Acta Oeconomica 72 (2022) 4, 457–475
DOI: 10.1556/032.2022.00031

AKADÉMIAI KIADÓ

Digitalisation-induced performance improvement: Don't take it for granted!

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Received: January 22, 2021 • Revised manuscript received: May 29, 2021 • Accepted: July 5, 2021

ABSTRACT

In a context of rapid technological change, digital manufacturing technologies bear the promise of enabling significant improvement in operational efficiency. However, evidence indicates that investing in smart digital solutions, *per se*, does not guarantee performance improvement. Smart factory projects may be derailed, failing to realise the expected operational benefits. This study addresses the gap between academic propositions regarding the unequivocally positive impact of digitalisation and the actual evidence.

It draws on data obtained from 18 interviews with technology providers, managers and front-line workers at 12 Hungarian manufacturing companies. We use the concepts of resource complementarity, task–technology misfit, and technology acceptance as a theoretical lens to categorise the seemingly idiosyncratic and context-specific operational problems.

We find that digital technology implementation produces inferior-to-expectations outcomes unless companies invest in and upgrade their complementary intangible resources. Four distinct, albeit strongly interrelated types of complementarities are identified: managerial, organisational, skill-related and technical complementarities. Managerial capabilities to adjust the organisational structure, improve workflows and develop a strategy to address technical problems are found to be paramount to eliminate task-technology misfit and enhance technology acceptance.

KEYWORDS

operational inefficiencies, complementary resources, digital technology adoption barriers, task-technology fit, technology acceptance

JEL CLASSIFICATION INDICES

M11, 032, 033

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1. INTRODUCTION

Both practitioners (business executives) and academics are now subscribing to the view that the digitally enabled improvement of resource efficiency, flexibility and responsiveness is more important than ever, and that COVID-19 has further accelerated enterprises' commitment to the digital transformation of their value creation processes (e.g., EIB 2021). There is mounting evidence, however, that few digital initiatives deliver on expectations (e.g., Gerth – Peppard 2016; Davenport – Westerman 2018). For example, recent surveys by Blackburn et al. (2020) and Correani et al. (2020) highlighted that the digital transformation projects showcase an astonishing high rate of failure: more than two thirds of the projects are stalled in the pilot phase, and/or exhibit poor return on investment. Failure to improve operational and business performance as a result of digitalisation is referred to as 'digitalisation paradox' (Gebauer et al. 2020).

The rapid expansion of business and management literature explaining the causes of inferior-to-expectations outcomes of firms' digitalisation initiatives (or elaborating on the contingencies of success), is therefore no surprise (see e.g., Sony – Naik (2020) for a survey). Studies point to an array of capabilities indispensable for achieving the expected return on investments in digital manufacturing technologies (DMT). Apart from leadership and change in management capabilities, profiting from digitalisation requires the capability to reinvent the business itself, redesign work practices, implement complementary organisational innovations, address skill gaps, and promote a digitally-oriented organisational culture.

Although achieving operational performance improvement is deemed child's play compared to capturing value from the digital transformation of business[1] (Warner – Wäger 2019; Björkdahl 2020), a burgeoning literature discussing implementation problems suggests that digitalising the shop floor is not necessarily easier than successfully accomplishing the digital transformation of business (Kamble et al. 2018; Gupta et al. 2019; Correani et al. 2020; Gillani et al. 2020).

Prior interviews with practitioners (e.g., chief information officers, operations managers, process improvement officers and front-line workers) also indicate that even narrowly efficiency-oriented smart factory projects may be derailed, failing to realise the expected operational benefits.

In an automotive plant in Hungary, for example, an operator vividly depicted how and why performance indicators *deteriorated* following the implementation of advanced digital production technologies:

> *"I used to work alongside a robot that was finally removed from our line. I would say, fortunately for us! Every time, following the completion of a work task, I had to wait for a couple of seconds before forwarding my piece to the robot. I finished a task, say, in thirty seconds, but the robot, responsible for the next processing stage, was still not ready. I was standing there and waiting five seconds to be able to forward the piece, since you are not allowed to pile up unfinished pieces for the robot. In contrast, when I was working with a human colleague, we were perfectly synchronised and did not have to wait for each other."*

[1]The flipside is that improved manufacturing capabilities are necessary but insufficient for improving business performance (Demeter 2003).

Although similar operational inefficiencies that follow the deployment of DMT are not rare, and there is an extensive body of literature offering a conceptual discussion of barriers to and contingencies of their elimination, still little is known about the shop-floor level details of these inefficiencies. In management studies, the richness of real-world empirics usually gets lost in the course of the coding exercises that follow the collection of primary data. Abstractly defined constructs such as the paramount importance of 'top management support', 'a strategic vision', and 'well-conceived implementation practices' are of little help in determining which digital solutions to invest in and how specifically they should be implemented.

Moreover, the abstraction inherent in developing a strong inductive theory (Glaser – Strauss 1967; Gioia et al. 2013) often results in a premature saturation of categories and themes, which is particularly inconvenient in the case of emerging topics, such as the impact of digital technology deployment on different shop-floor characteristics.

For example, while literature on the barriers to digitalisation seems to have achieved saturation (e.g., Kamble et al. 2018; Gillani et al. 2020; Götz et al. 2020; Raj et al. 2020), studies are mainly concerned with analysing the barriers to *adopting* DMT, rather than elaborating on the barriers to achieving operational efficiency improvement following the DMT adoption.

The purpose of this paper – that is part of a broader research focused on digitalisation-driven upgrading in factory economies[2] – is to address this gap in the literature by empirically illustrating and theoretically discussing critical failure factors in cases of unsuccessful implementation of digital technologies on the shop floor. The problems revealed in interviews with practitioners, managers and production workers are analysed by using relevant theories. Particular emphasis is laid on the subtleties of the shop floor, since these details – however context-specific they are – help managers get an intuitive understanding of the causes behind the inferior-to-expectations impact of digital technologies on operational performance.

Accordingly, the contribution of this paper is twofold. First, while the dominant majority of studies discussing digital transformation in a manufacturing context evaluate the affordances of digital technologies and highlight the expected positive impacts, this study elaborates on 'real-world' problems that may stymie operational performance improvement. In this vein, we address the big gap that exists between academic propositions and the actual evidence. Second, we delve into the subtleties of shop-floor experiences when classifying the factors behind inferior-to-expectations improvement in operational performance indicators into two general categories. The focus of the research represents a quasi 'taboo' theme for managers, hardly inclined to speak about inefficiencies and problems on the shop floor. Therefore, we adopt an exploratory research method that enables a rich contextual description of processes. Our approach combines the methodologies of industrial sociology studies taking technology as an object of social enquiry (e.g., Kallinikos 2011), business and management studies relying on interpretivist methods of analysis (Welch et al. 2011; Eisenhardt et al. 2016), and production and operation management studies focusing on the affordances and limitations of specific technologies.

The remainder of this paper is structured as follows. In the following sections we briefly summarise pertinent literature (Section 2), describe our methodological approach (Section 3),

[2]According to Baldwin's (2013) categorisation, economic actors in 'factory economies' specialise in the labour-intensive activities within international production networks.

and report and discuss our findings (Section 4). Section 5 provides some concluding remarks and comments upon the implications and limitations of our findings.

2. THEORETICAL BACKGROUND

2.1. Digitalisation of the shop floor and operational performance

The gradual convergence between manufacturing technologies and information and communication technologies (Monostori 2015) has rapidly transformed manufacturing operations and management and contributed to spectacular improvements in technology adopters' performance indicators (Ghobakhloo 2018; Büchi et al. 2020; Hortoványi et al. 2020; Szász et al. 2020).

In the context of this study, digital transformation is defined in a narrow sense,[3] as the use of digital technologies (e.g., the Internet of Things, additive manufacturing, machine learning, big data analytics and cloud computing) in applications, such as cyber-physical systems, collaborative robots, virtualisation and autonomous vehicles, to improve the operational performance of manufacturing plants (Monostori et al. 2016; Ghobakhloo 2018). The pervasive implementation of these networked technologies has contributed to the emergence of a new manufacturing paradigm characterised by flexible, intelligent, adaptive and responsive manufacturing production systems (Váncza et al. 2011; Colledani et al. 2014; Monostori et al. 2016).

The key principle of this new manufacturing paradigm, referred to as the fourth industrial revolution (Kagermann et al. 2013; Schwab 2016), is connectedness: the integration and interoperability of information across production and the related diverse functional areas (Frank et al. 2019). Cyber-physical production systems are designed to provide, capture and process production data, enabling operations to be monitored, controlled, coordinated and flexibly adapted in response to the changes in the internal or external environment (Monostori et al. 2016; Ghobakhloo – Fathi 2020). Accordingly, there is a consensus in scholarly opinions that smart factory technologies enhance resource efficiency and operational excellence, reduce costs, and increase flexibility and responsiveness (Brettel et al. 2014; Colledani et al. 2014; Adner et al. 2019; Hortoványi et al. 2020).

The operational inefficiencies to be eradicated by digital solutions are discussed in production and operations management literature focusing on the lean approaches in business enterprises.[4] Lean approaches are aimed at identifying and eliminating waste in production (and business) processes (classical references include Ohno 1988, Womack et al. 1990, and a recent survey is provided in Negrão et al. 2017). Operational inefficiencies, that is the manifestations of waste in manufacturing processes include among others, human idle time (e.g., waiting for materials, machine setup, defect management actions, and/or instructions), machine downtime, product defects, excessive work in progress and excessive inventories. Relatedly, an increasing body of research is devoted to developing appropriate metrics to measure the efficiency of various operations components, e.g., overall equipment effectiveness (e.g., Anvari et al. 2010),

[3]See Vial (2019) for a survey of competing and complementary definitions of digital transformation.

[4]Over and above the lean concept, there are several programmes and methods addressing inefficiencies, such as Six Sigma, Total Quality Management, World Class Manufacturing, etc (cf. Colledani et al. 2014 for a survey).

overall labour effectiveness (Braglia et al. 2020), overall material usage effectiveness (Braglia et al. 2018) and energy efficiency (Wen et al. 2021).

Studies elaborating on the linkages between lean manufacturing and the digitalisation of the shop floor (Buer et al. 2018; Tortorella et al. 2019; Ghobakhloo – Fathi 2020) tend to agree that the two concepts are strongly interrelated, supporting and reinforcing each other's performance in a synergistic manner.

2.2. Factors moderating the impact of DMT on operational performance improvement

Over time, with increasing adoption of digital technologies, scholars can rely on more and better data to assess their impact on adopters' performance. Evidence has been accumulating that investing in smart digital solutions, *per se*, does not guarantee performance improvements (Ghobakhloo – Fathi 2020; Mikalef et al. 2019, 2020).

Consequently, a growing stream of research started to apply the contingency theory (Sousa – Voss 2008) to explain the differences in operational performance improvement following the deployment of digital tools and solutions (e.g., Dubey et al. 2020; Szász et al. 2020). Contingency theory posits that different (operational) contexts require different resources, managerial approaches (e.g., work organisation methods), and organisational setups to achieve similar outcomes.

One of the most widely applied frameworks derived from the contingency theory is the technology–organisation–environment (TOE) framework to study the enabling factors and performance outcomes of new technology adoption (Gillani et al. 2020; Simões et al. 2020). The main premise of the TOE framework is that adopters' existing technological, organisational and environmental contexts exert a non-negligible influence on both the particularities and the outcomes of adoption.

If, as stipulated in the TOE framework, 'context' influences outcome, the obvious subsequent question is: what influences firms' TOE contexts? Answer is provided by the resource-based view of the firm (e.g., Wernerfelt 1984; Barney 1991), a theory closely related to the subject of this research. The resource-based view theorises that the (valuable, rare, inimitable and non-substitutable) properties of and the complementarity among firms' resources are the prerequisites of achieving sustained performance (Barney 1986): these are the factors creating an enabling context. Extending the resource-based view, the dynamic capability theory elaborates on the ways firms manage their resources: adapt, recombine and expand them *to create new complementarities* among them (Teece et al. 1997; Schilke et al. 2018; Eisenhardt – Martin 2000).

Applying the above-reviewed foundational theories to the context of this study, there are two questions to consider. First, are firms' tangible and intangible legacy resources (e.g. technology stock, information infrastructure, employees' skills and work organisation) adequate to ensure that the digital technologies integrated in the production system produce the expected operational benefits? Second, are the digital technologies, deployed to enhance firms' legacy resources, suitable for improving operational performance?

The first question refers to the problems associated with poorly developed or lacking complementary resources and dynamic capabilities (Milgrom – Roberts 1995; Eisenhardt – Martin 2000). Specifically, the resources that need to complement the digital shop-floor technologies are analysed by studies discussing dynamic capabilities in the digital age (e.g., Teece – Linden 2017; Teece 2018; Warner – Wäger 2019). These resources include managerial capabilities to adjust the organisational structure, improve workflows and adapt operational practices (Vial 2019; Sony – Naik 2020).

Furthermore, digitalisation-induced operational performance improvement strongly depends on managing and empowering the employees, building skills, including change in management skills and developing an adequate digital strategy (Hirsch-Kreinsen 2016; Dobrowolska – Knop 2020; Stein – Scholz 2020).

The adaptation or upgrading of the aforementioned complementary resources represents important contingency factors affecting the impact of digital technology deployment on the operational efficiency.

The second question, the issue of suitability, refers to the technology-related problems. It is analysed in studies elaborating on the technical barriers to digitalisation-induced operational performance improvement (Kamble et al. 2018; Raj et al. 2020). Furthermore, this question is the focus of the theories of 'task–technology fit' (TTF) (Goodhue – Thompson 1995; Venkatesh et al. 2003; Bendoly – Cotteleer 2008; Howard – Rose 2019), 'technology usability' and 'technology acceptance' (Davis et al. 1989; Lee et al. 2003).

TTF points out the crucial importance of *using* the technology at hand [and not trying to circumvent it] for performing the given tasks. The ability of technology to assist users in performing the required tasks is a matter of degree. The fit of the technology is moderated by users' perceptions, skills and the particularities of the environment in which the technology needs to be used. The flipside of TTF, coined by Howard – Rose (2019) is the task-technology misfit. It is observed, among others, when the applied technology contains too few or too many[5] features: both may frustrate users and worsen their performance. Relatedly, the usability theory posits that technical excellence is necessary, albeit insufficient. Products (including digital solutions for the shop floor) need to be easy to use, tailored to users' skills, and aligned with the contexts of their use, e.g., with work practices, to ensure technology acceptance.

Based on this brief review, we propose that digital technology implementation in the manufacturing shop-floor settings produces inferior-to-expectations improvements in the operational performance indicators unless companies invest in and upgrade their complementary intangible resources. Furthermore, technology choice, in terms of deploying solutions that can assist users in performing the required tasks is an additional factor moderating the degree of performance improvement. Figure 1 illustrates different theoretical lenses associated with our analysis and provides a concise summary of our arguments and propositions.

3. RESEARCH METHOD

3.1. Research design and data

To investigate the impact of digital technologies on the operational performance of manufacturing enterprises, an exploratory research design was adopted, involving qualitative data collection from semi-structured interviews (Patton 1990). Fieldwork is invaluable for obtaining insights in the features of technology implementation processes, and it is an adequate means of investigating emergent phenomena through multiple theoretical lenses (Eisenhardt 1989).

[5]For example, a 2D representation (a conventional picture) of a work task may prove insufficient for users to grasp its particularities, while too much and unnecessary visual information may distract users.

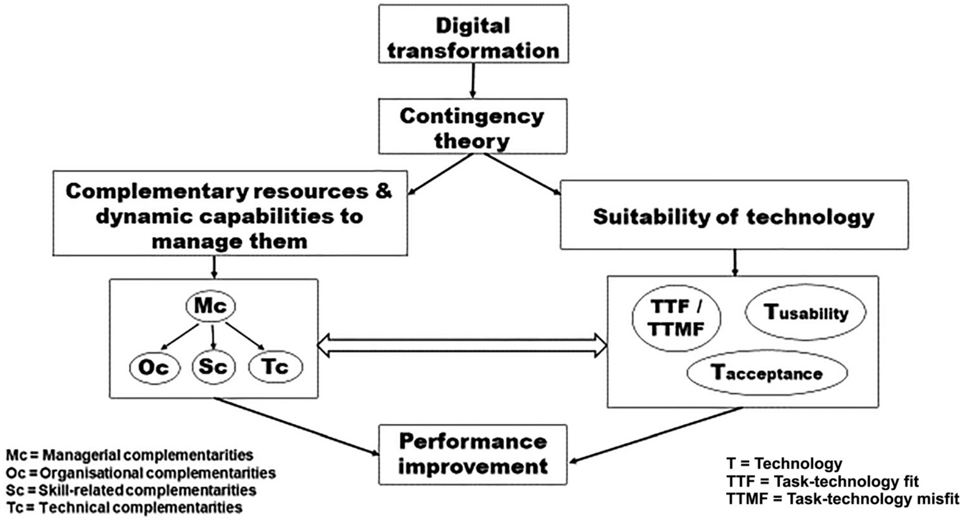

Fig. 1. The conceptual structure of this paper

The specific context of this study is Hungary: our sample comprises Hungarian manufacturing subsidiaries of global companies. Before selecting the companies to be interviewed, we conducted three expert interviews with the smart factory technology providers and the digital solutions providers, to gain orientation about the most recent advances in digital technologies and typical problems accompanying technology implementation. We had also asked these experts to make recommendations regarding high-flying manufacturing companies employing a variety of advanced digital solutions. These expert interviews and our prior studies of rapidly digitalising companies in Hungary have guided the selection of sample companies. Since except for some 'digital pioneers' the digital maturity of most companies is still in an infant stage, we used a criteria-based convenience sampling (Patton 1990).

The criteria we employed were as follows. We selected (i) large, (ii) foreign-owned companies (iii) operating in manufacturing industries considered frontrunners in digitalisation. Additionally, companies were selected on the basis that (iv) they have achieved a relatively high digital maturity level, i.e., companies that have invested in cyber-physical systems that capture production data, collaborative robots and/or smart solutions assisting shop-floor operators, line managers, quality inspectors and/or the maintenance staff.

Sample companies were selected from two databases: from the list of members of the National Industry 4.0 Technology Platform and from the author's hand-collected database of digitally mature companies, whose cases were reported in the business press articles.[6] To comply

[6]Two outlets proved particularly useful for the purpose of selecting information-rich cases: *Techmonitor* and *Gyártástrend*. This latter outlet organizes an annual competition called 'Factory of the Year'. Winners are announced in various categories, among others in a category of 'Industry 4.0', ranking companies by the sophistication of their shop-floor digital solutions. The yearly shortlists of winners in this category were also used as source of information for sample selection.

with criterion (iii), we focussed on the companies operating in the automotive ($n = 6$), electronics ($n = 2$) and machinery ($n = 4$) industries.

Apart from conducting interviews with managers directly involved in the digitalisation of the shop floor (e.g., plant managers, operations managers, line managers −12 interviews), we have gained access to shop-floor operators (3 interviews), which proved invaluable for capturing diverse perspectives on issues related to digital technology implementation (Eisenhardt – Graebner 2007).

Altogether, the data drawn upon in this study are 18 interviews (including 3 expert interviews) reporting the experiences of 12 companies. Interviews, lasting 60–90 min. each, were conducted in 2019 and early 2020. We took detailed notes during the interviews, 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 and notes to the financial statement.

3.2. Data analysis

As mentioned previously, the present study is part of a broader research focused on digitalisation-driven upgrading in factory economies. The broader theme of the investigation enabled us to build an atmosphere of trust before turning to explicit questions regarding implementation-related problems and operational inefficiencies.

Our approach was exploratory, guided by a semi-structured interview protocol containing open-ended questions (Appendix 1). For data analysis, we applied the interpretivist method of analysis (Welch et al. 2011; Eisenhardt et al. 2016), involving a detailed representation of informants' narratives. In this vein, occasionally long quotes are presented for an authentic depiction of the interviewees' experiences (Gioia et al. 2013).

For analysis, we adopted an iterative approach comparing the new findings against those obtained from previous interviews, and constantly refining the emerging structure of the qualitative framework. However, in contrast to the theory-agnostic approach of grounded theorizing (Glaser – Strauss 1967), we were drawing on the theoretical considerations outlined in Section 2 to guide both the design of the interview protocol and the analysis of the obtained data.

In this vein, this study responds to the call by Amundson (1998) for theory-driven empirical research, and leverages the applied, problem-oriented nature of production and operations management studies, the theoretically grounded approaches of business and management studies, and the exploratory approach of industrial sociology studies aiming at interpretive sensemaking.

4. FINDINGS AND DISCUSSION

Since a relatively high digital maturity was an important selection criterion, the managers interviewed had substantial experience with implementing digital solutions on the shop floor. Their accounts covered diverse technologies including collaborative robots, visualisation solutions assisting assembly workers, line managers, and quality control technicians, digital production control solutions, plant-specific digital messaging systems, Internet of Things solutions, and manufacturing execution systems.

Irrespective of the heterogeneity of our informants in terms of their occupational position, industry and experiences (positive or negative) with the digital solutions they have commented upon, their accounts exhibited a number of commonalities, enabling us to classify the seemingly idiosyncratic and company-specific problems into two general themes. These are (1) missing or insufficient investments in complementary resources and/or (2) low acceptance of the newly deployed technologies, caused among others by task–technology misfit.

4.1. Missing, inadequate, or insufficient investments in complementary resources

One of the interviewees' recurring complaints – much in line with the survey findings presented in the introductory section – was that the outcomes of technology deployment were inferior to prior expectations. For instance, the business unit manager of an electronics company, noted:

> *"We have deployed software that provides real-time information on overall equipment effectiveness and implemented Internet of Things solutions that enable advanced time measurement. We have even invested in a digital twin solution to simulate the production environment. These immensely expensive digital solutions have, however, failed to improve productivity by a meaningful degree."*

Conversations with managers suggest that the root cause behind the gap between the actual and the desired outcome was as follows: while smart factory solutions can indeed, *identify and provide real-time information* about waste, additional efforts and actions are necessary to *eliminate or reduce* waste, i.e., to bring the outcome in line with expectations. The underlying concept behind these and similar unfulfilled expectations is complementarity, specifically, the missing interactions between the new technology and the related company-specific resources, such as change in management capability (Milgrom – Roberts 1995).

Data obtained from interviewees have revealed four distinct, albeit strongly interrelated types of complementarities moderating the impact of DMT on operational performance improvement: managerial, organisational, skill-related and technical complementarities.

Managerial talent in managing change was found to be paramount to ensure that the desired outcomes live up to the expectations. As illustrated in Figure 1, managerial capabilities are intertwined with all other complementarities and collectively ensure the planned positive impact.

Accordingly, this section elaborates on these distinct types of complementarities, highlights the relevance of managerial complementarities for them, and provides rich real-world illustrations in the form of interview excerpts. These insights from the practitioner interviews serve as an illustration of the conceptual framework and the individual arguments. These details are instrumental, since they enable a deep and intuitive understanding of the nature of complementarities, by highlighting the adverse consequences of overlooking them.

On the organisational side, for example, managerial responsibility is straightforward in terms of adapting the organisational setup and aligning work practices with the requirements of DMT. The main lesson crystallising from the interviews is that in the digital era, cross-functional collaboration is indispensable. Digital technologies lay the foundations for cross-functional collaboration by enabling a horizontal and a vertical interconnection of functions and effective information sharing. However, the formal organisation of work also needs to be modified to leverage these affordances.

Accordingly, complementary investments are needed to develop capacity for managing the organisational change. Handling the process of change: assigning the necessary resources to the new types of organisational units, redefining the key performance indicators, modifying work processes, involving and training employees, and managing the conflicts associated with organisational change are important managerial challenges (Table 1, case a and c).

These latter ‘investments in complementary resources’ are particularly important since automation solutions may even magnify inefficiencies if work processes are not reorganised (Table 1, case b). Technology implementation needs to be preceded by careful planning also in term of identifying the most suitable tasks to be delegated to robots and identifying the specific areas where technology implementation is expected to boost efficiency (Table 1, case d).

In addition to the afore-discussed complementarities, our interviews point to a number of technical complementarities. The accounts indicate that since the technological components of the production system are strongly interconnected, actions targeted at improving the performance of specific components often result in problems emerging in other parts of the system. The plant manager of a machinery company presented a telling summary:

> *“Every time we try to enhance our production system by deploying a new digital solution, new operational inefficiencies emerge. Resolved problems breed new problems.”*

This interconnection is reflected, among others, by the enormous complexity of corporate software systems. New functionalities (e.g., digital applications assisting shopfloor workers) are relatively easy to create, at least compared with the huge effort it takes to integrate the new solutions with dozens of related systems within the corporate information system. The same issue emerged from the accounts of other informants referring to the fact that the process of technology deployment required more engineering and IT input than originally planned.

These narratives indicate that technical complementarities require *systems thinking*. Interviewees recurrently noted that the budget allocated to perform specific investments in the digital technologies had to be increased to solve the emerging related problems. Unless a whole range of newly emerging related problems were resolved, the expected efficiency improvement failed to materialise or was inferior to expectations.

Accounts on technological complementarities, again, highlight the importance of managerial complementarities, in terms of managers’ ability to use a system thinking approach to DMT deployment and take various associated investment tasks into account when planning the original investment.

Altogether, interview data indicate that managerial talent is a prominent complementarity, moderating the outcomes of DMT deployment. Managerial complementarity, that is the ability to arrange for the necessary reallocation of the workforce and other resources, addresses technical and skill-related complementarities, and redesigns the organisational practices, is closely intertwined with other complementarities.

Over and above managers’ understanding on the particularities of the new technologies and ability to address the related organisational, technical and skill requirements, traditional managerial assets, such as the ability to effectively utilise the legacy resources also proved to be beneficial in cases of DMT deployment. This is illustrated by the account of the plant manager of a machinery company:

> *“I had a hard time struggling with the headquarters and convincing the owners that we should not immediately fire the employees that have become ‘superfluous’ as a result of automation. For example,*

Table 1. Organisational complementarities intertwined with skill related and managerial complementarities

Cases	Illustrative interview excerpts
(a) business unit manager, automotive company	"We have redesigned our processes according to the value stream principles. This requires the bundling of the necessary competencies related to a given product family. Accordingly, instead of the traditional functional hierarchy, we moved to a process-oriented setup. The new teams encompass not only production operators and line managers but also the employees responsible for in-plant logistics, quality, maintenance and IT. This change has produced a great number of conflicts, jeopardising our performance indicators. "Why does XY interfere in my tasks and behave like a boss?" – that was the usual argument. Employees at all levels were slow to understand that requests can now arrive from any colleague, not only from a couple of 'bosses'."
(b) production worker, automotive plant	"A new robot was installed to improve our performance indicators, but no improvement was realised. The problem is that robots do not take on the full range of operators' tasks. For example, the screwing robot took over only 30 to 50 per cent of the job tasks of my colleague, who was sent to work to another line. Consequently, in addition to our usual tasks, our team had to take care of the remaining 50 per cent of my colleague's tasks. True, the robot performed the screwing tasks very precisely and rapidly, but for people working alongside the robots it was very difficult to adjust. Time pressure was so hard that we could not cope with the new requirements and committed more mistakes."
(c) managing director, machinery company	"Our programming team received the task of developing a document management system. Development took much longer than expected and I finally decided to investigate why programmers could not move the project forward to completion. It turned out that the newly installed messaging system was the 'culprit'. This system enabled machine operators or CNC setup persons to alert the programmers in case of perceived process anomalies. This messaging system kept distracting programmers from their basic duties and generated a number of conflicts between employees. It was finally decided that one programmer will be responsible for all incoming alerts every day, on a rotating basis, letting the others focus on 'programming'."
(d) operations manager, automotive company	"We invested enormous amount of time and money to automate quality inspection. Since every product that arrives on the conveyor is different, different (product-specific) parameters need to be checked. Arriving pieces are picked by a robot, which shows each side of the piece to a camera-based control system. The system reads the RFID tag of the arriving product and checks all the necessary parameters. Can you imagine what happened once we phased in this system? Performance deteriorated, because this kind of inspection took longer, than human-based quality checking. More importantly, false detections regularly occurred, since the results of image processing are influenced by ambient factors such as lighting conditions."

with the robotic process automation of line managers' time-consuming administrative tasks, half a dozen line managers have apparently become superfluous. However, since frontline workers were slow to develop and master the new routines required by the new digital technologies, we had to face a dip in operational performance. My proposal, which was finally accepted by the headquarters, was that instead of firing the worst employees following the deployment of labour-saving automation technologies, we should rather select the best ones, harness their company-specific experience and assign new tasks to them: that of training new practices to operators. In this way, we managed to achieve turnaround and harness the expected efficiency impacts of our overarching digitalisation project."

This case makes it clear that an excessively narrow understanding of the efficiency improvement, in terms of saving labour input, may also inhibit longer-term efficiency improvement. While slack resources ('superfluous operators') epitomise waste, the apparent inefficiency of not firing them trades off against resilience under turbulent changes in work practices and enables better resource leverage in the longer run. Accordingly, managerial talent was manifested in recognising and addressing this trade-off.

4.2. Technology acceptance and task–technology (mis)fit

The second general theme, in which the seemingly idiosyncratic and company-specific problems recounted by our interviewees were classified, is users' low acceptance of the newly deployed DMT or rather, their low acceptance of the new ways of working. The lack of users' acceptance was sometimes hard to distinguish from skill-related problems, frequently mentioned during the interviews. Indeed, the three concepts: 'inadequate skill-related complementarities', users' perception that 'using the given technology requires excessively high competences', and 'lack of technology acceptance' are interrelated. A line manager of an automotive supplier noted:

"At risk of some exaggeration, it took longer to train employees how to use the solution than to develop the solution itself. Indeed, some production workers would require a personal coach to hold their hands for weeks! I would think twice before implementing 'smart technologies' on the shop floor again."

In other cases, the inability of the chosen technology to fulfil its objectives and bring about the expected benefits was straightforward, indicating a task–technology misfit.

"We installed a smart process monitoring solution that sends alerts in case of anomalies. The shop floor was literally paralysed by false alarms: red lights were blinking, and a beep sound tried to grab workers' and maintenance staff's attention. It was so annoying that employees argued that the system should be removed. It took quite a while to fine-tune the system, set higher but not too high thresholds and make employees 'believe the alerts' afterwards. It was a typical crying-wolf situation." (Manager responsible for corporate planning and IT, automotive electronics company)

Again, these interviews highlight the significance of the managerial factor: the ability of the management to cope with technology-induced problems and accomplish the necessary adjustments to make perceived usefulness of the new technology unequivocal.

Low acceptance was, however, not always the consequence of task-technology misfit. Our results indicate that there is an inverse correlation between acceptance of new technologies and the accumulated experience with respect to the given task (prior domain-specific knowledge). Experienced employees often mistrust new solutions and stick to the techniques they have already mastered.

> *"We have deployed an advanced enterprise resource planning system for this client, yet they keep creating shop-floor production schedules in Excel. Schedulers claim that under the time constraints of everyday operations they are not capable to learn new tools and methods. It is no surprise that the company keeps facing delays because of wrong decisions based on outdated schedules or inconsistent data." (*Excerpt of an interview with a digital solutions provider)

In contrast, novices are found to become more easily comfortable with new ways of working aided by assistive digital technologies. However, according to interviewees, novices are less adept at perceiving process anomalies and taking control back: they would easily get 'out-of-the loop'. Accordingly, managerial capabilities to determine the right mix of employees to work with the new technologies is a crucial factor moderating technology acceptance.

Another issue that crystallised from the conversation with the practitioners is the importance of involving the would-be users of the relevant digital solutions in the implementation process. The business unit leader of an electronics company explained:

> *"Although workers tacit knowledge is tremendously important with respect to noticing signs that refer to production anomalies, for example unusual sounds or vibration, often they do not care since they do not want to waste time and/or generate conflicts because of false alarm. We decided to implement a light-based signalling system that alerts the shift leader. We asked frontline workers for advice, asking them for example, how many different colours, signalling different problems, should be included in the system. We have not only learned a lot from these "brainstorming sessions" about the nature of shop-floor problems but operators' commitment to alert shift leaders in case of perceived problems has significantly increased."*

Altogether, these narratives suggest that in line with the findings of classical technology acceptance models, the perceived usefulness of the newly deployed digital solutions shapes users' acceptance. Apart from choosing adequate technology (task–technology fit), managerial capabilities are found paramount also in terms of influencing the perceived usefulness through involving employees in the deployment process and adjusting the work processes if necessary.

5. SUMMARY, IMPLICATIONS, AND LIMITATIONS

While digital manufacturing technologies bear the promise of enabling significant improvement in operational efficiency, accumulating evidence has confirmed that a *possible improvement is not an actual improvement*: digital technologies do not automatically enhance the adopting firms' operational performance. Consequently, the ways digital technologies are implemented and the conditions moderating the outcomes of technology deployment deserve attention.

There is rapidly expanding literature in the fields of technology assessment and operations management, discussing how individual digital solutions can enhance performance. Relatedly, studies in production economics are concerned with the enablers of and barriers to the digital technology implementation. The key commonality of these perspectives is that they do not consider the possibility of negative or inferior-to-expectations outcomes. These studies take the improvement of operational performance for granted, once digital technology is implemented.

This paper aimed to fill this identified gap in the literature by adopting an exploratory methodology to elaborate on the factors behind shop-floor inefficiencies stemming from digital technology implementation – an everyday reality in manufacturing plants. Our qualitative data analysis approach identified two general factors underlying the variety of context-specific inefficiencies. The first factor is insufficient or ineffective investments in complementary resources, and consequently, the missing co-evolution between the technology stock and shop floor-specific intangible assets, such as managerial and technical skills, organisational and work practices. The second factor is poor acceptance of the newly deployed technologies, caused among others by task–technology misfit, which inhibits substantial improvement in adopting firms' operational performance.

Another finding is that these two general categories (complementary resources and technology acceptance) are closely related – as illustrated in Figure 1 by the arrows linking them.

The key managerial implication of our findings is that digital technology deployment, in itself, will not automatically bring about manufacturing excellence, since the expected performance improvement may remain inferior to expectations. To leverage the full potential of technology adoption, technocentric considerations need to be accompanied by a scrutiny of complementary organisational, managerial and technological requirements. Additionally, particular attention needs to be paid to finding out how frontline workers and employees in production support functions perceive the usefulness of these technologies.

Another lesson is that technological change must be viewed and managed not as a discrete transaction but as continuous and open-ended. While complementarities do not preclude achieving partial success in terms of improved performance indicators, the 'journey' to achieving impact from increased digital maturity requires a budget for continuous improvement instead of deciding on and allocating funding to discrete actions.

Regarding the theoretical implications of our findings, we used the concepts of resource complementarities, task–technology misfit, and technology acceptance as a theoretical lens to explain the factors behind shop-floor inefficiencies. We showed that the seemingly idiosyncratic and context-specific operational problems are related to these overarching concepts. Our results also confirm an important concept in innovation economics literature, namely that technological innovations are not isolated phenomena: they interact with, complement, or depend on other innovations (e.g., Freeman – Soete 1987; Dosi 1988).

Focusing on the subtleties of the shop floor, this research has deliberately adopted a limited scope of analysis, zooming in on technology adoption related problems in the manufacturing firms' operations. The imminent limitation stemming from the scope of this study needs to be acknowledged: while companion papers (Szalavetz 2017, 2019, 2020; Szalavetz – Somosi 2019) have discussed several positive effects of digital technologies in terms of improved manufacturing capabilities, resource efficiency and operational excellence, this study focuses only on shop-floor problems and inefficiencies. It is, therefore, indispensable to emphasize that this narrow focus is not intended to suggest a lack of positive developments.

Another limitation is the non-exhaustive nature of the framework in which our research is anchored. Since operational inefficiency is a complex and multifaceted issue, encompassing dimensions such as resource efficiency, process stability, accuracy, speed, value and costs,[7] other factors not considered here, might also underlie the shop-floor problems.

[7]Some of these dimensions are subject to trade-offs, and thus, require comparing the proverbial apples and oranges when determining priorities.

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Appendix 1. Questions guiding qualitative data collection about operational problems and inefficiencies

I. Questions aiming to collect company-specific data
II. Questions aiming to collect data about the specifics of digital technologies implemented
III. Questions related to the firm's strategic motivations of digital technology implementation
IV. Questions about the achievements related to the firm's digitalisation initiatives, and about the associated upgrading opportunities
V. Questions aiming to collect data about digitalisation-induced changes in the nature of work
VI. Questions about shop-floor details of digitalisation
- Which specific processing tasks were supported by digital technologies?
- Have you installed solutions that inform operators and facilitate the accomplishment of their tasks? Please provide details!
- Have you implemented digital solutions that support employees in other shop-floor functions? Please provide details!
- Were the new solutions easy to learn and work with? Did they require special training for employees?
- Did the newly implemented technologies deliver on prior expectations? If not, what were the main problems?
- Were the problems perceived mainly by the operators or also by/rather by employees in support functions? Please provide details!
- Please tell me stories about additional shop-floor level "teething problems" related to digital technology implementation! What were the root causes behind these problems? How did you resolve them?
- Was it necessary to make additional investments to make the digital solutions deliver? What kind of investments were necessary? Please tell me some real-world examples!
- I read several reports and blog posts issued by consultancy firms specialised in assisting the digitalisation initiatives of manufacturing companies. They all emphasise the role of managers in solving shop-floor problems. This came as a surprise for me, since I thought these problems are rather technical ones. Can you illustrate the role of 'managerial innovations' in solving such problems and tell me a case that happened in your company?

Note: The questions related to the broader theme of the investigation, focusing on digitalisation-driven upgrading in factory economies, are not detailed here.