Change* 145: 384–395.

Szalavetz A (2019b) Digitalisation, automation and upgrading in global value chains – factory economy actors versus lead companies. *Post-Communist Economies* 31(5): 646–670.

Szalavetz A (2020) Digital transformation and local manufacturing subsidiaries in central and eastern Europe: Changing prospects for upgrading? In: Drahokoupil J (ed), *The challenge of digital transformation in the automotive industry: Jobs, upgrading, and the prospects for development*. Brussels: European Trade Union Institute, pp. 47–64. Available at: https://etui.org/sites/default/files/2020-09/The-20challenge-20of-20digital-20transformation-20in-20the-20automotive-20industry-2020.pdf-page=49

Teece DJ (1986) Profiting from technological innovation. *Research Policy* 15(6): 285–305.

Waschull S, Bokhorst JA, Molleman E, et al. (2020) Work design in future industrial production: Transforming towards cyber-physical systems. *Computers & Industrial Engineering* 139: 105679.

Welch C, Piekkari R, Plakoyiannaki E, et al. (2011) Theorising from case studies: Towards a pluralist future for international business research. *Journal of International Business Studies* 42(5): 740–762.

Westney DE and Van Maanen J (2011) The casual ethnography of the executive suite. *Journal of International Business Studies* 42(5): 602–607.

Wurhofer D, Meneweger T, Fuchsberger V, et al. (2018) Reflections on Operators' and Maintenance Engineers' Experiences of Smart Factories, In: *Proceedings of the 2018 ACM Conference on Supporting Groupwork*. pp. 284–296.

Xu LD, Xu EL and Li L (2018) Industry 4.0: state of the art and future trends. *International Journal of Production Research* 56(8): 2941–2962.

Zuboff S (1988) *The Age of the Smart Machine: The Future of Work and Power*. New York: Basic Books.

Zysman J and Kenney M (2017) Intelligent tools and digital platforms: Implications for work and employment. *Intereconomics* 52(6): 329–334.

Appendix A

Basic data of the companies in the sample 2019 or the latest year available.

No.	Employment	Turnover (EUR million)	Share of exports (%)	Industry	Interviewee
1	358	18.2	11.0	Automotive	Managing director
2	13,096	8561.1	99.5	Automotive	Digital officer; operator performing a variety of assembly tasks, rotated between several different types of tasks
3	976	489.8	100.0	Electronics	Manager responsible for corporate planning and IT
4	808	59.3	99.8	Automotive	Plant manager responsible for both strategy and operations
5	1058	125.0	99.6	Machinery	Managing director
6	1016	580.1	98.9	Automotive	Chief information officer
7	1890	781.4	80.0	Automotive	Head of industrial engineering; operator working in assembly
8	581	89.4	92.4	Machinery	Managing director of operations; operator performing assembly and quality control tasks
9	890	92.1	92.1	Electronics	Business unit manager responsible for lean development
10	1121	171.8	98.7	Machinery	Process improvement leader
11	832	106.0	99.0	Automotive	Industrial strategy manager
12	614	73.1	84.9	Machinery	Director of operations responsible for overall equipment effectiveness and quality
13	2807	716.3	76.1	Machinery	Process engineering manager responsible for the optimisation of shopfloor processes

Appendix B

Examples of digitalisation-induced changes in the nature of work.

Investments in digital technologies	Changes in the nature of work	No(s)
Industrial automation, industrial robots	Increased process standardisation; workers relieved from performing specific physical tasks: Instead, employees become responsible for monitoring the machines, checking the quality of the output, and correcting any problems that may arise	1–13
Collaborative robots	Increased process standardisation, reduced skill requirements	2, 5, 7, 9, 11*
Real-time OEE calculation through IoT solutions	Increased work intensity, reduced idle time, increased transparency for line and plant managers	2, 4, 5, 6, 7, 9, 12, 13*

(continued)

(continued)

Investments in digital technologies	Changes in the nature of work	No(s)
Visualisation of production status	Increased transparency for line and plant managers, feedback for frontline workers	2–7, 9, 11, 13*
Digital error-proof solutions	Increased speed and efficiency of task execution, increased work intensity, reduced error ratio, reduced mental efforts, reduced importance of experience and tacit knowledge	2, 4–9, 11, 13*
Visualisation of assembly tasks	Increased speed and efficiency of task execution, increased work intensity, reduced error ratio, reduced skill requirements	Expert interviews
Automation of in-plant logistics, AGVs	Increased standardisation of processes, increased speed and efficiency of task execution, increased work intensity, disappearance of specific work tasks	2, 6, 7, 9, 11*
Digital solutions supporting quality control	Increased speed and efficiency of task execution, increased work intensity, reduced error ratio, reduced importance of experience and tacit knowledge, reduced mental efforts, data-driven decision-making	1–13*
Digital production monitoring, track and trace solutions	Increased transparency for line and plant managers, reduced importance of experience and tacit knowledge in certain tasks, data-driven decision-making	1–13*
Digital shift handover	Reduction of time spent on reporting, reduced interaction-intensity of this task, increased share of line managers' working time dedicated to managing people	2, 6, 7, 9, 11*
Automation of production scheduling	Increased speed of task execution, reduced interaction-intensity of this task, changes in the related skill requirements, reduced importance of experience and tacit knowledge, new tasks and increased task diversity for schedulers	2, 7, 11*
MES deployment	Increased speed and efficiency of task execution at all levels, reduced idle time, increased transparency, data-driven decision-making	2, 6, 7, 9, 11*
Worker augmenting technologies (tablets, maintenance databases)	Increased speed and efficiency of task execution, improved quality, reduced importance of experience and tacit knowledge compensated by multitasking	2, 6, 7, 9, 11*
Digital interconnection of workstations and the warehousing, maintenance, or engineering staff	Increased speed and efficiency of task execution, improved quality, support arrives earlier, reduced interaction-intensity of work	2–13*

(continued)

(continued)

Investments in digital technologies	Changes in the nature of work	No(s)
Support to employee training through digital solutions	Increased speed and efficiency of novices' learning the necessary tasks, increased ratio of 'do it right the first time'	2, 4, 9*
Digital interconnection of some interrelated support processes, such as procurement, order management, controlling	Increased process standardisation, reduced communication and interaction, increased transparency, improved quality and efficiency of task execution, fewer errors	2–13•

AGV = automated guided vehicles; IoT = Internet of Things; MES = manufacturing execution system; OEE = overall equipment effectiveness; No(s) = Companies mentioning this type of change; * = may not be exhaustive; • = the breadth, maturity, and sophistication of the given solutions are highly heterogeneous across the listed companies.