The impact of smart manufacturing technologies on work and organizational design: the role of technological maturity

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Abstract

The technological revolution, including Smart Manufacturing (SM), is changing manufacturing paradigms. Previous research focuses on technological considerations, disregarding its organizational implications. This study aims at providing evidences on how SM affects organization of work both at the micro level – i.e. job breadth and autonomy, cognitive demand and social interaction – and at the macro level – i.e. centralisation of decision making, hierarchical level and line and staff units configuration. We conducted a multiple-case study of 20 companies implementing Smart Manufacturing. Results presents four clusters of companies different for technological maturity levels and organization of work, contributing both to theory and practice.

Keywords: smart manufacturing, work design, organizational design

Introduction

Manufacturing paradigms are facing dramatic changes as a consequence of the 4.0 technological revolution. Our study focuses in particular on the organizational implications of Smart Manufacturing (SM). SM relates to the diffusion, implementation and application of networked information-based technologies to the manufacturing enterprise (Hirsch-Kreinsen, 2016). So far, the majority of the studies focused on technological implications of SM adoption, and its impact on competences. Studies on the impact of organization of work at the micro level (i.e. work design) and macro level (i.e. organizational design) are still scarce.

At a more general level, the interaction between implementation of (new) manufacturing technologies and organization of work at the micro and macro level has been debated since a long time (e.g. Cagliano and Spina, 2000; Trist and Bamforth, 1951).

We consider the literature on Advanced Manufacturing Technologies as a reference point for understanding SM implications on organizational aspects. Advanced

Manufacturing Technologies, in fact, refers to the application of information and communication technologies whose main goal is the automation and integration of the different stages of the manufacturing process (Russel and Taylor, 2002; Waldeck and Leffakis, 2007). Nevertheless, even evidence on organizational implications of AMT are not conclusive (Parker et al., 2017).

In addition, a crucial point to take into account is that SM entails a wide variety of different technologies. Organizations are implementing them at different paces and with different degrees of complexity, showing different degrees of SM technological maturity.

Given this, the aim of the paper is to explore how technological maturity affects the organization of work at the micro and macro level when introducing SM technologies. We assume the perspective of Parker et al. (2017), considering organization of work as dependent from technology, formulating the following research questions:

- RQ 1: In which way does technological maturity affect organization of work at the micro level in the context of smart manufacturing implementation?
- RQ 2: How the interplay between technological maturity and organization of work at the micro level affects organization of work at the macro level?

In order to answer to these research questions, we conducted a comparative case study involving 20 Italian manufacturing companies in different industries and of different size. The paper is structured as follows. First, theoretical background introduces the SM paradigm and existing evidences related to its organization of work, and additional insights from organizational implications of Advanced Manufacturing Technologies at the micro and macro level are presented, with the identification of the research framework and research questions. Second, methodology is illustrated. Third, findings are presented by illustrating characteristic of four different clusters of companies identified by the level of SM technological maturity and described in terms of organization of work at the micro and macro level. Discussion and conclusions end the paper.

Theoretical Background

Smart Manufacturing

Different conceptualizations and models of the digitalization of the manufacturing process have been proposed and several definitions can be found in the emergent literature, among which: Industry 4.0, Digital Manufacturing, Factory of the Future, Industrial Internet, Smart Factory, Advanced Manufacturing and Smart Manufacturing. We refer in particular to the conceptualization of SM, as it is considered sufficiently broad to encompass different types of technologies, but specific enough to identify an evolution compared to past advanced manufacturing technologies. SM refers to the pervasive implementation and application of networked, information-based technologies throughout the manufacturing and supply chain enterprise (Edgar et al., 2012; Hirsch-Kreinsen, 2016). These information-based technologies show significant variations in terms of application and complexity and, for this reason, several classifications have been proposed.

Given the relative newness and dynamism of the technological environment, together with the absence of a widespread reference model for what concerns the development of SM projects, there are very few aspects in this domain that are able to generate unconditional agreement. One of these is the notion of the huge benefits that companies can obtain when successfully adopting and integrating the new smart technologies. Instead, what it is still under debate is the nature of such benefit. In the literature, especially the practitioner-oriented one, we can find two major schools of thought. The first, which is also the one finding the larger support, states that the greater benefits of

SM are to be found in the operational improvement of production-related processes (e.g. Lorenz et al., 2016). The second, on the contrary, takes a more entrepreneurial perspective and claims that the real power of these technical advancements is the opportunity to radically rethink and entirely rebuild the business model of manufacturing companies (Kautzsch et al., 2016).

Organization of work in Smart Manufacturing: cyber-physical system as unit of analysis

SM has captured the attention of both practitioner and academic debates in recent years, with the majority of the studies still being focused on technological implications for company competitiveness.

A number of studies are facing the key questions of how SM technologies will reshape the work environment, working activities and – eventually – the organization of the factories, but empirical evidence is still missing on this aspect. The studies that focus on organizational implications of SM build on the concept of cyber-physical systems, which are defined as autonomously controlled physical entities (i.e., machines but also individual components) that make decentralized decisions, communicating with each other in an internet of data and services (Lee, 2008). These studies pertain to two main domains, which will be now briefly illustrated.

The first domain is represented by the theoretical contributions that analyze the impact that SM may have on the organization of work, borrowing insights from previous studies that focus on the interplay between technological change and organization and the nature of human work (e.g. Kurz, 2014; Ganz, 2014; Seghezzi 2015; Hirsch-Kreinsen, 2016). Theoretical arguments developed so far analyze this broader topic by identifying possible alternative future scenarios, based on general trends such as up-grading versus down-grading of jobs and skills, or centralization versus decentralization of decision making process. In particular, these scenarios are often summarized in two different possible developments: automation and job polarization versus complementarity (Kurtz, 2014; Gantz, 2014; Seghezzi, 2015; Hirsch-Kreinsen, 2016). In the automation scenario, the human activities are governed and ruled by autonomous machines. The production can be managed by cyber-physical system thanks to the adoption of sensors and other digital infrastructures. Automation refers to the transfer to the cyber-physical system of tasks related to government and control of production. The human work is therefore subordinated to the directives of these systems, which become the neuralgic center of the value chain in the plant. Workers activities are just limited to monitoring and controlling the cyber-physical systems: jobs characterized by a low number of simple activities, with little or no room for maneuver, in a way that can be addressed to as “Digital Taylorism”. In other words, automation implies job polarization, defined as the distinction – brought by the introduction of a specific technology - between workers that perform standard and routine jobs on one hand, and workers that carry out activities related to control and problem solving on the other hand (Goos and Manning, 2007; Frey and Osborne, 2003). In the complementarity scenario instead, workers would have full control over the cyber-physical systems and would use it as any other advanced production technology. This scenario foresees a high level of workers’ specialization and the goal of the cyber-physical systems is to monitor the overall production process, enabling specialized workers to improve particular sub-processes when the right circumstance occurs. We would still assist to a reduction of low skilled manual jobs but there would be an increase of both highly skilled personnel and of workers with average technical qualifications, able to communicate and interact with advanced digital tools (Autor et al., 2003). This kind of scenario implies an organization in which almost every manual routinized task is substituted by automation and what is left is 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 second domain is represented by the human-centric literature from engineering field, which analyzes SM technological implementation with a particular focus on the human-machine interaction (e.g. Romero et al., 2014). Contributions from this domain analyzes how the automation shape and re-shape tasks performed by humans in terms of physical tasks or cognitive tasks, and in terms of decision making, with a design perspective (Abbass et al., 2016; Bannat et al., 2011; Fantini et al., 2016; Romero et al., 2016). In other words, these contributions study how cyber-physical system 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. Literature show how the evolution of traditional manufacturing technology has bought to a growing focus on the design of the cognitive tasks when designing the human-machine interaction (Bannat et al., 2011). Obviously, this stream of literature is now dealing with 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. They talk about 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 (e.g. Smarter Operator as the operator interacting with intelligent personal assistant technology; Healthier Operator as the operator interacting with wearable tracker technologies).

The two above-cited domains do not provide conclusive empirical evidence on organizational implications of SM at the micro level. Moreover, studies from these domains lack considerations at the macro level on the organizational structures and models that can better support SM. Therefore, a review of the more general debate about the interplay between technology and organization of work has been carried out focusing in particular on contributions that study organizational implications of Advanced Manufacturing Technologies (Russel and Taylor, 2001).

Evidences from Advanced Manufacturing Technologies studies

The interplay between technology and organization of work is a complex phenomenon, which has been studied by many different disciplines with different approaches (e.g. sociology, HRM, operations, etc.), which show contrasting evidence (Parker et. Al., 2017). For the purpose of this work, we looked in particular at literature from operations management and HRM areas that studies Advanced Manufacturing Technologies (AMT). AMT relates to computer-based technological advances whose main goal is the automation and integration of the different stages of the manufacturing process (design, manufacturing, planning and control) through the application of information and communication technologies (Russel and Taylor, 2001; Waldeck and Leffakis, 2007). We can therefore assume that SM can be considered as a further declination of AMT classification, and consequently AMT literature that explores organizational implications is a relevant area of investigation for the purpose of this study.

Organizational implications can be investigated at two different levels: the micro level, i.e. work design of the individual roles in terms of job breadth, job autonomy, cognitive demand and social interaction (e.g. Wall et al., 2001); and the macro level, i.e.

centralization of decision making power, number of hierarchical levels, and line and staff units configuration (Mintzberg, 1980).

When looking at the impact that the introduction of AMT has at the micro-level, mixed evidences can be derived on the different dimensions of work design at the micro level. Regarding the job breadth – defined as the number of tasks that an individual job has to perform – and how it is affected by the implementation of AMT, some studies show how AMT increases the job breadth of the operator (e.g. Morris and Venkatesh, 2010). Other studies instead do not support this hypothesis (e.g. Bayo-Moriones et al., 2017). When considering job control and autonomy – defined as the autonomy that the operator has in deciding time, method, and the activities that are not part of the core job – results are mixed (e.g. Wall et al., 2001), but they seem to support the argument that AMT may increase job autonomy both at the individual and group level (e.g. Bayo-Moriones et al., 2010; Patterson et al., 2004). It is important to underline that several studies show how experienced control is directly linked to commitment, satisfaction and stress (Karuppan and Schniederjans, 1995; Pierce et al. 2004), and how "the operators' response to technological coupling is contingent upon their desirability of control" (Dvash and Manneheim, 2010). When analysing cognitive demand dimension - which can be related to monitoring activities or to problem solving activities (Wall et al., 2001) - available knowledge show how AMT may increase both monitoring and problem solving demand for the operator (e.g. Shulman and Olex, 1985). Finally, evidences about the impact that AMT have on social interaction of individual jobs performed by the operators are not conclusive in AMT domain. Several studies show how AMT decrease the social interaction (e.g. Wall et al., 2001). Some studies show instead how AMT seems to foster social interaction and team working (Bayo-Moriones et al. 2017; Basaglia et al., 2010).

When looking at studies that inquiry the relationship between AMT implementation and organization of work at the macro-level in terms of general organizational structure, very little empirical evidence can be found (Gregory and McDermott, 2011; Zammuto and Connor, 1992), making impossible to derive conclusions on what happens to centralization of decision making power, number of hierarchical levels, and line and staff units configuration when introducing AMT.

Another important aspect that is underlined by AMT literature is that AMT implications and success heavily depends on the extent of AMT pervasiveness and integration in the existing manufacturing system. Available knowledge shows how companies that implement stand-alone AMT, instead of AMT integrated across the different phases of the manufacturing process, do not have significant improvements in performance (e.g. Cagliano and Spina, 2000). As a consequence, it can be derived that also in SM implementation, specific characteristics of work at the micro and macro level may depend on the technological maturity, defined as number of SM technologies implemented and level of integration between the different technologies.

Research questions and framework

Based on the above background, we can conclude that even if some indications on the interplay between technology and organization of work at the micro and macro level can be found in literature, they are not conclusive. We assume the perspective of Parker et al. (2017), considering organization of work at the micro and macro level as dependent from technology, and therefore we formulate the following research questions.

RQ 1: In smart manufacturing implementation, in which way does technological maturity affect organization of work at the micro level?

RQ 2: How the interplay between technological maturity and organization of work at the micro level reshape organization of work at the macro level?

Figure 1 summarizes the research framework and research questions of the study.

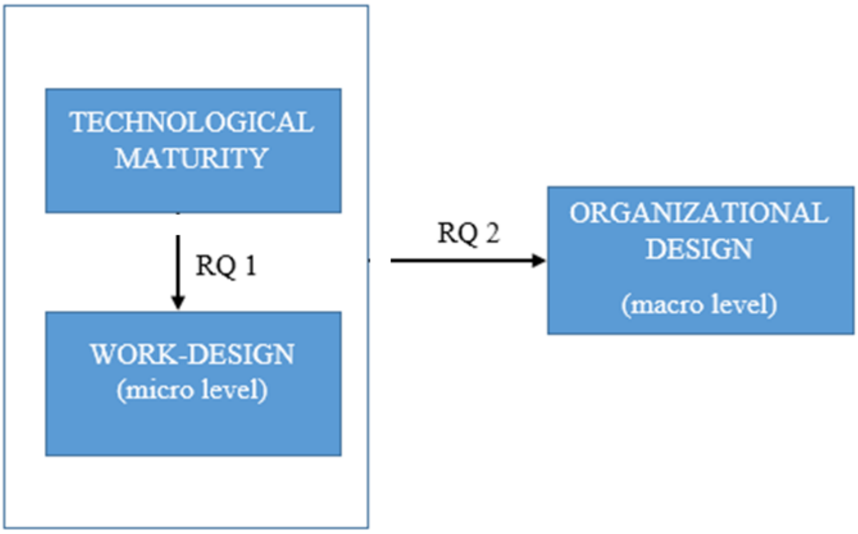

Figure 1 – Framework of the study

Technological maturity is described with the following dimensions:

- Number of SM technologies implemented
- Level of integration between the different technologies (integration at the phase/process level, integration at the production system level, integration with suppliers' and/or customers' systems)

Work design at the micro level is described with the following dimensions, adapted from Wall et al. (2001):

- Job breadth
- Job autonomy
- Cognitive demand
- Social interaction

Organizational design is described with the following dimensions:

- Centralization of decision making power
- Number of hierarchical levels
- Line and staff units

Methodology

In order to inquire the above, 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) and it is a methodology particularly appropriate to cope with situations where there are more variables of interest than data points (Yin, 2009).

Sample and data collection

The sample is composed by 20 Italian manufacturing companies who recently implemented SM technologies, from different manufacturing industries (furniture, chemical, food, textile) and of different sizes. The unit of analysis is the plant or the organizational area interested by the implementation of the new SM technologies. Data were collected through semi-structured interviews to different roles such as operators, supervisors, union representatives and top management. For each company, at least two interviews have been carried out, aiming at collecting data both from management and employee perspective. The interviews were conducted between January and June 2017. The themes included information on the background of the interviewee, information on the SM project, job content at the individual and group level, organizational structure and coordination mechanisms, work environment, workers' satisfaction, achieved results and performances. Each interview lasted around forty-five minutes and was conducted in Italian. The audio of each interview has been integrally recorded and transcribed. In addition, secondary data were collected and analysed to complement primary data from interviews.

Data analysis

Around 130 transcribed pages of primary sources were collected. Each transcribed source was read, coded, and analysed by different researchers, through a series of meeting, re-reading, and re-coding. Through a process of comparison and understanding the most important codes were detected. Data have been triangulated with company reports and secondary-source information of public domain.

Findings

Companies have been clustered based on technological maturity with the identification of following scenario: the integration of a small number of SM applications was pursued only within the process where they were applied (Cluster 1); the communication between different SM applications integrates different processes of the production system, with a low/medium number of applications (Cluster 2) or with a medium/high number of applications (Cluster 3); the integration was pursued also with suppliers and/or customers processes with a medium/high number of SM applications implemented (Cluster 4). Each cluster has then been characterized by work design dimensions of the roles most impacted by the implementation of SM, and by the effect of this implementation on organizational design dimensions.

Tables 2 and 3 show the characteristics of the different clusters at the micro and macro level.

Table 1 – Work design (micro level)-
((*)Increased after the implementation of SM)

Cluster	**Job breadth**	**Job autonomy**	**Cognitive demand**	**Social interaction**
Cluster 1	Low - Limited number of tasks	Low - prescriptive jobs	Limited – mainly manual activity	With the team leader
Cluster 2	Medium (*)	Medium (*)	Mixed evidences - Mainly manual in two cases	With the team leader
Cluster 3	Medium/high (*)	Medium/high (*)	Increased	With the team leader
Cluster 4	High (*)	High (*)	Increased where not already high before	Mainly with the team leader

Table 2 – Organizational design (macro level)

Cluster	Centralization of decision making power	Number of hierarchical levels	Line and staff units
Cluster 1	Centralization for core activities	No change in number of hierarchical levels	No changes in line and staff units
Cluster 2	Decentralization – increased decision making power at the local levels	Reduction or planned reduction of number of hierarchical levels	Reduction of staff units (outsourcing or re-integration of activities in core units)
Cluster 3	Decentralization – increased decision making power at the local levels	Reduction or planned reduction of number of hierarchical levels	Mixed evidence (reduction of staff units only in two cases)
Cluster 4	Further decentralization and increased decision making power at the local level in two cases	No change in the number of hierarchical levels – reduction was already implemented before the introduction of SM technologies	Mixed evidences – (increasing of the staff units in 3 cases)

Results show that Cluster 1, including companies in an early stage of maturity in SM technology, exploits the new technology to increase formalized work routines at the micro level, with no impact on the macro level. For example, in the case of a textile company belonging to this cluster, after the implementation of 36 new waving machines (i.e. advanced manufacturing solutions) in some phases of the production line, specialization of job was reinforced. New roles are dedicated to specific activities, such as maintenance and programming, with a limited job breadth and autonomy, low cognitive demand, no team working, centralization of decision making at the central level, and no change in hierarchical levels.

Cluster 2 and 3, both characterized by an integrated SM at the production level, show how SM enabled an organizational shift towards less formalized and centralized work routines at the micro level and consequently less centralized hierarchical structures at the macro level. For example, in the case of a food and beverage company belonging to cluster 3 which implemented predictive maintenance solutions in all the different phases of the production process, job breadth of the operators on the line increased since operators on the line have added maintenance to their tasks, and their autonomy in decision making have increased. Also, the number of hierarchical levels have been decreased.

Cluster 4, with a highly integrated SM technology - not only at the production level, but also with suppliers' and/or customers' system - show how SM technologies enable further reduction of formalization and centralization of activities at the micro level, while organizational choices and changes at the macro level had been considered as enablers of the changes at the micro level and were put in place before the changes at the micro level. In other words, companies of Cluster 4 show how highly integrated SM technology can be successful 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. For example, in the case of a mechanic company belonging to this cluster, which implemented several SM technologies such as advanced manufacturing solutions, additive manufacturing, augmented reality and cloud manufacturing, integrating these technologies with customers and supplier systems, job breadth, autonomy and cognitive demand of the operators on the production line and also of operators that support customers have further increased. 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 approach, which have been considered by the company as a fundamental aspect to manage complexity and customer satisfaction.

An important aspect to cite is that Cluster 4 shows better performance (in terms of productivity and reduction of waste) then the other clusters.

Discussion

Description of the clusters show how technological maturity discriminates characteristics of organization of work at the micro-level, answering to RQ1. Moreover, the fact that, for Cluster 4 - with SM technologies highly integrated both internally and externally – organizational restructuring at the macro-level has been a necessary antecedent for successfully exploiting SM benefits provides answers to RQ2.

Our findings are in line with the socio-technical view of the interplay between technology and organization. As for all previous technological waves, also the implementation of SM technologies has a relevant impact on the organization of work, as also underlined by this study. A number of academic contributions - mainly in the manufacturing field - and many practitioners consider this impact in a deterministic way (i.e. there is one best way to organize work as a consequence of the opportunities and constraints introduced by the new technology). However, as shown in the large body of literature that studied previous waves of technological change, the interplay between technology and organization is much more complex, and a strategic choice is possible to design the organization of work in a way that is coherent with the vision and aims of each specific company. This view is aligned with the socio-technical system approach, which sees the co-design of technology and organization proved to be more effective in terms of productivity and competitiveness, but also on employees-related performance. Our findings are consistent with this view, by showing how the integration of SM technologies in manufacturing processes should imply the re-design of human work at different levels (e.g. Bodrozic and Adler, 2018).

Conclusion

The study shed light on the interplay between technology and organization in SM scenario. We contribute to theory by showing how micro and macro level organizational dimensions are affected by or affect SM implementation in case of different degrees of technological maturity. We contribute to practice by offering to SM implementers some insights on the importance of taking into account organizational choices at the proper stage of SM introduction and coherently with its (actual or desired) technological maturity.

Limitations and direction for future research

The limitations of this study set the avenues for future research. First, by studying only Italian cases in which the unions have an active role, we did not take into considerations two "higher level influences" (Parker et al., 2017) such as: (i) the national culture dimensions (e.g. power distance and uncertainty avoidance) that may bias formalization and centralization of decision making related to organization of work; (ii) 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.

Second, since SM technologies show different degrees of complexity and operational impact, it may useful to further cluster different technologies and their different purposes, identifying the organizational implications that these different uses cases may have.

Third, 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 organization (e.g. job crafting) of work, and the implications related to quality of work and stress due to new settings in job autonomy.

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