

The interplay between smart manufacturing technologies and work organization

The role of technological complexity

Raffaella Cagliano and Filomena Canterino
School of Management, Politecnico di Milano, Milano, Italy

Annachiara Longoni
Ramon Llull University, Barcelona, Spain, and

Emilio Bartezzaghi
School of Management, Politecnico di Milano, Milano, Italy

The role of
technological
complexity

913

Received 13 February 2019

Revised 18 June 2019

7 August 2019

Accepted 16 August 2019

Abstract

Purpose – The purpose of this paper is to provide evidence on how smart manufacturing (SM) affects work organization at both micro-level – i.e. work design, described in terms of operator job breadth and autonomy, cognitive demand and social interaction – and at macro-level – i.e. organizational structure, described in terms of centralization of decision making and number of hierarchical levels in the plant.

Design/methodology/approach – The paper reports on a multiple-case study of 19 companies implementing SM.

Findings – Results present four main configurations differing in terms of technological complexity, and micro and macro work organization.

Research limitations/implications – The paper contributes to the academic debate about the interplay between technology and work organization in the context of SM, specifically the authors find that the level of technology complexity relates to different characteristics of micro and macro work organization in the plant.

Practical implications – Findings offer valuable insights for practice, with implications for the design of operator jobs, skills and plant organizational structure, in light of the challenges generated by the implementation of SM technology. Guidelines on how policymakers can foster the implementation of SM technology to enhance social sustainability are proposed.

Originality/value – This study advances a novel focus in studying SM, i.e. work organization implications of this new manufacturing paradigm instead of its mere technological implications.

Keywords Manufacturing technology, Organizational structure, Plant design

Paper type Research paper

Introduction

Manufacturing paradigms are facing dramatic changes as a consequence of the 4.0 technological revolution. Our study focuses in particular on the concept of smart manufacturing (SM) that refers to networked information-based technologies for manufacturing enterprises (Hirsch-Kreinsen, 2016). So far, the majority of studies focused on technological implications of SM adoption, and its impact on operators' competences. However, there is wide evidence that technological changes often fail due to organizational misalignment, such as lack of employees' empowerment to exploit the new technologies (e.g. Kolodny *et al.*, 1996). Thus, we propose that studying the link between technology and work organization at the micro-level (i.e. work design) and macro-level (i.e. organizational structure) is of utmost relevance, also for SM successful implementation.

The authors kindly acknowledge Laboratorio CISL Industria 4.0, and in particular Luigi Campagna and Luciano Pero as Scientific Committee (together with Emilio Bartezzaghi) for the possibility to use the empirical data coming from their research project.



At a more general level, the interplay between implementation of (new) manufacturing technologies and work organization has been debated since a long time (e.g. Cagliano and Spina, 2000; Trist *et al.*, 2013; Bendoly *et al.*, 2006). Literature on technological implementation in general and on Advanced Manufacturing Technologies (AMTs) – defined as the application of information and communication technologies with the main goal of automating and integrating the different stages of the manufacturing process (Russell and Taylor, 2002; Waldeck and Leffakis, 2007) – has been considered as a reference point for understanding SM implications on organizational aspects. Although SM could be considered a further advancement or extension of the concept of AMTs and other IT-based technologies, there are also unique characteristics of these new technologies that might ask for further exploration of the interplay between technology and work organization (Kusiak, 2018).

Given this, the aim of the paper is to explore how SM technologies interplay with work organization at the micro and macro-level to configure new socio-technical systems. We do so assuming a socio-technical perspective, which considers the company as a system characterized by both technological variables and social variables, such as the people, the organizational structure and the culture. According to this view, both types of variables should be taken into account when designing an effective organization (Trist *et al.*, 2013).

Theoretical background

Work organization in SM setting belongs to the broad category of phenomena related to the interplay between technology and organization. To build a proper theoretical background about the relationship between SM technologies and work organization, different streams of literature have been investigated, due to the interdisciplinary nature of the topic. The main constructs that will be presented in the theoretical background section are the following: the distinguishing features of SM, discussed by organizational, operations management and information system literature; the interplay between technology and work organization based on insights from past and more recent studies about technology implementation and AMTs in the operations management and organizational literature; and recent debates on work organization implications of SM from organizational and engineering literature.

Smart manufacturing

Manufacturing processes are significantly changing as a consequence of the so-called 4.0 technological revolution, but there is a paucity of proved successful cases related to the implementation of SM technologies (European Commission, 2017). The number of theoretical studies and contributions are still greater in number than the studies providing empirical evidence and insights (e.g. Buer *et al.*, 2018; Frank *et al.*, 2019).

SM refers to the pervasive implementation and application of networked, information-based technologies throughout the manufacturing and supply chain enterprise (Davis *et al.*, 2012; Hirsch-Kreinsen, 2016), which results in creating a flexible and intelligent manufacturing system which is able to adapt in real-time to changing conditions (Kusiak, 2018; Wang *et al.*, 2016). SM can be adopted in different variations characterized by different levels of complexity depending on the range and integration of technological applications involved (e.g. Frank *et al.*, 2019; Kusiak, 2018 – see a list in Table I).

Interconnectivity and intelligence features are the characteristics that enable the 4.0 technological revolution, and therefore make SM a new manufacturing paradigm which is different from the previous ones (Frank *et al.*, 2019). Such features and SM technological complexity are challenging organizations to reshape the work environment, working activities and – eventually – the organization of the factories (Maghazei and Netland, 2017). However, empirical evidence on how these technologies and organization design are interplayed is limited.

Category	List of technologies
Automation and advanced manufacturing	Robots Collaborative robots Automatic non-conformities identification in production
Additive manufacturing Augmented and/or virtual reality	Additive manufacturing (3d- printers connected to softwares) Augmented and/or Virtual Reality software and devices for Smart training Smart maintenance New product development Virtual commissioning (digital twin)
Vertical integration and horizontal integration	Simulation of processes (digital manufacturing) Sensors, actuators and programmable logic controllers (PLC) Manufacturing execution system (MES) Enterprise resource planning (ERP) Supervisory control and data acquisition (SCADA) Machine-to-machine communication (M2M)
Remote operations Traceability	Remote production through software and devices Traceability for final products Traceability for raw materials
Artificial intelligence	Artificial intelligence for predictive maintenance Artificial intelligence for production
Energy management	Energy efficiency monitoring system Energy efficiency improving system
Connectivity and analytics -enabling technologies	Internet of Things Cloud computing Big data Analytics

Table I.
Smart manufacturing technologies list

Source: Adapted from Frank *et al.* (2019)

Technology and work organization: findings from previous literature on IT-based technology implementation and advanced manufacturing technologies

The main theoretical lens adopted by the operations management literature when studying the technology-organization design interplay is the socio-technical theory (Trist *et al.*, 2013). In this perspective, workplace is the result of the opportunities and constraints deriving from the available technology (i.e. the production process) and opportunities and constraints of social nature (i.e. the actors involved and their objectives and needs). Opportunities and constraints of social nature are usually analyzed from a work organization and design perspective (e.g. Parker *et al.*, 2017). According to the dominant approach in organization studies, work organization can be investigated at two different levels: the micro-level and the macro-level. In particular, the micro-level refers to work design of the individual roles in terms of: job breadth (also called task variety), as the number of tasks that an individual job has to perform; job autonomy, as the autonomy that an individual has in deciding time and methods regarding core activities; cognitive demand, as presence of monitoring or problem-solving activities; and social interaction, as the exchange of information with other individuals (e.g. Wall *et al.*, 1990). The macro-level instead, typically refers to the centralization of decision making power and hierarchical structure (Mintzberg, 1980).

A first approach that can be of useful reference for SM refers to the broad theme of implementation and adoption of IT-based technologies, such as enterprise resource planning (ERP). This approach takes into consideration users' needs and perception with the concept of task-technology fit (TTF) (e.g. Bendoly, 2007; Bendoly and Cotteleer, 2008; Kositanurit *et al.*, 2006). In particular, TTF is originally defined as "the degree to which a

technology assists an individual in performing his or her portfolio of tasks” (Goodhue and Thompson, 1995, p. 216). In other words, the assumption of TTF theory is that technology positively affect performances if there is a fit between the characteristic of the task and the characteristic of the technology utilized for that task, which is at the basis of users’ reaction and adaptation to the new technology. Many different studies have applied TTF theory to show interesting relationships between users’ perception about the TTF and users’ reaction to the technology (e.g. circumvention of the new technological systems in case of misfit) in the investigation of use of different technologies and different kinds of workplace (e.g. Bendoly, 2007; Bendoly and Cotteleer, 2008). However, TTF has been recently criticized for different reasons, such as the fact that it is not able to clearly separate the characteristics of the technology and the characteristics of the task; that outcomes such as users’ reaction are treated as outcomes of the TTF even if they should be considered as part of the construct; that the majority of the studies do not really study the concept of “fit” since they do not propose technology-task effective pairings in a given context; and for measurement-related issues (see Howard and Rose, 2019). To overcome limitations of past studies, a recent piece (e.g. Howard and Rose, 2019) suggests to measure TTF and in particular the characteristics of the task by using the dimensions of work design (Wall *et al.*, 1990) to map the different characteristics of the tasks, such as task variety and task autonomy. Nevertheless, TTF is a useful reference model because it shows that tasks and technologies may interact to produce effects that are greater than the sum of their parts (Howard and Rose, 2019), bringing the attention on observing the contingencies of the context in which technologies are applied (Bendoly and Cotteleer, 2008).

The interplay between both micro- and macro-level work organization dimensions and technology is also considered by the operations management literature on the adoption of computer integrated manufacturing and the AMTs (Cagliano and Spina, 2000). At the micro-level, some studies show that AMTs increases the job breadth of the operator (e.g. Morris and Venkatesh, 2010); but other studies instead do not support this hypothesis (e.g. Bayo-Moriones *et al.*, 2017). Results are mixed also in terms of job control and autonomy (e.g. Wall *et al.*, 1990), but they seem to support the general argument that AMTs may increase job autonomy both at the individual and team level (e.g. Bayo-Moriones *et al.*, 2017). In terms of cognitive demand, previous contributions show that AMTs may require more monitoring and problem-solving for the operator (e.g. Shulman and Olex, 1985). Finally, evidences about the relationship between AMTs and social interaction are not conclusive. Several studies show how AMTs might decrease the social interaction (e.g. Wall *et al.*, 1990); however, other studies show how AMTs might foster social interaction and team working (Bayo-Moriones *et al.*, 2017; Basaglia *et al.*, 2010). Overall, evidence suggests a shift toward richer and broader jobs, with higher autonomy and social interaction, but also that there is high variation due to a number of contingent factors (Parker *et al.*, 2017). Instead, very little empirical evidence can be found on the effects of AMTs on work organization at the macro-level, i.e. on the centralization of decision-making power and the number of hierarchical levels (Stock and McDermott, 2001).

In addition, both streams of operations management literature on IT-based technologies and AMTs consider that the levels of automation and integration of the technology adopted affect organization design dimensions resulting in different organizational models (Altmann *et al.*, 1992; Zuboff, 1988) and performance (e.g. Cagliano and Spina, 2000). For example, available knowledge shows that companies that implement stand-alone AMTs, instead of AMTs integrated across the different phases of the manufacturing process, do not have significant improvements in performance (e.g. Cagliano and Spina, 2000; Das and Jayaram, 2007). This is particularly true for those systems in which interdependencies between

different tasks, processes and units are high, and where technologies such AMT and ERP should support workers with difficulties associated with breakdowns in information flow (Bendoly *et al.*, 2006). As a consequence, it can be inferred that also in SM implementation, specific characteristics of work at the micro and macro-level might depend on the level of technological complexity, defined as number of SM technologies implemented and level of integration between the different technologies.

Work organization in smart manufacturing

Recent contributions on the organizational implications of SM build on the concept of cyber-physical systems, which are autonomously controlled physical entities (i.e. machines and also single components) that make decentralized decisions, communicating with each other in an internet of data and services (Lee *et al.*, 2015). These studies pertain to two main domains: one focuses on the effects of cyber-physical systems on operators' work design with a systemic view; and one more oriented to study the design of the interface and interaction between the cyber-physical systems and the operator on the single tasks or activities.

Concerning the interplay between cyber-physical systems and operators' work design, theoretical arguments developed so far analyze this broader topic by identifying possible alternative future scenarios often summarized in two opposing views: Automation and job polarization vs complementarity (Ganz, 2014; Hirsch-Kreinsen, 2016; Kurtz, 2014). In the automation scenario, human activities are governed and ruled by autonomous machines. In this case, automation refers to the transfer to the cyber-physical system of tasks related to governance and control of manufacturing processes. Thus, the manufacturing process can be managed by the cyber-physical system thanks to the adoption of sensors and other digital infrastructures. The operator's work is therefore subordinated to the directives of the cyber-physical systems, which become the neuralgic center of the value chain of the manufacturing process. Operator activities are just limited to monitoring the cyber-physical systems. Jobs are characterized by a low number of simple operational activities, with little or no room for maneuver, in a way that can be addressed to as "Digital Taylorism." Within this scenario, there is still space for few jobs characterized by high autonomy and cognitive content, mainly related to the design, implementation and "training" of the cyber-physical systems. In other words, automation implies job polarization, defined as the distinction – brought by the introduction of a specific technology – between operators that perform standard and routine jobs on one hand, and operators or specialists that carry out activities related to control and problem solving on the other hand (Goos and Manning, 2007). In the complementarity scenario instead, automation concerns manual routinized task, while operators would have full control over the cyber-physical systems and would use it to collect information to better control and to improve sub-processes when the right circumstance occurs. We would see a reduction of low skilled manual jobs but there would be an increase of both highly skilled personnel and of operators with average technical qualifications, able to communicate and interact with advanced digital tools (Autor *et al.*, 2003) and a high number of multitasking positions - characterized by a high degree of structural openness, a very limited division of labor and high flexibility (Böhle and Rose, 1992).

The human-centric literature within the engineering field takes a particular focus on the human-machine interplay. Contributions analyze how the automation shape and re-shape tasks performed by operators and decision making, with a design perspective (Bannat *et al.*, 2011; Romero *et al.*, 2016) and study how cyber-physical systems should be designed to support operators in physical and or cognitive tasks when interacting with automated machines, following technological progress and technological constraints and limitations. This stream of literature considers the operator at the center of manufacturing processes and shows how the evolution of traditional manufacturing technology brings a growing

centrality of the cognitive contents of operators' tasks thanks to an augmentation potential of the technologies themselves (Bannat *et al.*, 2011).

Recently this stream of literature focused on SM implementation. For example, Romero *et al.* (2016) proposed a classification of the "Operator 4.0," extending the concept of cyber-physical system by stressing the central role of the operator and the role of technology to "augment" the capabilities and capacity of operators. They talk about the human cyber-physical system, defined as "engineered systems of systems [...], using context-sensitive, advanced communication and adaptive control technologies to support inter-agent systems of humans, machines and software to interface in the virtual and physical worlds towards a sustainable and human-centric production system" (p. 8). They propose specific examples of Operators 4.0 based on their interaction with a specific SM technology. However, they mainly aim at giving prescriptive indications on how to design the human-machine interfaces, without considering the actual impact that technologies have on the organizational characteristics.

The two above-cited literature streams on SM technologies do not provide conclusive indications on organizational implications at the micro-level since they are mainly theoretical speculations of possible scenarios rather than clear indications coming from empirical evidence. Moreover, studies from these domains lack considerations at the macro-level on the organizational structures and models that can better support SM. Therefore, the research framework of the present study builds in particular on the consolidated dimensions of analysis coming from AMTs and IT-based technology implementation studies, which can be considered the "backbone" of the more recent theoretical argumentations about organization of SM (Hirsch-Kreinsen, 2016).

Research questions and framework

To extend previous studies on the interplay between technology and work organization at the micro and macro-level and provide specific evidence related to SM, we adopt the socio-technical systems approach as a general frame for our inquiry. According to this view, it is not advisable to separately design (and manage) the technical and social subsystems; also, it is possible to identify different work organization configurations that are equally effective with the same technology, and that are selected on the basis of social and contingent characteristics (Trist *et al.*, 2013). This approach, in fact, assumes that the co-design of a configuration consisting of both technological and work organization elements is more effective in terms of productivity and competitiveness, and also on employees-related performance (Van Eijnatten *et al.*, 2008).

Following the evidence of the IT-based technology implementation and of the AMTs literature, we expect that different socio-technical system might emerge as a consequence of the introduction of SM, due to different degrees of technological complexity - meaning number of technologies and level of integration between different technologies and processes at a local, process or system level- may enable different choices of work design and different organizational structures at the macro-level (Bendoly *et al.*, 2006). We consider this frame to fit the SM context since the ongoing discussion on the effects of SM technologies on operator roles and their work environment shows how work organization and technology are interdependent (e.g. Romero *et al.*, 2016). Therefore, the following research questions are formulated and summarized in the conceptual framework proposed in Figure 1:

- RQ1. What are the socio-technical configurations that emerge in manufacturing plants that adopt SM technologies?
- RQ2. Does the work organization at micro and macro-levels differ depending on the technological complexity?

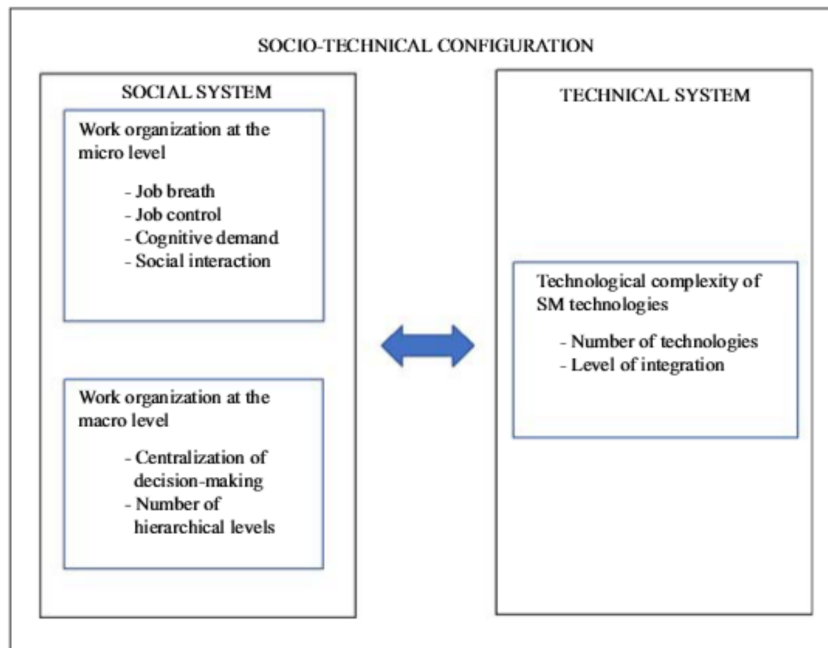


Figure 1.
Conceptual framework
of the study

In line with the socio-technical approach, the socio-technical configuration is mapped as a combination of technical and social system characteristics. The technical system is described in terms of technological complexity of SM technologies present in the company, with the following specific dimensions (Singh, 1997): number of SM technologies implemented; and level of integration between the different technologies along manufacturing processes (the integration is realized through the use of one or more inter-connected technologies). The social system is described in terms of work organization dimensions at the micro-level and at the macro-level (Wall *et al.*, 1990).

Methodology

In order to inquire the above research questions, we applied an inductive methodology (Gioia *et al.*, 2013; Corbin and Strauss, 2008). While deductive studies aim to test hypotheses, our study aims to generate new theoretical implications through an inductive approach. Specifically, a multiple case-study research has been carried out. A case study is an empirical research investigating a phenomenon within its real context (Denzin and Lincoln, 1994). It is a methodology particularly appropriate to cope with situations where there are more variables of interest than data points and where new phenomena are inquired (Yin, 2014). Thus, case study was identified as the appropriate methodology due to the novelty related to SM topic, since this methodology allows to thoroughly inquiry and understand the complexity and the nature of the phenomenon under inquiry (Voss *et al.*, 2002).

Case selection

Purposeful, non-random samples based on theoretical underpinnings are suggested for qualitative studies to increase content validity and generalizability (Eisenhardt, 1989). Thus, selection was performed to control for extraneous factors and increase generalizability. For example, we selected companies of different size (medium and large), different industries, and adopting different SM technologies to increase generalizability but we focused on a single country (i.e. Italy) since the study was framed into a broader Italian project. This choice is also reasonable from a methodological point of view. Country legislation and policies might affect the adoption of SM and the underlying approach to automation.

For example, being the Italian incentive scheme strongly favoring the purchase of new technologies belonging to the Industry 4.0 cluster, many companies just bought the technology without deeply reflecting on the changes they would need to implement it in their processes and organization. At the same time, no incentives were given for organizational redesign and training support, so these aspects were often overlooked. However, the most relevant criteria that did not allow for a random selection was the identification of companies at a mature stage of SM implementation to investigate their adoption process and results. For this reason, the research process was carried out within the “Laboratorio Industria 4.0,” a project managed in collaboration with one of the major Italian Unions, which was interested in identifying some guidelines for the successful implementation of new SM technologies both for the social and economic sustainability of manufacturing companies. The process adopted a collaborative research orientation, in order to achieve rigorous and significant results (Canterino *et al.*, 2016). A research team composed by researchers and union delegates was constituted, with researchers informing the research protocol and process to ensure rigor, and with union delegates being involved in the data collection as insider action researcher (Bartunek, 2007; Maestrini *et al.*, 2016). To ensure comparability of the findings, beyond the formal research protocol, union delegates were trained on interviewing for case study purpose and in their first interviews the union delegates have been always coupled with a researcher (Coghlan, 2007).

The case selection process was carried out in two main steps. First, a list of 35 Italian companies of the manufacturing industries that applied for incentives in the context of Italian “Piano Calenda” (i.e. the national program for incentivizing Italian companies to implement SM technologies through fiscal and tax benefits) was compiled with the help of the Union and on the basis of the previously listed criteria. Second, to ensure that the new technologies were applied in the production process at a stable regimen, and that the effect of the new technologies on the work organization was then observable, data were collected about the actual level of implementation of SM technologies through interviews with the top management, visit to the plants, and secondary data. The final selected sample included therefore 19 case companies, from different industries and of different size, and with different SM technologies implemented that could provide an interesting setting for the study.

Data collection

The unit of analysis is the plant interested by the implementation of SM technologies. Data were collected from October 2016 to December 2017 through semi-structured interviews with employees having different roles at different organizational levels such as operators, supervisors, union representatives, top managers and plant managers. The interviewed roles are different in different companies because for every single case the roles more involved in the implementation of the SM technologies were different. The interview protocol (see Online Appendix A, available at: <https://bit.ly/2ILxFlq>) followed the research framework and was structured in five sections, collecting information about: the background of the interviewee and the company; information on the SM project; job content at the individual and group level; organizational structure and coordination mechanisms; and achieved results and performances.

Data collection was conducted on site (Yin, 2014) in Italian by at least two between researchers and union delegates, following the interview protocol and in line with the collaborative research orientation of the study (Bartunek, 2007). The audio of interviews has been integrally recorded and transcribed. After each site visit, each interviewer edited the field notes and checked them for accuracy. Questions arising from the interview notes were answered by interviewees through follow-up e-mails and telephone calls. Furthermore, after conducting the interviews and the analysis, description of findings regarding their case were shared with informants to increase interpretative validity. In addition, secondary data

about SM technologies implemented by the company were collected from internal documents, archive material and websites, to complement primary data from interviews. Table II summarizes the companies analyzed and the data sources for each company. See Online Appendix B (available at: <https://bit.ly/2ILxFlq>) for description of SM technologies adopted in each company and their level of integration.

Data coding and measurement

About 130 transcribed pages of primary sources were collected. Coding and measurement were performed with the aims of reducing the potential that confirmation bias could influence the results and of increasing descriptive validity and theoretical validity (Strauss and Corbin, 1990). Thus, each transcribed source was read, coded and analyzed by different researchers, through a series of meeting, re-reading and re-coding (Gioia *et al.*, 2013). Through a process of comparison and understanding, the relevant codes were detected. Specifically, the variables have been assessed according to what illustrated in Table III.

Data analysis

The data analysis involved two stages: a within-case analysis and a cross-case analysis. In the first stage, to increase descriptive validity, multiple data sources and multiple researchers were involved in the analysis to triangulate the information. The researchers identified the main concepts and attributes related to each company in terms of SM technologies implementation and work organization characteristics before and after the implementation of SM technologies, by combining data from the interviews and secondary data sources. Then, they met to consider alternative evaluations concerning the concepts, attributes and assessment of the studied company until they all agreed. The output of this stage has been the creation of a first table, describing each case in terms of technological complexity and work organization characteristics both before and after the technological implementation. In the second stage, cross-case analysis was performed to identify socio-technical configurations in the context of SM. First, the plants were grouped based on the SM technological complexity identifying four main technological complexity scenarios. Based on this categorization, similarities and differences among groups of plants in terms of work organization after the introduction of SM were identified. See Online Appendices C and D (available at: <https://bit.ly/2ILxFlq>) for details on cross-case analysis and exemplary coding.

Findings

In order to answer to the research questions plants have been grouped based on technological complexity with the identification of the following combinations: the implementation of a small number of different SM technologies integrated only within the production process (Configuration 1 – process-automated factory); the implementation of a low-medium number of different SM technologies to integrate different processes of the production system (Configuration 2 – partially integrated factory); the implementation of a medium/high number of different SM technologies to integrate different processes within the production system and the production system with other departments, such as Engineering or R&D (Configuration 3 – fully integrated factory); and the implementation of a medium/high number of different SM technologies that integrate internal operations processes also with suppliers and/or customers (Configuration 4 – smart factory). Each group of plants has then been characterized in terms of social system features, namely, job breadth, job control and autonomy, cognitive demand, social interaction at the micro-level, and centralization of decision making and hierarchical levels at the macro-level. This classification allows to highlight four different socio-technical configurations, thus answering to *RQ1* (see Figure 2).

Table II.
Description of
the sample and
data sources

Company	Industry	Size	Respondents' position and No of interviews	Company	Industry	Size	Respondents' position and No. of Interviews
Alfa	Food and beverage	€2.774bn	Plant supervisor; operator; union representative (4 interviews)	Lambda	Pharmaceutical	€1.327bn	Plant manager; operator (2 interviews)
Beta	Furniture	€7,000 employees €173m 348 employees	CEO; operator (and union representative) (2 interviews)	Mu	Furniture	927 employees €399m 5,600 employees	CEO; operator (and union representative) (2 interviews)
Gamma	Textile	€1.5bn	Plant Manager; union representative; operator (3 interviews)	Nu	Mechanic and automotive	€1bn	Plant manager; operator (2 interviews)
Delta	Electronics	€3,200 employees €5.5bn 6,200 employees	Plant responsible; operators (2) (3 interviews)	Xi	Mechanic machines	7,000 employees €1.350bn 4,180 employees	(3 interviews) R&D manager; Plant manager; CEO; operator (2) (5 interviews)
Epsilon	Food and Beverage	€1.7bn	Plant manager; HR Director; union representative (5 interviews)	Omicron	Food and beverage	€2,849bn	Plant manager; HR Director; operator (2) (4 interviews)
Zeta	Energy Utilities	€70bn 11,000 employees	Local network manager; union representative; operator (2) (4 interviews)	Pi	Energy Utilities	1,251 employees €2.560bn 2,900 employees	Local network manager; union representative; operator (2) (4 interviews)
Eta	Mechanic and automotive	€113bn 306,000 employees	Plant Manager; plant specialist; operator (2); union representative (4 interviews)	Rho	Electronic	€7bn 43,500 employees	Plant manager; union representative; operators (2) (3 interviews)
Theta	Food and beverage	€10.3bn 3,600 employees	Plant manager; team leader; operators (3) (5 interviews)	Sigma	Chemical processes	€109m 740 employees	CEO; plant manager; operator (1)
Iota	Furniture	€319m 548 employees	CEO; operator (and union representative) (3 interviews)	Tau	Chemical processes	€30m 70 employees	CEO; Plant manager; union representative; operators (2) (5 interviews)
Kappa	Chemical processes	419 million 1,766 employees	Plant manager; union representative; operator (4 interviews)				

	Dimension	Definition
Technological variables	Number of technologies	Low – one main type of SM technology implemented Low/Medium – 2-3 types of SM technology, but few different specific technologies for each type implemented Medium/High – 4 types of SM technologies High – Above 4 types of SM technologies, and several different technologies for each type implemented
	Level of integration	Integration mainly at production phases level Integration mainly at production processes level Integration between production processes and other departments Full integration of operation processes
Organizational variables	Job breadth	Limited – low variety and number of tasks assigned to the same worker Multi-tasking – high variety and number of tasks assigned to the same worker
	Job control and autonomy	Low – Prescription of work procedure Medium – Prescription of work procedure and autonomy in controlling High – Autonomy in controlling and problem solving
	Cognitive demand dimension	Manual job Both manual and cognitive (monitoring and controlling) job Mainly cognitive (monitoring and controlling/problem solving) job Only cognitive (monitoring and controlling/problem solving) job
	Social interaction	Individual job Formal team working and interaction mainly with the team leader that coordinates individual work Formal team working and intra-team coordination Formal team-working and inter-team interaction
	Centralization of decision making	Centralization at plant management level Decentralization at team level Decentralization at the worker level
	Hierarchical structure	Vertical organization Presence of bottom-up flows in vertical organization Flat organization

Table III. Assessment of variables

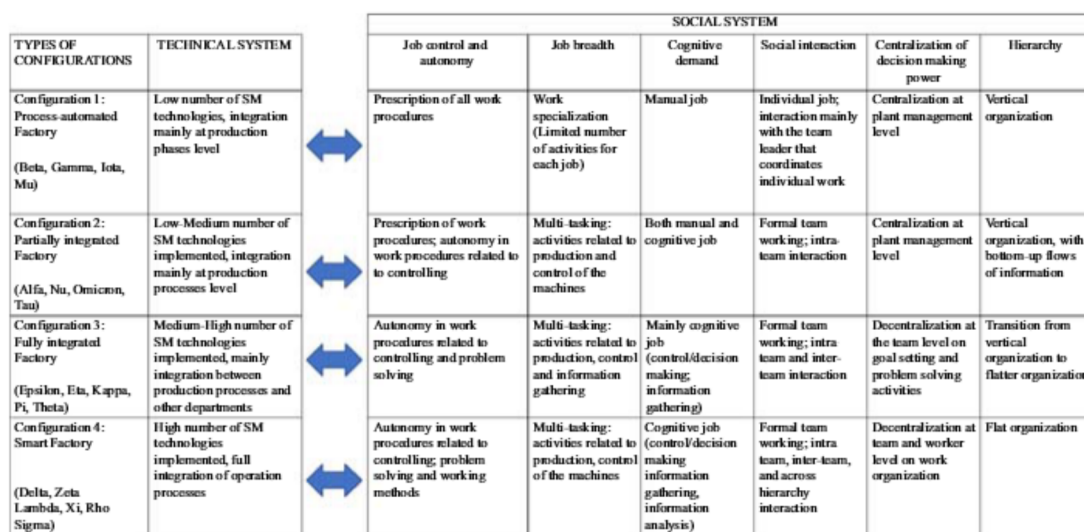


Figure 2. Description of configurations in terms of technical and social system characteristics

Process-automated factories

Results show that process-automated factories – comprised with companies that show limited complexity in SM technology – exploit isolated applications of the SM technology related to automation and advanced manufacturing to increase formalized work design, routines and procedures at the micro-level. After the implementation of the SM technologies, job breadth of operators is low with a limited number of activities performed by the same operator, work is mainly manual and activities are formalized with limited autonomy. The new activities introduced by the SM technology are managed by new dedicated roles. Social interaction is increased, since in all the cases the SM technology allows to implement formalized team working with a formal team leader, but the work remains individual and each operator performs the tasks independently from the others belonging to the same formal team. The interaction is mainly between the single individual and the team leader, and not intra-team between peers. Decision making is centralized at the plant management level, with no delocalized power at more operational levels. The hierarchical structure is vertical as it was before the implementation of the SM technologies. In some cases, when the formal team-working with a team leader is introduced, the number of hierarchical levels of the plant even increases.

One exemplary case of this type of configuration is the Gamma case in the textile industry. Gamma implemented 36 new waving machines that can be programmed centrally and that produce a finished garment in wool or cotton, with a single thread and without seams. After the implementation of this new equipment in some phases of the production line, specialization of job is reinforced. In fact, for each new task introduced by the SM technology – which was mainly manual – a new dedicated role has been created. Some examples of these new roles are: the programmer of the machines, who follows a specific procedure; the maintenance man, who is responsible for maintenance procedures on all the machines including the programmable ones; the model maker:

The same operators that were using the old looms, are now using the modern machines, after some training that was needed to explain them how to manage the same tasks but with a new procedure. For the new tasks, such as the programming of the machine, we decided to create a new dedicated role, to maintain work specialization and the distinction between different types of workers (Plant manager, Gamma).

The work is carried out by teams, because individual tasks are interconnected both in terms of timing and method, but the teams do not have a formal responsibility for the results and no interaction between team members is needed, with the team leader coordinating the activities of individuals:

The kind of activities I carry out with the new machines are very similar to the ones that I was carrying out before, it's just a new procedure. I need to wait for the machines to be programmed but then I do not need additional information from my colleagues on the line. I follow the procedure (Operator of the weaving department, Gamma).

In terms of decision making, SM technologies did not change the centralization at the plant management level in terms of scheduling of activities and monitoring of performance. The hierarchical structure remained vertical with no change in number of hierarchical levels.

Partially integrated factories

Partially integrated Factories are comprised with companies that implement a medium number of SM technological applications that integrates all or almost all the different processes of the production system. Results show that, after the implementation of SM technologies, job breadth of the operators generally increases, with more activities assigned to the same operators, requiring both manual and cognitive work. After the

introduction of SM technological applications, the same operator typically carries out activities related to production and to control of the machines. Work procedures remain formalized, with prescription of activities and limited autonomy. Social interaction is increased, because in all the cases belonging to this group the new set of tasks are more interdependent and the member of the same formal team exchange information not only with the team leader but also with the other team members. Also, the team is often responsible for giving feedbacks and suggestions for further technological improvement. Decision making is centralized at the plant level for all the decisions about scheduling of activities and monitoring of performance. The formal hierarchical structure does not change, with the number of hierarchical levels remaining the same and with the macro organizational structure being vertical both before and after the implementation of the SM technologies. However, in all the cases, after the implementation of SM technologies, some bottom-up flows of information are reinforced.

An example of this type of configuration is Nu case, which is a motorbike manufacturer that introduced robots and a software to partially automate and exchange information about the painting activities across the new product development, manufacturing and assembly process of some specific models of motorbikes. With this new SM technology, no new roles are created, but the operators become multi-tasking, since they carry out activities related to both product transformation, remote control of the robots and quality control. The operators' work content is both manual and cognitive. In fact, some activities such as the application of the sealant on the body of motorbike and the quality control remain manual also after the implementation of the SM technologies. Some new cognitive activities related to the remote control of the robots and data management are also introduced with the SM technologies:

During the painting phase, I can remotely control the painting robots through a tablet. Then, I need to control that the paint is uniform and as a final step I have to manually apply the sealant and grind the camshaft (Operator of the painting department, Nu).

The work is performed in team, and the new software foster intra-team communication and group discussion on the daily work routine. The team is also responsible of suggesting further technological improvements:

We now can communicate more with the colleagues of different shifts through the notes that we leave in the dedicated section of the software on the tablet. Since we are all aligned on what happened, it's easier to discuss in groups possible improvement of the procedure based on what didn't work (Operator from painting department, Nu).

The macro-level organization has not changed with the introduction of SM technologies: decision making is centralized at the plant level and there has been no change in the hierarchical structure which has remained vertical also after the technological change. However, the automation and digitalization of the process, together with the feedback from the teams allows bottom-up exchange of information about the production process:

The new technology allows us to gather very useful suggestions from operators about possible improvements of the technology and of the procedures. Before the implementation of the technology, we had a formal system for suggestions with a suggestion box, where operators at the end of the shift could leave their feedbacks with a hard-copy form. But it was seldomly used. Now they communicate information to us with the tablet almost daily, sharing the suggestions they discussed in teams (Plant manager, Nu).

Fully integrated factories

The fully integrated factories configuration is comprised with companies that implement a high-medium number of SM technological applications along different processes of the

manufacturing system carried out with other departments of the company, such as the Engineering department, the Sales department or the R&D department. This group of companies is characterized by a shift toward less formalized and centralized work routines. After the implementation of SM technologies, job breadth increases since operators become multi-tasking, performing activities related to production, control and information gathering. Job autonomy also increases in activities related to monitoring and controlling. Activities become mainly cognitive and manual work is limited, with machines substituting the human work in performing repetitive and simple tasks. Social interaction is increased: work is performed in team as it was before the SM implementation in all the cases classified in this group; with the interaction being now not only intra-team, but also inter-team. Decision making is decentralized at the team level in terms of objectives and problem-solving. Interestingly, this group of plants shows how the introduction of SM technologies that integrate production processes with other departments allowed to reduce the number of hierarchical levels, shifting from a more vertical organization toward a flatter organization.

One exemplary case of this type of configuration is Theta case in the food and beverage industry. Theta is a manufacturer of branded chocolate and confectionery products that implemented different SM technologies, namely: smart packaging machines with touch screen and simple and intuitive control, and self-analysis in case of stops or technical problems; automated and programmable lifting and palletizing devices; labeling systems, identification and handling systems with bar code recognition and QR code for products and raw materials; and automated warehouse interconnected with SAP management system, enabling to manage stocks and production peaks in real time. The specific nature and characteristics of work of the operators depend on the specific process, but in general the operators are responsible for supervision, control and direct intervention in case of malfunction. After the implementation of SM technologies, the prescriptive procedures are abandoned, and the operator is expected to solve problems and decide what to do by herself:

Before the implementation of the new technology, I had to move pallets partially manually and partially with the forklift. It was a kind of repetitive and strenuous task. Now my daily routine has completely changed: I control smart machines, and I have to solve problems when machines are not able to perform autonomously 100% of the movements. For me, this is a real “philosophical” change of my role, since now I don’t see myself just as an executor of manual activities (Operator of the warehouse, Theta).

Work is performed in teams. Each team has weekly meetings to share objectives and solving problems. Moreover, intra-team meetings are called for improvement of processes across production boundaries:

We realized that SM can really empower employees to have a more active and proactive role not only in their daily routines, but also for continuous improvement and for learning and development of new practices. We are now organizing periodical workshops in which operators work together with people from other departments to identify areas of improvement and innovations related to processes across production boundaries, such as traceability of product and raw materials (Plant manager, Theta).

After the implementation of the SM technologies some mid-management hierarchical levels have been removed, passing from a traditional vertical structure to a flatter organization:

The smart technologies have been implemented with the objective to empower the operators and exploit their potential. For doing so, we have also reduced the number of hierarchical levels and the supervision roles in the plant, empowering more the teams of operators which can autonomously decide how to organize for achieving assigned objectives (Plant manager, Theta).

Smart factories

The last configuration is the Smart Factory. This group is comprised with companies that show a highly integrated SM approach, integrating production processes not only with other departments and processes inside the company, but also with suppliers' and/or customers' operations system. This type of configuration is characterized by a social system in which operators experience autonomy in work procedures, related to controlling and problem-solving. Operators are multi-tasking also in this case: activities are related to production, control of the machines, data gathering and data analysis. The job is mainly cognitive, since the operators are responsible for supervision of the machines and should take decisions on the basis of the available information. Formal team working is present, with intra team, inter-team and across-hierarchy interactions. Decision making on how to organize work is decentralized at team and operator level. Hierarchical structure is characterized by a limited number of hierarchical levels, generally with a flat organization. It is important to underline that the macro organizational structure characterized by flat organization and decentralization was already present in most cases before the SM implementation and was not modified by the SM technologies, as instead happened to the micro-level dimensions such as job breadth, job control, cognitive demand and social interaction. In three cases (namely Rho, Sigma and Zeta) an organizational re-design toward a flatter organization was considered as necessary requirement for the implementation of such technologies, in order to simplify and optimize operations and decision-making processes.

One exemplary case for the Smart Factory configuration is the Xi case in the mechanical industry that produces machines for ceramics, packaging, food and automation. Xi implemented during the recent years many different SM technologies related to connectivity and analytics, vertical and horizontal integration, artificial intelligence, additive manufacturing and energy management. The technological advancement in SM technologies is widespread in the various phases of the production process, with integration with the suppliers and customers. The processes involved by the introduction of these technologies are new product development, manufacturing and assembly and after-sales logistics. New technologies have made it possible to improve customer service – thanks to remote assistance and customer care, to reduce lead times and delivery times, faults and costs associated with waste and rework; further improvements in ergonomics and a reduction in the physical fatigue of operators are also planned. Job breadth, autonomy and cognitive demand of the operators on the production line and also of operators that support customers have further increased thanks to the latest SM technologies. One straightforward example is represented by the operators of the department dedicated to the fabrication of machinery for ceramics production, in which a new 4.0 machine has been developed. This new machine is able to print customized tiles through an additive manufacturing technology that allows the production of tiles with any kind of drawing or graphic required by the customer. Operators working in this department are now asked to carry on, besides traditional activities, new activities related to programming of the machine, but also activities related to the coordination with the R&D department and even related to the support to the final customers in the customization process:

Traditional tiles production is still carried out with standard machines, but all the operators have learned also to work with the new 3D printing machines. This new technology brought a number of new activities for me, for which I have to interact with both the R&D Departments and the final customers. [...] With the support of the sales people, we [team of operators in the tiles production department] can organize meetings in the production department with the customer, in order to explain the main functionalities and the levels of customization that can be obtained, showing sample tiles realized from previous production. Before the implementation of this new machine, it rarely happened to speak with the final customer! I consider this as radical change for my role (Operator in the tile production department, Xi).

About the macro-level, flat organization and decentralization of power were put in place way before the implementation of SM, with the adoption a lean organization, which has been considered by the company as a fundamental aspect to manage technological complexity but also customer satisfaction:

If we put the sensors on the production line without analysing the process, I'm digitizing the waste. First you have to optimize the process, and design the content of the work, and then you have to introduce the technology (Plant Manager, Xi).

The machine must be designed on the operator, and not vice versa, otherwise overheads are created on the single workstation which will worsen productivity and in the end affecting performance towards the final customer (R&D Manager, Xi).

Discussion

Our findings shed light on the interplay between SM technologies and work organization. By providing empirical evidence on the relationship between SM technological complexity and work organization at micro and macro-levels in a plant, the study contributes to the operations management literature on different aspects, that will be now illustrated together with directions for future research and managerial implications.

Peculiarities of SM technology in affecting work organization at the micro-level

First, our analysis of the four types of socio-technical configurations shows how technological complexity is coupled with specific choices in terms of work design at the micro-level. In particular, findings show that for low levels of SM technological complexity – i.e. few technologies adopted in a specific manufacturing process- the associated social system is characterized by not-empowered operators that have limited job breadth and job autonomy, and do mainly manual work with limited exposure to monitoring, control and decision-making tasks. Instead, in presence of higher levels of SM technological complexity, operators are empowered through higher levels of job breadth and job autonomy, and the cognitive demand they experience increases.

If we draw back our results to the literature that analyses the impact SM have on operators' work design at a theoretical level, the first case is aligned with the automation and job polarization scenario; instead the second case is aligned with the complementarity scenario, where the operator has full control over the cyber-physical systems, being multitasking and interacting with the technology to elevate its tasks (Böhle and Rose, 1992; Kurtz, 2014; Ganz, 2014; Hirsch-Kreinsen, 2016). This is interesting because, despite the literature presents these two scenarios as competing explanations of the impact of SM on the work organization, we propose that the level of technological complexity discriminates between these two situations. Specifically, when the application of SM technologies is used to enable the integration with different manufacturing processes and with processes involving also other departments, customers and suppliers, there is an increase in the number of operators' activities. Similarly, higher levels of SM technological complexity also bring an increase in the operator experienced control on the activities performed and decision making, as compared to the situation before the SM implementation. All this brings higher operator cognitive demand and more responsibility. In addition, higher levels of SM technological complexity foster team working and higher interaction because they facilitate the information flow and they increase the interdependency between different activities (Bayo-Moriones *et al.*, 2017; Basaglia *et al.*, 2010; Waldeck and Leffakis, 2007). In other words, findings underline how different levels of integration between processes result in different levels of intelligence and adaptability of the SM system – where intelligence and adaptability are the result of both the technical and the social components of the

socio-technical system. In the presented cases, the higher the intelligence of the technological system, the more empowered and enriched roles are needed, since rich and complex data are generated to support operators in decision making instead of substituting human intelligence. Therefore, technological complexity can be considered as an important variable that pushes toward the adoption of swarm organizations. This view is also in line with the dominant perspective in the human-centric literature, that views SM technology as an enabler of operators manual and cognitive activities (e.g. Longo *et al.*, 2017; Romero *et al.*, 2016). Our findings allow to give both an empirical support to this conceptual position and a further indication on how the organization of work actually changes as a consequence of this potential use of SM technology.

The above-mentioned aspect can also be considered as a further distinguishing feature of SM technologies if compared to other IT-based technologies previously studied in manufacturing settings, as they not only provide information, but they also support the operator in decision making, empowering the more operational roles (Bendoly and Cotteleer, 2008).

Work organization at the macro-level as a possible enabler for SM technologies

At the macro-level, findings provide evidence on the interplay between technological complexity and the work organization despite not being investigated by previous SM literature. In particular, also in this case different levels of SM technological complexity are associated with different work organization characteristics at the macro-level. Specifically, higher levels of SM technological complexity are associated to the introduction of a flat organization in the plant.

We can argue that for the most complex SM technology applications, macro-organizational choices may be considered as enablers of successful technological implementation. In other words, Smart Factories show how highly complex SM technology applications can be successfully implemented only “on top” of a coherent re-organization at the macro-level, with organizational choices being antecedents for the successful implementation of complex integrated SM systems. This consideration supports recent argumentations on possible links between lean organization and SM (Buer *et al.*, 2018), and in particular on the few studies that suggest that lean manufacturing – including the so called “soft practices” are antecedents of SM implementation (e.g. Wang *et al.*, 2016).

Directions for future research

Based on what discussed above, our results suggest that the types of SM technologies implemented and their level of integration along manufacturing processes are key variables to include when studying the effects of SM on the role of the operator and the micro-level work organization. If this element is not considered, biased results could be found leading to misleading implications and categorization of different technologies. This result is for example relevant to interpret results from previous works (e.g. Frank *et al.*, 2019) that consider as separate SM technologies from smart working technologies (i.e. technologies that support and empower operators’ work). Therefore, an interesting area for future research could be related to further clustering of different technologies on the basis of their different purposes and on the basis of associated tasks characteristics. Moreover, this study opens up the need for further research on the macro-organizational dimensions in operations management when studying SM implementation, which have been rather neglected so far (Stock and McDermott, 2001). Further research could also be developed in order to understand if contingent variables other than technological complexity might also influence the extent to which SM lead to the implementation of the swarm organization model.

Finally, this study highlights several further areas that, although not included in the original aim of the paper, could be of utter relevance for future research on organizational implications of SM. These areas relate to the possibility for SM of enabling informal and

bottom-up processes that modify micro and macro work organization (e.g. job crafting) of work, and the implications related to quality of work and stress due to new settings in job autonomy.

The limitations of this study also set the avenues for further future research. First, by studying only Italian cases in which the unions have an active role, we did not take into consideration two “higher level influences” (Parker *et al.*, 2017) such as: the national culture dimensions (e.g. power distance and uncertainty avoidance) that may bias formalization and centralization of decision making related to work organization; and the role of the unions (organizations where unions are highly participating may bring to fostering bottom-up processes). Future studies should take into consideration these dimensions by including in the sample companies differentiated by national culture and with different levels of unionization. Second, since selected companies showed different levels of awareness about organizational structure, further research should be conducted in order to develop a clearer understanding if organizational maturity can be considered as an antecedent of the technological complexity or vice versa. This could bring to a more effective identification of the most appropriate technological choices and work organization implications also in SM scenarios and could inform the process to be used to design and implement SM strategies.

Managerial implications

Besides the theoretical contributions discussed above, this work contributes also to practice by offering to operations managers that implement SM technologies insights on the importance of taking into account the relation between technological choices and the work organization in the plant; our results offer also interesting implications for policymakers that have to plan regulations and incentives to stimulate and support the adoption of such technologies.

For operations managers, the most important implication is related to the importance of considering the plant organizational structure and operators work design together with the technological strategy of the company when introducing SM technologies, since the intelligence and flexibility of the system may have different effects on shaping and re-shaping the role of the operators and their empowerment in the plant. First, companies must understand and reflect on their as-is approach to work organization, namely, the set of choices at the micro and macro-level which characterize the plant before the implementation of SM technology. Second, companies should reflect on which is the organizational configuration that they want to implement in coherence with their SM strategy. These considerations should take into account the actual and desired level of SM technological complexity, which should also be carefully identified. In this sense, this study offers a guide to map work design dimensions at the micro-level (namely operator job breadth, job autonomy and control, cognitive demand, social interaction) and at the macro-level (namely centralization of decision making power, number of hierarchical levels in the plant) that appear to be coherent with different levels of technological complexity in the SM context. Specifically, companies have two main options: adopting SM technologies at an incremental level fostering traditional work organization at the plant level characterized by limited operator roles and vertical organizations; or adopting SM technologies through an advanced approach by creating new organizational environments characterized by empowered operators and flat organization at the plant level. This last option is in line with both recent technological and organizational trends oriented to new forms of work organization fostering both organizational performance and worker well-being (Longoni *et al.*, 2014).

For policymakers, we show that different SM technological settings lead to different approaches of work organization. Policymakers should be very careful when incentivizing the adoption of SM technologies. Both academics and practitioners are debating whether SM will be an enabler of better jobs and operator well-being or be a crucial tool for firm

efficiency but negatively affecting jobs (i.e. reducing work opportunities and salaries) (World Economic Forum, 2016). Our study shows that depending on the SM technological choice the socio-technical configuration to adopt might change with more technologically complex solutions being associated to empowered operators and new forms of work organization; and less complex SM solutions being associated to traditional and mechanistic work environments with limited operator roles and traditional top-down governance structures. Thus, policymakers aiming to increase firm efficiency as well as operator well-being might consider incentivizing not only more advanced and complex SM technological solutions, but also the careful re-design of work organization.

Conclusions

SM is in the spotlight of both practice and research. SM technological change, that may be implemented with different levels of technological complexity, is expected to strongly impact work organization at different levels. However, so far operations management literature and scientific studies have mainly dealt with the technological aspects of SM and their implications on company processes and operator competences. The purpose of this study was to address the understudied area of work organization in the plant, and in particular which is the interplay between technological complexity and work organization at the micro and macro-levels in SM context.

Four configurations have been identified, characterized by different levels of technological complexity, i.e. with a different number of SM technologies implemented and different levels of integration among them. Findings show how low levels of technological complexity in the SM context are associated with an organizational scenario in which operators perform a limited number of tasks, with limited job autonomy, cognitive demand, while higher levels of technological complexity are associated to an increased number tasks, job autonomy and cognitive demand for operators. Similarly, a higher level of technological complexity is associated to decentralization of decision making and a reduction in the number of hierarchical levels.

Assuming a socio-technical perspective, findings empirically support preliminary insights provided by SM studies that foresee the suitability of SM in enabling more effective human-centric and socially sustainable manufacturing and organizational paradigms (Romero *et al.*, 2016). In addition, we identify the level of technological complexity as the discriminant for such work organization in comparison to a traditional one. Moreover, the study offers valuable practical insights related to the importance of including work organization considerations when defining the technological strategy within companies.

To conclude, our findings show how the interplay between technology and work organization cannot be considered in a deterministic way – i.e., there is just one best way to organize work as a consequence of the opportunities and constraints introduced by the new technology – as it is argued in a number of academic contributions – mainly in the manufacturing field – and by many practitioners (e.g. Khanchanapong *et al.*, 2014). A strategic choice is possible to design the work organization in a way that is coherent with the vision and aims of each specific company, in line with what is showed in the large body of literature that studied previous waves of technological change.

References

- Altmann, N., Köhler, C. and Meil, P. (Eds) (1992), *Technology and Work in German Industry*, Routledge, London.
- Autor, D.H., Levy, F. and Murnane, R.J. (2003), "The skill content of recent technological change: an empirical exploration", *The Quarterly Journal of Economics*, Vol. 118 No. 4, pp. 1279-1333.

- Bannat, A., Bautze, T., Beetz, M., Blume, J., Diepold, K., Ertelt, C., Geiger, F., Gmeiner, T., Gyger, T., Knoll, A., Lau, C., Lenz, C., Ostgathe, M., Reinhart, G., Roesel, W., Ruehr, T., Schuboe, A., Shea, K., Stork genannt Wersborg, I., Stork, S., Tekouo, W., Wallhoff, F., Wiesbeck, M. and Zaeh, M.F. (2011), "Artificial cognition in production systems", *IEEE Transactions on Automation Science and Engineering*, Vol. 8 No. 1, pp. 148-174.
- Bartunek, J.M. (2007), "Academic-practitioner collaboration need not require joint or relevant research: toward a relational scholarship of integration", *Academy of Management Journal*, Vol. 50 No. 6, pp. 1323-1333.
- Basaglia, S., Caporarello, L., Magni, M. and Pennarola, F. (2010), "IT knowledge integration capability and team performance: the role of team climate", *International Journal of Information Management*, Vol. 30 No. 6, pp. 542-551.
- Bayo-Moriones, A., Billon, M. and Lera-López, F. (2017), "Are new work practices applied together with ICT and AMT?", *The International Journal of Human Resource Management*, Vol. 28 No. 4, pp. 553-580.
- Bendoly, E. (2007), "Resource enablement modeling: implications for studying the diffusion of technology", *European Journal of Operational Research*, Vol. 179 No. 2, pp. 537-553.
- Bendoly, E. and Cotteleer, M.J. (2008), "Understanding behavioral sources of process variation following enterprise system deployment", *Journal of Operations Management*, Vol. 26 No. 1, pp. 23-44.
- Bendoly, E., Bachrach, D.G., Wang, H. and Zhang, S. (2006), "ERP in the minds of supervisors: joint roles of task interdependence and cultural norms", *International Journal of Operations and Production Management*, Vol. 26 No. 5, pp. 558-578.
- Böhle, F. and Rose, H. (1992), *Technik und Erfahrung: Arbeit in hochautomatisierten Systemen*, Campus Verlag, New York, NY.
- Buer, S.V., Strandhagen, J.O. and Chan, F.T. (2018), "The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda", *International Journal of Production Research*, Vol. 56 No. 8, pp. 2924-2940.
- Cagliano, R. and Spina, G. (2000), "Advanced manufacturing technologies and strategically flexible production", *Journal of Operations Management*, Vol. 18 No. 2, pp. 169-190.
- Canterino, F., Shani, A.B., Coghlan, D. and Brunelli, M.S. (2016), "Collaborative management research as a modality of action research: learning from a merger-based study", *The Journal of Applied Behavioral Science*, Vol. 52 No. 2, pp. 157-186.
- Coghlan, D. (2007), "Insider action research: opportunities and challenges", *Management Research News*, Vol. 30 No. 5, pp. 335-343.
- Corbin, J. and Strauss, A. (2008), "Basics of qualitative research: techniques and procedures for developing grounded theory", Sage, Los Angeles, CA.
- Das, A. and Jayaram, J. (2007), "Socio-technical perspective on manufacturing system synergies", *International Journal of Production Research*, Vol. 45 No. 1, pp. 169-205.
- Davis, J., Edgar, T., Porter, J., Bernaden, J. and Sarli, M. (2012), "Smart manufacturing, manufacturing intelligence and demand-dynamic performance", *Computers and Chemical Engineering*, Vol. 47 No. 1, pp. 145-156.
- Denzin, N.K. and Lincoln, Y.S. (1994), *Handbook of Qualitative Research*, Sage, Thousand Oaks, CA.
- Eisenhardt, K.M. (1989), "Building theories from case study research", *Academy of Management Review*, Vol. 14 No. 4, pp. 532-550.
- European Commission (2017), "Digital transformation monitor key lessons from national industry 4.0 policy initiatives in Europe", available at: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Policy%20initiative%20comparison%20v1.pdf
- Frank, A.G., Dalenogare, L.S. and Ayala, N.F. (2019), "Industry 4.0 technologies: implementation patterns in manufacturing companies", *International Journal of Production Economics*, Vol. 210 No. 1, pp. 15-26.
- Ganz, W. (2014), *Welche Rolle spielen die Dienstleistungen in der Industrie 4.0?*, FES-Fachgesprächs Industrie 4.0, Berlin.

- Gioia, D.A., Corley, K.G. and Hamilton, A.L. (2013), "Seeking qualitative rigor in inductive research: notes on the Gioia methodology", *Organizational Research Methods*, Vol. 16 No. 1, pp. 15-31.
- Goodhue, D.L. and Thompson, R.L. (1995), "Task-technology fit and individual performance", *MIS Quarterly*, Vol. 19 No. 2, pp. 213-236.
- Goos, M. and Manning, A. (2007), "Lousy and lovely jobs: the rising polarization of work in Britain", *The Review of Economics and Statistics*, Vol. 89 No. 1, pp. 118-133.
- Hirsch-Kreinsen, H. (2016), "Digitization of industrial work: development paths and prospects", *Journal for Labour Market Research*, Vol. 49 No. 1, pp. 1-14.
- Howard, M.C. and Rose, J.C. (2019), "Refining and extending task-technology fit theory: creation of two task-technology fit scales and empirical clarification of the construct", *Information & Management*, Vol. 56 No. 6, pp. 103-134.
- Khanchanapong, T., Prajogo, D., Sohal, A.S., Cooper, B.K., Yeung, A.C. and Cheng, T.C.E. (2014), "The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance", *International Journal of Production Economics*, Vol. 153 No. 1, pp. 191-203.
- Kolodny, H., Liu, M., Stynne, B. and Denis, H. (1996), "New technology and the emerging organizational paradigm", *Human Relations*, Vol. 49 No. 12, pp. 1457-1487.
- Kositanutrit, B., Ngwenyama, O. and Osei-Bryson, K.M. (2006), "An exploration of factors that impact individual performance in an ERP environment: an analysis using multiple analytical techniques", *European Journal of Information Systems*, Vol. 15 No. 6, pp. 556-568.
- Kurtz, C. (2014), *Mensch, Maschine und die Zukunft der Industriearbeit*, Maschinen entscheiden: vom Cognitive Computing zu autonomen Systemen, Monaco.
- Kusiak, A. (2018), "Smart manufacturing", *International Journal of Production Research*, Vol. 56 Nos 1-2, pp. 508-517.
- Lee, J., Bagheri, B. and Kao, H.A. (2015), "A cyber-physical systems architecture for industry 4.0-based manufacturing systems", *Manufacturing Letters*, Vol. 3 No. 1, pp. 18-23.
- 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 and Industrial Engineering*, Vol. 113, pp. 144-159.
- Longoni, A., Golini, R. and Cagliano, C. (2014), "The role of new forms of work organization in developing sustainability strategies in operations", *International Journal of Production Economics*, Vol. 147 No. 1, pp. 147-169.
- Maestrini, V., Luzzini, D., Shani, R.A.B. and Canterino, F. (2016), "The action research cycle reloaded: conducting action research across buyer-supplier relationships", *Journal of Purchasing and Supply Management*, Vol. 22 No. 4, pp. 289-298.
- Maghazeei, O. and Netland, T. (2017), "Implementation of industry 4.0 technologies: what can we learn from the past?", *IFIP International Conference on Advances in Production Management Systems*, Springer, Cham.
- Mintzberg, H. (1980), "Structure in 5's: a synthesis of the research on organization design", *Management Science*, Vol. 26 No. 3, pp. 322-341.
- Morris, M.G. and Venkatesh, V. (2010), "Job characteristics and job satisfaction: understanding the role of enterprise resource planning system implementation", *MIS Quarterly*, Vol. 34 No. 1, pp. 143-161.
- Parker, S.K., Van den Broeck, A. and Holman, D. (2017), "Work design influences: a synthesis of multilevel factors that affect the design of jobs", *Academy of Management Annals*, Vol. 11 No. 1, pp. 267-308.
- Romero, D., Bernus, P., Noran, O., Stahre, J. and Fast-Berglund, Å. (2016), "The Operator 4.0: human cyber-physical systems and adaptive automation towards human-automation symbiosis work systems", *IFIP International Conference on Advances in Production Management Systems*, Springer, Cham, pp. 677-686.

- Russell, R.S. and Taylor, B.W. (2002), *Operations Management*, 4th ed., Prentice-Hall, Upper Saddle River, NJ.
- Shulman, H.G. and Olex, M.B. (1985), "Designing the user-friendly robot: a case history", *Human Factors*, Vol. 27 No. 1, pp. 91-98.
- Singh, K. (1997), "The impact of technological complexity and interfirm cooperation on business survival", *Academy of Management Journal*, Vol. 40 No. 2, pp. 339-367.
- Stock, G.N. and McDermott, C.M. (2001), "Organizational and strategic predictors of manufacturing technology implementation success: an exploratory study", *Technovation*, Vol. 21 No. 10, pp. 625-636.
- Strauss, A. and Corbin, J. (1990), *Basics of Qualitative Research*, Sage, Thousand Oaks, CA.
- Trist, E.L., Higgin, G.W., Murray, H. and Pollock, A.B. (2013), *Organizational Choice (RLE: Organizations): Capabilities of Groups at the Coal Face Under Changing Technologies*, Routledge, London.
- Van Eijnatten, F.M., Shani, A.B., Leary, M.M. and Cummings, T.G. (2008), "Sociotechnical systems: towards designing and managing sustainable organizations", in Cummings, T.G. (Ed.), *Handbook of Organization Development and Change*, SAGE, Thousand Oaks, CA, pp. 277-309.
- Voss, C., Tsiriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations and Production Management*, Vol. 22 No. 2, pp. 195-219.
- Waldeck, N.E. and Leffakis, Z.M. (2007), "HR perceptions and the provision of workforce training in an AMT environment: an empirical study", *Omega*, Vol. 35 No. 2, pp. 161-172.
- Wall, T.D., Corbett, J.M., Clegg, C.W., Jackson, P.R. and Martin, R. (1990), "Advanced manufacturing technology and work design: towards a theoretical framework", *Journal of Organizational Behavior*, Vol. 11 No. 3, pp. 201-219.
- Wang, S., Wan, J., Zhang, D., Li, D. and Zhang, C. (2016), "Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination", *Computer Networks*, Vol. 101 No. 1, pp. 158-168.
- World Economic Forum (2016), "The future of jobs: employment, skills and workforce strategy for the fourth industrial revolution", Global Challenge Insight Report, World Economic Forum, Geneva, available at: www3.weforum.org/docs/WEF_Future_of_Jobs.pdf
- Yin, R.K. (2014), *Case Study Research: Design and Methods*, 5th ed., Sage, Thousand Oaks, CA.
- Zuboff, S. (1988), *In the Age of the Smart Machine: the Future of Work and Power*, Basic Books, New York, NY.

Corresponding author

Filomena Canterino can be contacted at: filomena.canterino@polimi.it