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ORIGINAL ARTICLE

Examining the development of a digital ecosystem in an Industry 4.0 context: a sociotechnical perspective

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Abstract

To respond to increased competition, manufacturing organisations have started developing digital ecosystems within a supply chain by adopting Industry 4.0 technologies. That approach promises to improve organisational efficiency by automating operations and decision-making activities. The development of the digital ecosystem passes through vertical and horizontal integrations of technologies. Vertical integration represents the integration of various organisational units, and it is a milestone in the process of reaching horizontal integration where different organisations integrate their production processes in a supply chain. The extant literature reveals that the vertical integration of an organisation is challenging to achieve, as the adoption process of Industry 4.0 employs a technocentric perspective without considering the way that technology users can cause strong workforce resistance against Industry 4.0 adoption. The sociotechnical perspective addresses this issue by considering both technology and users during the adoption process. Therefore, this paper illustrates the applicability of the sociotechnical approach to an in-depth single case study of an Italian manufacturing group which successfully adopted Industry 4.0 technologies. We show the adoption process of Industry 4.0 technologies, highlighting the outcome of the adoption and proposing sociotechnical enabling factors that assist in achieving vertical integration.

Keywords Industry 4.0 · Sociotechnical theory · Single case study · Industry 4.0 vertical integration · Industry 4.0 ecosystems

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Introduction

Manufacturing organisations face fierce competition from competitors in developing countries, which undermine their market share through competitive prices and quality products (Margherita and Braccini 2020b). Governments worldwide address this challenge by promoting Industry 4.0 (henceforth I40) industrial plans to support the competitiveness of a country's manufacturing sector (Evans and Annunziata 2012; Kagermann et al. 2013). These plans encourage organisations to adopt technologies—including Big Data, the Internet of Things, and Robotics—to optimise and automate the production process through programmable cyber-physical systems (CPS) that automatically control machinery in assembly lines. The way organisations use I40 technologies allows them addressing problems along the assembly line without human interaction, and through autonomous machines (Lee et al. 2015).

Moreover, organisations integrate these technologies to develop a digital ecosystem of manufacturing organisations in a supply chain (Kagermann et al. 2013; Müller et al. 2018). The development of this digital ecosystem passes through two phases. In the first phase, called vertical integration, each organisation internally integrates several units. In the second phase, called horizontal integration, organisations in the supply chain share the information, integrating the production process and facilitating collaboration amongst partners (Kagermann et al. 2013; Müller et al. 2018). Adopting I40 technologies, which enable vertical integration, is necessary to undertake horizontal integration and reach a digital ecosystem.

The exploration of the digital ecosystem of I40 technologies is at an early stage. Most of the studies focus on the vertical integration of the internal organisational units by implementing I40 technologies. That is a challenging process for organisations, because they experience various issues during the adoption process. These difficulties rely on the lack of proper organisational actions to implement I40 technologies (Sony and Naik 2019a, b). I40 adoption is a complex process that consists of end-to-end digital integration of technologies and requires a well-prepared workforce to manage those technologies (Kagermann et al. 2013). The integration of I40 technologies is problematic as there is no best practise to follow, and there is a scarcity of experts to lead I40 projects (Sony and Naik 2019b).

To date, most of the studies exploring I40 adoption have followed a "technocentric perspective". This perspective privileges the integration of the technologies within the production plant without considering the workforce who are the users of these technologies. However, some studies have argued that this perspective is not appropriate for I40 adoption because workers are not prepared to manage these technologies due to a lack of proper competences and skills, which can cause strong workforce resistance against I40 adoption (de Sousa Jabbour et al. 2018; Liao et al. 2017). Workers require specific training and vocational courses along the adoption process to accept and to use I40 technologies (Prause et al. 2017; Sayar and Er 2018; Margherita and Bua 2021).

Therefore, these studies call for workers' involvement during the adoption process of I40 technologies and a sociotechnical perspective for I40 adoption

(Kagermann et al. 2013; Sarker et al. 2019). The sociotechnical perspective conceives of the organisation as a work system composed of social and technological systems that are "jointly optimised" to operate effectively (Bostrom and Heinen 1977; Lyytinen and Newman 2008). This perspective allows us to study the changes within the work systems, the interrelations amongst the two systems, the consequent sociotechnical equilibrium, and the improvements delivered by the novel I40 work system (Bostrom and Heinen 1977; Sony and Naik 2020).

Within this framework, the main goal of this study is twofold. First, the paper illustrates an I40 adoption employing a sociotechnical perspective. To this end, we conducted an in-depth case study of an Italian manufacturing organisation producing bathroom ceramics that successfully adopted I40 technologies. Second, we propose sociotechnical enabling factors for the effective vertical integration of I40 technologies. The study answers the following question: "What are the sociotechnical enabling factors for an effective Industry 4.0 adoption?".

The paper is structured as follows. The section "Related literature" is devoted to the relevant literature on I40 initiatives and the sociotechnical approach. The article continues in the section "Research method" with the research method. We outline the case study in the section "Case description", pointing out the traditional work systems, the I40 adoption process, and the I40 work systems. The section "Findings and discussion" shows the improvements of both systems and the enabling factors for I40 adoption. The paper ends in the section "Conclusions, study limitation and implications" with conclusions and implications for researchers and practitioners.

Related literature

This section presents the I40 initiative, the works that have investigated I40 adoption, and the sociotechnical perspective.

Industry 4.0

Inspired by the German government, I40 is an industrial initiative that aims to innovate production processes by adopting leading-edge technologies, including Big Data, the Internet of Things, and Robotics. I40 allows for deploying the generic concept of cyber-physical systems (Kagermann et al. 2013) that automatically control machinery and address mechanical issues on the assembly line without human interaction (Lee et al. 2015). I40 adoption promises to deliver value in organisations by establishing a more efficient production process, reducing natural resource usage, and providing safer workplaces (Braccini and Margherita 2019; Margherita and Braccini 2020c).

To this end, the I40 initiative claims to develop a digital ecosystem of organisations within a supply chain to exploit these technologies fully. The development of a digital ecosystem passes through vertical and horizontal integration (Blunck and Werthmann 2017; Kagermann et al. 2013).

Vertical integration is internal to the organisation and represents the integration of several organisational units, including marketing and sales or technology development, by end-to-end digitally integrated technologies across different levels (Kagermann et al. 2013). The vertical integration also allows for a flexible and reconfigurable production infrastructure adapted to each specific customer order or even changing market requirements. Vertical integration is a requirement to start the process of achieving horizontal integration.

Horizontal integration represents the digital information sharing that facilitates collaboration amongst partners within a value chain, including the customer (Müller et al. 2018). This integration addresses specific areas of an organisation (e.g., purchasing, production, logistics) that are connected with all the value chain's external partners.

Horizontal integration characterises inter- and intra-organisation smart networking of cross-company and internal-company measures that digitalise the information flow of internal programmable logic controllers of value chain actors (Stock and Seliger 2016). The integration of the horizontal value chain optimises the information flow and flow of goods from the customer to the organisation and vice versa (Blunck and Werthmann 2017). In horizontal and vertical integration, we see an I40 technology ecosystem.

The literature exploring digital ecosystems by I40 technologies is at an infant stage. Most of the studies are focussed on exploring how organisations achieve the vertical integration that is a challenging process due to difficulties in adopting I40 technologies (Prause et al. 2017; Sayar and Er 2018). A lack of best practises and experts hamper I40 adoption (Sony and Naik 2019a).

Some studies employ a technocentric perspective which considers technologies as the main driver of the benefits, because these technologies increase the automation of operations and decision-making activities (Kang et al. 2016). Thus, during the adoption process, organisations may privilege technology implementation and integration without considering the workforce (Prause et al. 2017). However, Sayar and Er (2018) showed that the technocentric perspective is inadequate for I40 adoption, because workers require specific training to be effective in the use of I40 technologies. They showed that even if an organisation implements I40 technologies, workers might not accept those technologies or use them, which can result in economic losses.

Prause et al. (2017) further describe the failure to adopt I40 technologies. They explain the technocentric perspective is not sufficient for effective vertical integration of I40 technologies, because workers do not manage them properly. Also, these considerations are due to a lack of involvement of users at the adoption stage. In line with this, some studies claim that the workforce should take part in the adoption process, because they are not currently prepared to use these technologies due to a lack of proper competences and skills (Margherita and Braccini 2021), which causes strong workforce resistance against I40 adoption (Bonekamp and Sure 2015; de Sousa Jabbour et al. 2018; Kamble et al. 2018; Margherita and Braccini 2020a; Müller 2019).

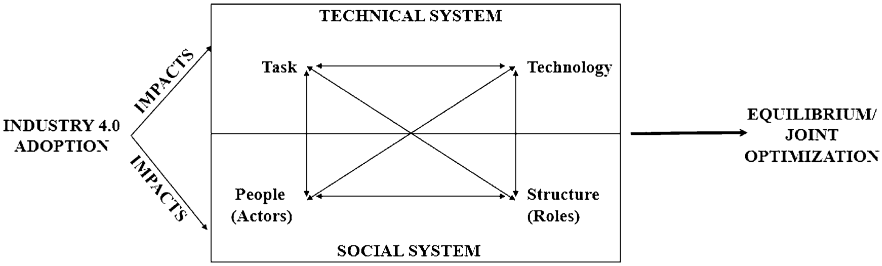

Fig. 1 The sociotechnical model (Bostrom and Heinen 1977; Leavitt 1964)

The sociotechnical perspective

The term "sociotechnical" was coined in the 1950s by Trist and Emery. They studied the implementation of the "Longwall Method" in a coal mine and documented worker responses. Workers migrated from a traditional method of extracting coal to a new semi-mechanised "Longwall Method" for gathering coal (Trist 1981). The researchers showed that productivity decreased unexpectedly, albeit the new method supposedly facilitated workers' tasks. This outcome occurred, because managers did not consider the social system (people, relationships, organisational structure) during the adoption phase. The former method allowed workers to perform a variety of tasks using different tools, or better, workers had a high degree of element of job enrichment (Leonardi 2012). Conversely, the new method "destroyed" these social patterns, generating worker dissatisfaction that turned into resistance to the technology which eventually resulted in a decrease in productivity.

To solve this issue, the technology adoption should be considered with a sociotechnical perspective (henceforth STP) that considered both the social issues and the technical issues (Sarker et al. 2019). The STP posits that the conjoint optimisation of both systems leads to effective technology adoption within the organisation.

The STP employs the work system theory, which provides a perspective for understanding systems in organisations (Alter 2013; Von Bertalanffy 1972). The STP describes the organisation as composed of social and technical systems. The former includes the workers, their roles, and the organisational rules. The latter includes the technologies for accomplishing organisational tasks (Trist 1981).

Bostrom's sociotechnical model (Fig. 1) synthesises the findings around the STP (Bostrom and Heinen 1977). The model depicts the main elements which are impacted by new technologies within the organisation. The model views organisational systems as multivariate systems of four interacting components—task, structure, actor, and technology. Still, during technology adoption, sociotechnical systems are open systems. They have to be continuously adapted to the environment to maintain the state of equilibrium. The equilibrium or joint optimisation of both systems involves stable relationships between the system components and their environment. This joint optimisation leads to improvements in both systems.

In technical systems, the improvements concern better performance and achieved economic objectives, whereas the improvements in the social system concern enhanced job satisfaction and a higher quality of work-life balance (Land 2000; Sarker et al. 2013).

Research method

This study targets the STP of a case of I40 adoption, showing the social and technical improvements and the enabling factors of I40 adoption. The study illustrates a single case study of an Italian manufacturing organisation in the ceramic industry which adopted various I40 technologies. We selected the organisation as a revelatory case, since it was the first mover in adopting I40 in its domain (Yin 2002).

As primary data, we collected four face-to-face, semi-structured interviews with four key informants (Kumar et al. 1993), including members of the steering committee of the I40 adoption—the chief executive officer (CEO) and the chief production officer (CPO)—and two workers operating in the traditional and novel production processes. We decided to interview these two groups, because their voices often diverged on themes related to how work conditions changed after the technology adoption (Sawyer and Jarrahi 2014).

We conducted semi-structured interviews in December 2018 during an organisational visit that lasted 3 h. The average length of each interview was 30 min. We also collected observations of the production line, observing the operations of smart machines, control systems, and activities performed by workers on the line. We followed the track indicated in Table 1. We slightly adapted the interview track according to the roles of each interviewee.

We conducted observations of the I40 production line and compiled field notes. We further gathered secondary data. We included official balance sheets and articles from distinguished national newspapers regarding the traditional production process, the I40 adoption process, the I40 production process and its improvements.

We gathered the organisation's official balance sheets using the database AIDA[1] and additional articles from distinguished national newspapers from their official websites. Moreover, we employed the data obtained from a previous analysis of the same case unit (Ruggieri et al. 2016).

We triangulated all the data to enhance the validity and reliability of the study and reduce subjectivity in empirical evidence (Denzin 2006; Walsham 2006).

After that, the research team collected all the data sources in a data corpus and integrated them into a single research database which we coded following the guidelines for the validity and reliability of qualitative inquiry (Corbin and Strauss 2015; Locke 2001). The sociotechnical model (Fig. 1) has been used as a sensitising device to identify critical events in the work context and assess their impact. In Table 2, we summarise the most relevant interview and newspaper excerpts for the aspects

[1] AIDA is an online database, owned by Bureau van Dijk, containing financial information of more than 500,000 Italian companies. AIDA has official balance reports of Italian companies of the last 10 years.

Table 1 Track interview

Interviewee	Questions
Management (CEO and CPO)	Organisational facts: worker number, turnover level Features of I40 technologies Needs triggering the I40 adoption The management I40 adoption process Worker participation in the I40 adoption process Changes in work practise triggering I40 adoption Technical systems improvements from the I40 adoption Social Systems improvements from the I40 adoption
Workers	Type and nature of the work performed Experience in the production process before I40 adoption Social systems for the workers from the I40 adoption Changes in working conditions before and after the I40 adoption Personal awareness of the benefits of I40 adoption

discussed in the case description. Finally, we propose a full narrative of events and their interactions in a visual form (Langley 1999). This visual expression narrates the implementation process from the beginning to end as a sequence of incidents that affect the work system.

Case description

This section illustrates the STP application in a single case study of an Italian manufacturing organisation. It describes the traditional work systems, the causes and adoption process of I40, and the I40 work system.

Table 2 Interview and newspaper excerpts

Topic	Source	Interview excerpts
Detail of I40 adoption	CEO	We were lucky to have enough space, our partner set up the implementation of each technology thoroughly whilst we previously communicated to workers these changes
Technical system of the traditional work system	CPO	The traditional production process is here. These are the moulds to create the product, which are then dried. We switch on the oven for twelve hours to bake the products at the end of the day. Workers moved the products to the logistics unit
Social system of the traditional work system	CPO	One operator manages one machine. Everything is manual. These operators are in charge of producing the goods with the help of moulds. Then, we have operators that move the goods by forklifts that drive
I40 social systems improvement	CPO	Employees thanked us. Heavy manual labour was the critical issue of the factory. Now their tasks have changed favourably
Worker role in the traditional work system	CPO	During the production, the worker establishes a relation with each product. A worker moves the semi-finished good, shaping it, and obtains visual and sensorial feedback regarding the product quality
I40 technical system improvement	CEO	This I40 application is the first in the ceramic industry. We risked a lot, but our production increased by 30%, and we reduced defects and damaged products during the transports from 30% down to 9%
I40 technical system improvement	Article	The company is environmentally friendly. They reduced the usage of natural resources, increasing the efficiency of the production line
I40 social system improvement	Article	The company improves workforce conditions through I40. We requalified the worker, and now, they are technology experts. Currently, technologies move product in automation and workers control the system through a computer. The company also provides several vocational courses for workers
Worker role in I40 work systems	Worker 1	I am supervising these four machines which produce washbasins. The work I do now is less manual and more mental. I can activate and stop the machine, and I help set up the device better by providing feedback to technology experts
Worker role in I40 work systems	CPO	Now, the worker is close to the mechanical arm. He knows how to craft the product. In case of mistakes of the mechanical arm, he can detect them and stop production
Job enlargement for workers	CEO	Only the workers know how to improve the processes because they operate with these pieces of machinery. We welcome their feedback
Worker role in I40 work systems	Worker 2	We feel safer than before. We cannot enter the robot area when robots are producing, whilst we supervise the process. And the forklift drivers are in safety
Training programme for apprentices	CPO	We hired this young worker. Now he is working in the traditional factory to get craft skills. Then, after a preparation course, we will move him to the I40 factory as a supervisor

Table 2 (continued)

Topic	Source	Interview excerpts
Low-work quality	CPO	Once, we proposed to production line employees to work on Sunday with well-payed overtime. They refused to work since the works are so physically hard to perform
Low product quality level	CEO	Our organisation based the competitive advantage on the higher quality over the market. The traditional product process does not allow it anymore
Risk of I40 adoption	CEO	We were the first manufacturing organisation in adopting these technologies. The risk relies on the lack of best practises to follow during these phases
Joint optimisation of I40 work system	CPO	Workers complained regarding the machinery speed, as they cannot follow the production tasks properly. Therefore, we reduced that speed since we do think that quality comes chiefly from human work
The adoption process of I40 technologies	CPO	"We hired two technology experts to automate the process and teach workers how to use the novel machines. We also help workers to understand the machine proving vocational courses outside the firm" (CPO)
The adoption process of I40 technologies	CPO	In the beginning, workers were contrary to these technologies because these pieces of machinery automate the production. After some months, they thanked us because these technologies helped them to operate in a better way and with better conditions
The motivation of the I40 adoption	CEO	We do not want to import ceramics because we know how to produce it in a better way. Our strategy is to increase the quality of our products. If we import ceramics and we produce 5000 products fewer, We have to fire 50 people. For us, Industry 4.0 was the way to maintain stable employment and optimise production

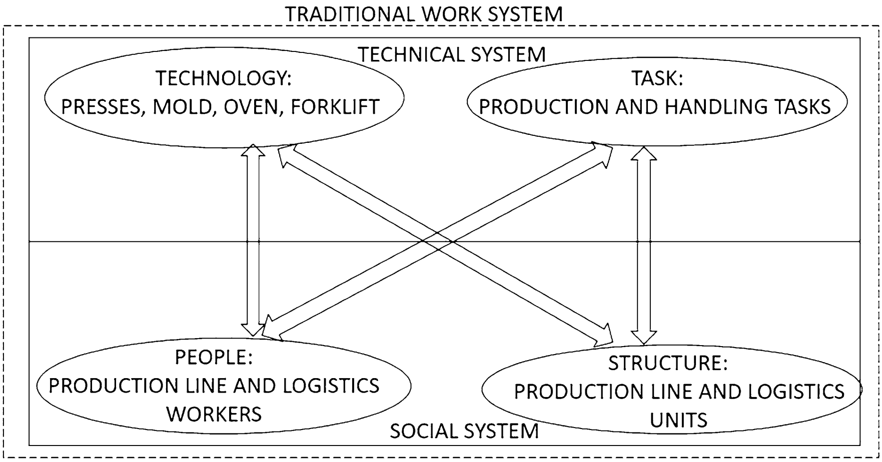

Fig. 2 The traditional work system

The traditional work system

The unit of analysis is a medium-sized Italian manufacturing organisation of the sanitary ceramic industry employing around 200 workers located in the Lazio region. The organisation produces bathroom ceramics with a creative design and enduring materials, and it is attentive towards environmental sustainability and innovation in the product and process. The traditional work system includes all the activities accomplished during the traditional production process from the production of the goods to the logistic unit. Figure 2 summarises the main components of the traditional work system.

The traditional production process consists of three phases: primary, secondary, and support. The primary phase encompasses all the activities needed to prototype and produce the goods. In the first step, workers are in charge of production tasks. They realise a series of chalk moulds in the shape of the sanitary ceramics. These chalk moulds dry in the desiccation room for 15 days. Afterwards, workers pour the ceramics' main elements, vitreous china and fireclay, into these chalk moulds and leave them there for some days.

After that, these moulds are opened to extract the raw and humid sanitaryware. The products created in the following phase are entirely handmade. Expert artisans place these articles over lathes and the complete manual refining of the sanitaryware's shape.

After that, the products are dried through continuous ventilation over a drying belt and thoroughly inspected. Those products which pass the inspection are enamelled by highly specialised workers in cabins and then baked in a high-temperature oven. At the end of this process, the finished goods undergo a quality control check, and those in compliance are packed and stored in the warehouse by workers using a forklift.

Goods which do not pass the quality inspection are destroyed and recycled. Such articles are reprocessed in the secondary phase to address production mistakes. Finally, in the support phase, workers prepare the product for shipment and ensure disposal of the waste produced in the process.

The major concerns regarding the traditional production process are as follows:

- *Inefficient technical system* Although workers were experts in production tasks, the technical systems employed in the production process were inefficient, which resulted in a high rate of semi-finished products that had to be reprocessed or recycled.
- *Lack of apprentices* The human resource department struggles to find young apprentices to hire along the production line to replace old workers. This issue is due to the awareness that the ceramic production operations are demanding and pose several work hazards (Dantas de Sena Junior et al. 2016).
- *Issues during the handling of products* During the transport via forklifts driven by workers, mishaps occur because of incorrect placement of the goods or use of brakes.
- *Low-quality level of product* The organisation bases the competitive advantage on higher product quality. However, competitors have reached the same quality level through their production processes. The traditional work systems cannot support this strategy anymore.
- *Low quality of work* The traditional work system involves demanding tasks, which is demotivational and stressful for workers.

The adoption process of Industry 4.0

The management of the organisation decided to adopt I40 technologies to innovate the traditional production line. They chose an organisation leader to develop manufacturing pieces of machinery and also guide the adoption phase. The CEO emphasised the risks regarding the adoption phase of I40 technologies. The organisation was the first mover in adopting these novel technologies. The I40 pieces of machinery required a reengineering of the production process and a physical factory layout redesign due to several large-sized pieces of machinery.

The management decided to adopt autonomous machines—like self-driving forklifts, robotised arms, and fully automatic conveyors—to produce products and move them from one phase of production to another to address the traditional work system issues. The technology developer manages the end-to-end integration of I40 technologies by interconnecting their control systems with the CPS that govern the technologies. The management planned the innovation and discussed the plan with all workers.

The management motivated the adoption of these technologies, because they are necessary to guarantee the company's long-term survival in a market dominated by low-cost producers in developing countries with low labour costs. The adoption phase lasted 5 years.

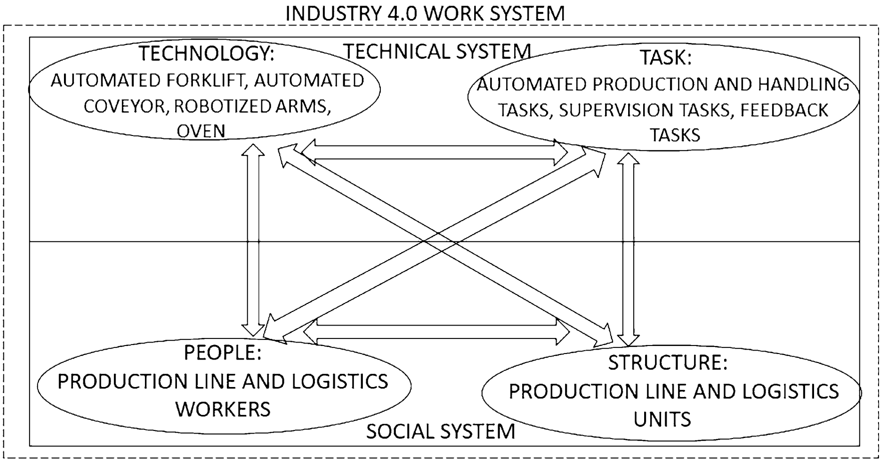

Fig. 3 The Industry 4.0 work system

This innovation significantly changed workforce operations and required workers with digital competencies. The company offered workers the opportunity to retire or leave the position if they were unwilling to learn new skills. All those who accepted the offer to stay were able to attend vocational training courses provided by the technology developers. The reaction of workers was initially adverse, because they expected these technologies to kill their jobs through automation. Soon, their response became favourable, because workers comprehended that these technologies only automate their demanding muscular activities and improve their work conditions.

A team composed of technicians and managers led the I40 adoption. The technicians acted as facilitators between the production line workers and the management to reach both systems' joint optimisation (Mumford 2003). The management stated that the main issue was the speed of I40 technologies, which hampered workers in the management of their operations. Accordingly, technology experts adjusted the speed of I40 technologies. Thus, workers can manage the machinery and I40 technologies to maximise production.

Finally, the organisation maintained the traditional work systems to produce goods with a demand level which does not justify the high fixed costs of the I40 work systems.

The Industry 4.0 work system

The I40 work system includes all the activities during the novel production and logistics units. Different kinds of robots take on hard muscular work previously performed by workers. By applying the sociotechnical lens, Fig. 3 summarises the main components of the I40 work system.

Along the process, workers act as supervisors. They check whether the pieces of machinery are in compliance with guidelines and they evaluate the quality of

Table 3 Industry 4.0 work systems' improvement

Improvements in Industry 4.0 work systems	
Technical systems	Social systems
Output quantity increased by 30%	Safer work environment
Higher product quality	Reduction of work incidents
Increased gamut of products	Higher job satisfaction
Reduction of defects from 30 to 9%	Less intense work
	Workers as supervisors
	Better training programme

the product at each production phase. The products are then placed on shelves and moved by autonomous fork trucks along the assembly line and eventually stored in the warehouse. Whether the workers mark the part as defective or damaged, the trucks deliver it to a secondary phase. Furthermore, technologies digitally trace the complete production process. The traceability of data concerns the lead time, the machines that processed the product, and the workers controlling or operating them.

Also, production line workers are in charge of providing feedback to technology experts to improve technology operations and avoid issues that occurred along the line.

Findings and discussion

This section presents the improvement of I40 work systems and their enabling factors and thus answers the research question.

Improvements in Industry 4.0 work systems

I40 adoption led to improvement in the technical and social work systems. Table 3 summarises the improvements for both systems.

Regarding the technical systems, the organisation increased output quantity by 30% and the gamut of products offered to customers from 11 to 16. I40 adoption also reduced the lead time. I40 adoption increased the quality level of the products. In the traditional production process, the organisation only used traditional ceramics mixture. In contrast, in the I40 production system, the traditional ceramics mixture can be mixed with different minerals (such as gold and silver). According to the CEO, these technologies allowed the organisation to govern their production processes, creating more practical and enduring products with a refined design, leading to a higher quality product.

Moreover, the shift of operations from workers to autonomous robots that took over all the physical work also contributed to reducing defects and damaged products during the transport, which decreased from 30% down to 9%. Still, thanks to the CPS, these technologies improved product tracking, reducing measures of order inaccuracy. CPS also continuously analyses information concerning the processes and provides comprehensive reports on the machinery status and predictions regarding future production trends.

Regarding the social systems, I40 adoption contributes to a safer and healthier work environment. The I40 technical system alleviated several issues, such as using dangerous materials that increase powder in the plant and pollution in the air. Furthermore, demanding muscular tasks are now performed by machinery, reducing the likelihood of workers coming to suffer from occupational diseases. At the same time, the automation of such operations reduced the number of work incidents, particularly in the handling phase of products, and increased the satisfaction and life quality of workers. Also, workers enriched their tasks, because they supervised technologies and provided feedback to technology experts to improve I40 technology operations and avoid issues that occurred along the line.

Finally, the management proposed a better and articulated training programme to encourage young workers to become apprentices. Contrary to the traditional production process training that involved only a short period of training on the job on the machines, the apprentice for I40 line initially learned the artisanal mastery of crafting ceramics into the traditional work systems. They are then moved into the I40 work systems when they have acquired enough knowledge of ceramic production. Apprentices are also enrolled in vocational training to develop digital competencies to manage these technologies. Thus, they contribute to maintaining a stable I40 production process. Accordingly, this programme allows developing proper competencies to work in the ceramic industry and makes for more engaging work. Similarly, the management also enrolled experienced workers in training courses to develop and enrich their digital skills.

Enabling factors for Industry 4.0 adoption

Applying the STP lens, this investigation pinpointed three sociotechnical enabling factors for an effective I40 adoption: *a worker-centric work system, unchanged organisational value system and status quo of workers*, *CPS for improving the production process, and an approach of not controlling workers.*

- *Worker-centric I40 work system* The traditional work systems rely mainly on artisanal competences of workers for producing the goods. Human craft, as the CPO said, made quality products. I40 technologies innovated work practises, reducing demanding and mechanical movements that correspond to the absence of task significant elements and allow for job enlargement. Indeed, the worker's role is increasingly fundamental during the production process and through continuous feedback systems. Workers act as supervisors to check control quality. Also, they provide feedback to technology experts to improve the production process.
- *Unchanged organisational value system and status quo of workers* Within the traditional work system, the more competent workers have more experience and competences in crafting ceramics. Instead, the I40 work system requires, beyond these qualifications, digital competencies to deal with I40 technologies. These could cause issues on the organisational value system and worker status quo

within the organisation. For instance, a newly recruited worker possessing higher digital competencies can be considered suitable by the management to work on the I40 assembly line, whilst more experienced workers who do not have those competencies may not. The organisation carried out two actions to address this issue: vocational courses and a training programme in the traditional assembly line for newly recruited workers. Through the vocational courses, experienced workers filled the gaps in their understanding of digital competence. In contrast, the training programme maintained an unaltered organisational value system privileging the ownership of artisanal competence over digital competences.

- *CPS for improving the production process, not to control workers* I40 technologies are often related to control issues because of increasing control and supervision over workers at the operative level that employ these technologies to complete their tasks (Evans and Annunziata 2012; Kagermann et al. 2013; Kang et al. 2016). In our case, CPS acquire data along the entire production process, providing accurate real-time information to the management in terms of production quantity and time for accomplishing tasks. The organisation exploits this information to monitor the process rather than to control the employees. Also, workers contribute to improving the production process by providing feedback to technology experts, which implies that the workers take a proactive role.

Conclusions, study limitation and implications

The study's main contribution is to apply the STP to I40 adoption to illustrate the system improvements and the sociotechnical enabling factors. We used the sociotechnical lens, proposing a full narrative of all the events starting from the organisations' traditional work system, the I40 adoption process, and the new I40 work systems.

The study has implications for researchers and practitioners. Regarding the implications for practitioners, we investigated the I40 adoption process, which can be used as a guideline for similar organisations implementing these technologies. Managers should also consider the users of technologies during the I40 adoption. We highlighted how the management handles the workforce to accept I40 technologies and the importance of training courses to build digital competencies. The shakedown of I40 technologies occurs when workers perceive and comprehend that these technologies increase organisational productivity, work practises, and workforce conditions.

The study is useful for policymakers interested in developing incentives for I40 initiatives. Incentives should be designed both for the purchase of these technologies and for training courses.

Regarding the implications for researchers, the study provides further evidence that there is a need to treat I40 adoption as a larger sociotechnical matter rather than exclusively one of technical system delivery. To advance the topic of I40 adoption, we suggest investigating the barriers and workaround practises that impede successful adoption (Alter 2014). We also call for further studies to detect future digital competences to handle these technologies and investigate the appropriation process, employing the adaptive structuration theory or task-technology fit (DeSanctis and Poole 1994; Goodhue and Thompson 1995).

The study focuses on the vertical integration of I40 technologies. A further step to study the digital ecosystem in the I40 realm is the horizontal integration of technologies amongst organisations. The STP reveals that the integration of novel technologies impacts the organisation's social system, which implements the technology and the organisation of the supply chain (Sony and Naik 2020). Since this discourse is underdeveloped, we encourage scholars to conduct qualitative research, particularly action research, ethnography, and exploration of a single case study to explore the sociotechnical consequences of horizontal integration of I40 technologies.

Moreover, we also encourage scholars to investigate the topic of the end-to-end integration of I40 technologies. In our case, this phase was successful, because the technology developer designed all I40 technologies and their integrable control systems. Therefore, a promising research avenue is to consider the opposite situation by investigating the end-to-end integration of various I40 technologies of different technology developers. What are the sociotechnical consequences for the organisation?

Our study has some limitations. It is exploratory in nature and based on an organisation located in Italy. Our study results are mostly generalisable to organisations operating in the European context that share similar characteristics—industry type, firm size, and level of governmental support for the adoption of these technologies—to the Italian context. Nevertheless, we encourage researchers to investigate the vertical integration of I40 technologies in other contexts and countries, such as developing countries, Asian countries, and North and South American countries.

Data availability The data that support the findings of this study are available from the corresponding author on request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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