Moving towards digitalization: a multiple case study in manufacturing

Moving towards digitalization: a multiple case study in manufacturing

Andrea Zangiacomi[1], Elena Pessot[1,2], Rosanna Fornasiero[1], Massimiliano Bertetti[3] and Marco Sacco[1]

[1]*STIIMA-CNR, Institute of Intelligent Industrial Systems and Technologies for Advanced Manufacturing - National Research Council of Italy, Milano, Italy*

[2] *Department Polytechnic of Engineering and Architecture, University of Udine, Italy*

[3] *Pordenone Technology Centre, Pordenone, Italy*

Email: andrea.zangiacomi@stiima.cnr.it, (Corresponding Author)

This work presents a multiple case study analysis aimed at depicting a managerial perspective for the implementation of a transformation path towards Industry 4.0 (I4.0) in manufacturing value chain. Starting from the analysis of the literature on values and impacts of digitalization and I4.0 in operations and supply chain management, the research investigates three key dimensions to take into account when defining the digital transformation path from a managerial perspective: investments in I4.0 technologies, ability in perceiving the path towards digital transformation, and knowledge sharing. For each dimension, patterns of managerial practices and related challenges for the implementation of the I4.0 paradigm has been identified, building on the insights and experiences of different players of the manufacturing supply chain (companies, service and technology providers, competence centres, ranging from large enterprises to SMEs). . The results proposed in terms of key challenges, common mistakes and best practices according to the level of digital implementation, represent an overview of reference that can support companies in understanding which are the most important issues to be addressed when facing the adoption of digital and innovative technologies.

Keywords: Industry 4.0; Digital transformation; Operations; Supply Chain; Value chain; Case studies

1. Introduction

Nowadays, pressing challenges such as acceleration of technological progress, scarcity of resources and globalisation, force companies to redefine manufacturing industry towards becoming adaptive and fully connected along value chains and product life cycle phases to create increased value for customers and remain competitive (Khan and Turowski, 2016; Porter and Heppelmann, 2015). Increasing global competition and the need for flexibility in production ask in fact for transformed production processes which enable high level of connectivity and integration between business processes and systems (Fatorachian and Kazemi, 2018) across all organizational levels and all actors of the entire value chain (Erol et al., 2016). Manufacturing firms are increasingly evolving towards the support of global supply chains, enabled also by the new functionalities of the digital technologies (Jardim-Goncalves et al., 2017). In this sense, digitalization – and the adoption of digital technologies in manufacturing – represents a novel paradigm and is initiating an industrial transformation (Agrifoglio et al., 2017), often defined under the label of Industry 4.0 (I4.0) as its application in the manufacturing environment (Chiarello et al., 2018).

After the first introduction of the concept in Germany in 2011, the paradigm of I4.0 has been translated and reinterpreted in theory and practice, resulting in the lack of a commonly shared definition (Chiarello et al., 2018, Liao et al., 2017), with still many uncertain aspects (Yin et al., 2018) and an increasing scope (Camarinha-Matos et al., 2017). Nevertheless, the conceptualization of I4.0 entails the increasing interconnection of machines, smart products, services and systems, and inter-related solutions (Tortorella and Fettermann, 2017) through the combination of many constituent technologies (Chiarello et al., 2018) that enable the communication between digital/virtual and real/physical world (Fatorachian and Kazemi, 2018), the networking and vertical, horizontal and end-to-end integration (Camarinha-Matos et al., 2017;

Schneider, 2018), autonomous data collection and analysis (Buer et al., 2018), the real time synchronization of flows and the unitary and highly customized production (Moeuf et al., 2017).

I4.0 technologies in operations include a variety of enabling production technologies as well as IT solutions that integrate automation with Cyber Physical systems (CPS) and internet of things (IoT) to connect physical devices that are enabled to communicate and interact with each other (Fatorachian and Kazemi, 2018). These technologies are both field-specific and general purpose (Chiarello et al., 2018) and have been clustered in different ways (e.g. Chiarello et al., 2018; Fatorachian and Kazemi, 2018; McKinsey Digital, 2015; Xu et al., 2018), according to their nature or the context of application. For example, Ben-Daya et al. (2017) show that IoT (and related technologies such as smart things and RFID tags) has a key role and impact in various supply chain processes and areas of supply chain management, from sourcing to reverse logistics. Conversely, the methods and materials used in direct digital manufacturing, or 3D printing, vary accordingly to the application and the type of product or prototype (Holmström et al., 2016). A further example regarding clustering is the inclusion of virtual and augmented reality technologies under the label of "big data" (Chiarello et al., 2018) or human-machine interaction (McKinsey Digital, 2015).

Focusing on the operational level, the adoption of I4.0 technologies has been proved to enable the achievement of a higher degree of customization of products and connected services, the automation and optimization of operations, and improved information sharing, decision-making, resource productivity, flexibility and collaboration (Agrifoglio et al., 2017; Fatorachian and Kazemi, 2018; Moeuf et al., 2017). This transformation has then extended from the production to the whole value chain and the business models, making them flexible and dynamic in matching end users and stakeholders’ requirements (Khan and Turowski, 2016; Oesterreich and Teuteberg, 2016; Schmidt et al., 2015; Schumacher et al., 2016). Nowadays, the traditional supply chain is facing disruptions (Ivanov et al., 2018) and companies are in general unprepared to face the digital economy’s complexities or leverage its opportunities (McKinsey Digital, 2015): even if they have started a digital supply chain transformation, they may lack a clear understanding of what this transformation implies. Companies must develop an environment in which they can manage information and processes simultaneously across the extended supply chain, evolving towards networks where the single nodes are smart factories connected (Erol et al., 2016): this evolution of supply chain is more connected, intelligent, responsive, and predictive (SAP, 2018).

Implementing a transformation path towards successful adoption of I4.0 technologies and practices implies both disruptive changes and far-reaching opportunities in improving competitiveness for companies, starting from the manufacturing industry. Indeed, beyond technological issues, a digitalization path requires to consider also the advances at managerial, organizational and strategic level (Schumacher et al., 2016), resulting in several challenges for managers to successfully implement a I4.0 transformation (Schneider et al., 2018). Previous literature mainly focused on specific topics such as factors influencing the potential use of I4.0 (Schmidt et al., 2015), the relationship between I4.0 and lean manufacturing (Buer et al., 2018; Tortorella and Fettermann, 2017), the new skills required (Skevi et al., 2014). Nevertheless, the structural shifts following the increasing adoption of digital technologies are not yet well understood (Holmström et al., 2016), many aspects are still unknown and uncertain (Yin et al., 2018) and worldwide companies are still investigating the supporting practices and benefits of the I4.0 paradigm (Buer et al., 2018).

The goal of this work is to investigate managerial practices following the adoption of I4.0 technologies in manufacturing companies, building on the practical insights gained from different actors along the manufacturing value chain already involved in a digital transformation path and facing related challenges. The study aims to contribute to the ongoing debate on the implications of the digitalization and I4.0 evolution for the field of operations management (Schiavone and Sprenger, 2017), by exploring the experienced challenges, the enablers to be leveraged and the involved managerial processes and value chain actors. With the purpose of drawing a better picture of digital transformation in operations management (Gölzer and Fritzsche, 2017), and specifically in the 'manageable issues that can be influenced *directly* by company managers' (Schneider, 2018), the research questions were formulated as follows:

RQ1. Which are the key dimensions to take in account when defining the digital transformation path from a managerial perspective?

RQ2. How are manufacturing companies facing the transformation path following the adoption of digital technologies? Which are the challenges and current practices?

A set of business cases including different players in manufacturing value chain of northern Italy facing this path and ranging from large companies to SMEs, technology and service providers to competence centres, have been selected and analysed in order to address these points.

This paper has been organised in the following way: section 2 focuses on the research backgrounds and presents a literature review on the main dimensions of analysis for a digital transformation path. Section 3 describes the methodology adopted highlighting the research questions and related research design and methods, i.e. the multiple-case analysis, data collection and analysis. In Section 4, business cases presentation and findings in terms of practices and challenges for the digital path are described. Results are then discusses in section 5 and finally, conclusions are drawn in Section 6.

2. Theoretical background

Nowadays, the adoption and exploitation of digital technologies have dramatically changed business processes and affected the overall business outcomes. This is true especially for manufacturing companies, where the adoption of I4.0 technologies involves connectivity and integration among activities and stakeholders at all levels (Müller et al., 2018; Khan and Turowski, 2016). I4.0 includes a variety of technologies that connect and integrate physical devices, intelligent machines and human actors enabling the digitisation and automation of the operations, the value chain and the business model (Oesterreich and Teuteberg, 2016; Schmidt et al., 2015; Schumacher et al., 2016). While emerging as a technology-based manufacturing paradigm, I4.0 brings new challenges at different levels of manufacturing contexts (Holmström et al., 2016) and novel opportunities in terms of both new business models and new operational and organizational structures, resulting in a fundamental revolution (Fatorachian and Kazemi, 2018). In this sense, shifting to I4.0 practices requires focusing on proper strategies, mechanisms and capabilities. Nevertheless, a detailed roadmap for the realisation of I4.0 is still missing (Liao et al., 2017), and there is the need to explore the good and best practices and related challenges in the implementation steps of I4.0 in manufacturing enterprises (Müller et al., 2018), in a systematic and integrated way. Evidence from literature highlights that the transformation path of companies towards digitalization requires considering how they are addressing expenditures for specific technologies and implementation efforts towards digitalization, how they are perceiving the changes and challenges encountered, and how they are managing the R&D&I activities in terms of knowledge sharing within and outside company's boundaries.

2.1 Investments in I4.0 technologies

Beyond a strategic vision towards digital transformation, companies should ground on a deep understanding of technologies opportunities (Heavin and Power, 2018) and how to prioritize and invest on them (McKinsey Digital, 2015). Worldwide companies are sharply increasing the quantity and quality of IT investments, aiming to reconfigure or even substitute existing operating models and chase the innovation rate by using digital technologies (McAfee and Brynjolfsson, 2008). Developing appropriate IT capabilities and infrastructure, including process, knowledge and communication technologies, has been recognised among major overarching challenges and driving impacts on performance both at corporate and supply chain level (Kache and Seuring, 2017; Sambamurthy et al., 2003). Digital solutions and technological innovations enabling I4.0 include IoT, CPS, integrated software systems, cloud computing, mobile, big data analytics, machine learning, integrated with new high-tech production processes, such as 3D printing and hybrid manufacturing, and adaptive and smart manufacturing equipment and systems such as collaborative robots (cobots) and machine-to-machine communication (Fatorachian and Kazemi, 2018; Liao et al., 2017; Moeuf et al., 2017; Srai et al., 2016). These are significantly influenced by each other, but differently implemented in different contexts. The diversity in the design and implementation of digital solutions is mainly due to the almost endless variety of their purposes (Gölzer and Fritzsche, 2017). Therefore, a major concern to be considered in the digitalization process in the value chain is a proper formulation of the problem to be solved with I4.0 technologies across organizational levels and actors beyond company boundaries, in order to effectively access and leverage the diverse knowledge sources

(Erol et al., 2016), bearing in mind the risk deriving from security perspective (Khan and Turowski, 2016).

Previous contributions in operations management literature have mainly studied the implications of digital technologies in terms of specific technologies (Xu et al., 2018) or enabled processes such as Big data Analytics (Kache and Seuring, 2017), data processing (Gölzer and Fritzsche, 2017), operations management (Zangiacomi et al., 2017), production planning and control (Moeuf et al., 2018). Companies are recognized to differ both in their technological competence and in their managerial skills and capabilities to manage and assimilate the inputs form the introduction of a new technology (Bessant and Rush, 1995). Therefore, they need to better understand and focus on new individual technologies and their applicability in their specific environments to achieve maximum benefits (Khan and Turowski, 2016), towards a comprehensive digital technology capability (Heavin and Power, 2018) driving flexibility (Ivanov et al., 2018) and responsiveness (Kache and Seuring, 2017).

The targeted development of problem-specific competencies and leveraging current management practices, such as the lean production practices, will then enable to make employees as empowered change agents and therefore obtain larger performance improvements (Tortorella and Fettermann, 2017).

2.2 Ability in perceiving the path towards digital transformation

Companies need to be aware of the changes and challenges encountered while promoting I4.0 initiatives (Moeuf et al., 2017).

The adoption of I4.0 technologies for the management of operations can support the implementation of effective digital business strategies (Schiavone and Sprenger, 2017), with a scaling up of the single enterprise environment (Srai et al., 2016). These should in turn be oriented to provide flexibility and adaptability of the production environment at the process level (Khan and Turowski, 2016). Indeed, the first practical experiences in operations with I4.0 have mainly dealt with prototypes and pilot projects (Gölzer and Fritzsche, 2017). Conversely, there is still uncertainty and ambiguity on how digitalization will evolve the governance structures (Srai et al., 2016). This results in a dilemma on which should be the priorities and the focuses of investments (Heavin and Power, 2018).

The positioning as a user or a provider of I4.0 technologies has a large impact on business models of enterprises (Müller et al., 2018), as it requires the definition of a road map and long-term investments (Khan and Turowski, 2016). Better collaborations between manufacturing enterprises and service providers are key in facing the challenge of an innovation ecosystem governance and supporting the performance monitoring (Jardim-Goncalves et al., 2017). This is possible thanks to a better connectivity, also enabled by the new technologies, between suppliers and customers within the value chain (Müller et al., 2018).

Therefore, projects towards I4.0 and digital transformation can be an opportunity to change – and not only improve – actual processes and seize new opportunities to enlighten new potential benefits (Moeuf et al., 2017). Overall, a successful, long-term transformation path should consider integration of infrastructural capability and connectivity (Srai et al., 2016), moreover a step-wise approach is needed (Khan and Turowski, 2016).

2.3 Knowledge sharing

A key area to be considered in a digitalization path is the proper sharing and integration of knowledge and skills within and across companies' boundaries (Fatorachian and Kazemi, 2018). Companies are challenged to develop the requested skills, competencies and collaboration to engage in an industrial ecosystem in order to properly handle the shift to the new I4.0 paradigm (Schneider, 2018). Beyond the financial investment, a key challenge is indeed represented by the availability of qualified staff at all organizational levels, able to cope with the increasing technological and organizational complexity of operations (Erol et al., 2016).

Critical factors for developing the so-called digital capabilities are the attraction of digital talents and the setting up of a governance that should cross functional departments (McKinsey Digital, 2015). Companies are required to properly balance the integration of data scientists and other staff with a key competence in IT and digital technologies compared to the provision of more training and resources for managers and operations staff (Heavin and Power, 2018). For example, R&D resources could be allocated in the operations department to speed-up the innovation process (Kache and Seuring, 2017). In this sense, existing talents could be retrained, even following the advice and models from educational institutes (Skevi et al., 2014).

Management can benefit from the adoption of the emerging digital technologies as it enables exchanging knowledge and sharing data with the external network and in particular with companies from the same sector or value chain, (Agrifoglio et al., 2017) universities and research centres. Literature widely recognises the importance of the collaborative manufacture capabilities in involving diverse stakeholders in innovating towards I4.0. The achievement of a successful transformation of the manufacturing industry towards this paradigm results in appropriately answering challenges by sharing skill and knowledge according to a networking effort (Srai et al., 2016). Collaboration is in fact at the heart of most challenges in I4.0, and the area of Collaborative Networks can be considered as a major enabler for this industrial transformation (Camarinha-Matos et al., 2017). Along this line, there is the need to leverage both on opportunities for knowledge transfer with innovation intermediaries and elicited by the internal employees. The processes of transformation enabled by the technological innovation are characterised by multiple interactions and the need for systems integration, as often the knowledge on the technology is available from a combination of sources (Bessant and Rush, 1995). Following this, the integration of data (and the analysis of integrated data) requires new methodologies for exchanging, storing and managing the information valuable for a decision making that can lead to a reduction of costs and improved performance (Khan and Turowski, 2016). Moreover, leveraging the value created requires to share feedbacks and the reached outcomes in the different organizational levels of the company and across the value chain (McKinsey Digital, 2015).

3. Methodology

3.1 Research context

This study is part of a research aiming at investigating the implementation level of I4.0 technologies in the manufacturing value chain of the Alps regions. European manufacturing is suffering from loss of production volume share (e.g. due to outsourcing in low cost markets) but is still at the forefront of competitiveness and sustainability in terms of innovative capabilities (Skevi et al., 2014). As digital transformation represents both an industrial and a political issue, most of the European governments have made I4.0 a priority and are adopting large-scale policies to increase productivity, competitiveness and improvement of the high-tech skills of the workforce. Starting from the Industrie 4.0 Working Group in Germany, states are then moving to promote systematic programmes and investments to support the development and enhance the evolution of the industrial production towards these new practices. Among main industrialised countries, Italy has developed national and regional strategic plans providing a wide set of consistent and complementary measures promoting investment in innovation and competitiveness, at regional and national level, such as the Enterprise 4.0 plan. Other relevant Italian implementation actions for the I4.0 path are represented by national and regional clusters on manufacturing. In particular, the National Intelligent Factory Cluster has defined a long-term strategic roadmap for the development of the enabling technologies to face the innovation challenges of the Italian manufacturing industry (Associazione Cluster Fabbrica Intelligente, 2014). On the one hand, these supporting measures resulted in an increasing trend of domestic orders in the industry, a growth in the acquisition of machineries and a better awareness on the need of competitiveness and employment in manufacturing. On the other hand, focusing on the operational field, companies of the manufacturing chain are still struggling to leverage and exploit in a successful and sustainable way the opportunities offered by such technologies.

This research studies the phenomenon of the digital transformation of manufacturing companies in a single country-context, i.e. Italy, following the recognition that country-specific factors are key determinants in the process of technological change (Nuvolari and Vasta, 2015).

3.2 Research design

This research has been designed to have as unit of analysis the organization, i.e. the companies in the manufacturing value chain, but aims to take into account also the interfaces with and the implications on other actors of the supply chain. This allowed to integrate the perspectives of different actors and their different perceptions along the dimensions of analysis in an integrated overview of the digitalization process. A multiple case study was adopted as research design to explore (Eisenhardt, 1989; Voss et al., 2002) the managerial challenges encountered by companies facing the path towards I4.0. Indeed, multiple case study allows cross-case comparison to recognise emerging patterns of relationships among constructs and investigate a contextual phenomenon (Yin, 2013; Eisenhardt and Graebner, 2007) as the difficulties encountered and the practices adopted by companies in the transformation path.

To enhance the reliability and validity of the case research (Yin, 2013), the research protocol has been designed as illustrated in Figure 1, and further described.

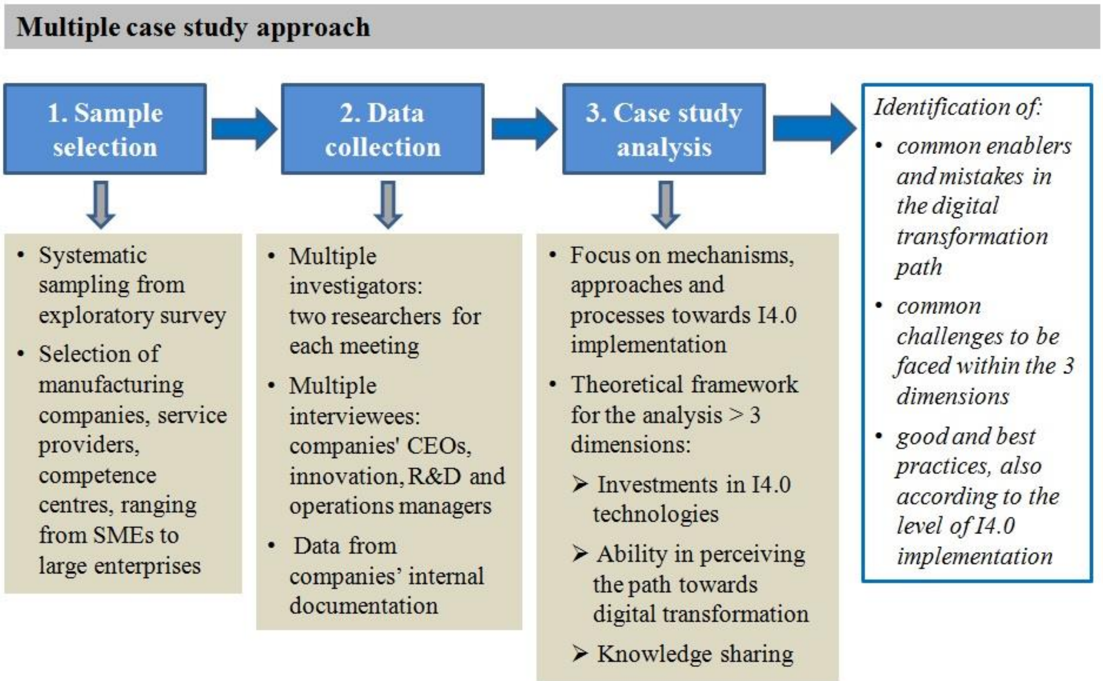

Figure 1: The multiple case study approach adopted in the study

Aiming to investigate the perspective of multiple players, a set of companies from different industries of the manufacturing supply chain in the north of Italy has been identified. The search was conducted starting from the sample of organizations participating in a previous survey (Pessot et al., 2017), based on their role and position in the value chain. The final sample of 20 companies demonstrated to be sufficiently heterogeneous (Yin, 2013) in terms of business, i.e. type of organization and sector, and level of digitalization. In the selection process both the approach embraced by the companies in adopting I4.0 technologies, i.e. how they are actually 'moving towards digitalization', and the level of implementation of this path have been considered. We distinguished the approach into:

- Strategy: the organization has an overall I4.0 strategy in place, with a clear view to innovate the business and address it totally towards digitalization, a constant support from the top management, investments in training and a shared digital culture;
- Goals and KPIs: the organization planned or set clear business goals and KPIs (e.g. for a single o few functions or departments, or starting several I4.0 initiatives to support current business);
- Project: the organization is undertaking a single or few stand-alone projects, involving one function or a restricted team.

. Table 1 provides an overview of the selected cases in terms of type of organization (manufacturing company, service provider, competence centre), size (number of employees), main business, approach embraced in the implementation / adoption of I4.0 technologies, technologies implemented / adopted.

ID	Type of organization	Size (n° employees)	Main business	Approach	I4.0 technologies
MC1	Manufacturing company	<50	Mechanical Manufacturing	Strategy	CPS, cloud computing, software systems
MC2	Manufacturing company	>250	Plant-making and Steel-making	Strategy	Cloud computing, software system, CPS
MC3	Manufacturing company	>250	Home appliance	Goals and KPIs	Software systems, IoT, augmented reality
MC4	Manufacturing company	>250	Wood Heating System	Goals and KPIs	Social media, IoT, software systems, augmented reality, cobots
MC5	Manufacturing company	>250	Professional equipment	Goals and KPIs	Cobots, 3D printing, augmented reality, software systems, IoT, big data and analytics
MC6	Manufacturing company	>250	Mechanics / mechanical engineering (technologically sophisticated mechanical components)	Goals and KPIs	Big data and analytics, cloud computing, virtual reality
MC7	Manufacturing company	<250	Production of combination vehicles for sewer and industrial cleaning for liquid and dry waste	Project	3D printing, software systems
MC8	Manufacturing company	<250	Production of whirlpools	Goals and KPIs	Mixed reality systems, cloud computing

MC9	Manufacturing company	<250	Production of filtration and microfiltration equipment, products and accessories, quality control instruments	Goals and KPIs	CPS, IoT, mobile devices, AI algorithms
MC10	Manufacturing company	<250	Production of special and heavy weight trailers and semi-trailers	Project	Software systems, 3D printing, big data, cobots
MC11	Manufacturing company	>250	Production of high performance rubber soles	Goals and KPIs	3D printing, IoT, big data
SP1	Service Provider	<50	Information Technology	Strategy	Mobile, CPS, software systems, business analytics
SP2	Service Provider	<50	Consulting company in the IT sector	Strategy	IoT, cloud computing, software systems
SP3	Service Provider	<250	International consulting company, support to the development of innovative IT Solutions and Start Ups	Goals and KPIs	Big data and analytics, software systems, mobile
SP4	Service Provider	<50	Training, consultancies for digital projects to companies, development of innovative technologies and support to startups launch	Project	Big data, IoT, AI, software systems
SP5	Service Provider	<50	Traceability and real time information sharing solutions for the supply chain actors of the footwear sector	Strategy	Mobile, cloud computing, CPS
SP6	Service Provider	<50	Consultancy on ICT solutions	Strategy	IoT, software systems, cognitive computing, advanced data analytics, augmented reality
CC1	Competence centre	<50	Advanced Mechatronics	Goals and KPIs	3D printing, cobots, IoT
CC2	Competence centre	<50	Lean management school based on digital pilot factory	Strategy	CPS, cobots, rapid simulation, software systems
CC3	Competence centre	<50	Technology transfer and innovation centre	Goals and KPIs	IoT, AI, CPS, cobots, big data and analytics

Table 1: Overview of the case studies.

The last column of Table 1 includes respectively the technologies adopted by the manufacturing companies, the technologies provided by the service providers (or the ones on which they offer consultancy) and the technologies researched by the centres of competence (or the ones on which they offer support for their adoption). Each case proved to have a certain level of adoption of I4.0 technologies, ranging from IoT to cobots, or demonstrated having a key competence in the adoption or implementation of these technologies, with differential paths. For example, both MC5 and MC7 are implementing 3D printing, but MC5 is extending this technology from the prototyping to the production and identified clear performance indicators in a 3-year scenario, while MC7 is developing a project on the introduction of 3D printed prototypes in the engineering area for supporting product configuration. SP1 and SP6 provide consultancy on data analytics with a dedicated business area, but with different applications: SP1 mainly focuses on manufacturing analytics, i.e. the analysis of production data and performance, integrating the aspects of alignment with strategic goals and business intelligence for decision-making of medium and big companies; SP6 mainly supports small and medium enterprises in applying solutions that integrate technology and competences of human resources in the company core industrial processes.

3.3 Data collection and analysis

The data collection employed both primary and secondary sources. Firstly, per each case in-depth interviews have been conducted with managers having a significant understanding of the challenges faced in the digitalization path (i.e. CEOs, innovation, R&D and operations managers) at company site. Multiple respondents per each case and multiple investigators were involved in the different interview meetings to enhance validity (Yin, 2013) and reliability of the collected data (Voss et al., 2002). Specifically, the interviews were conducted following a research protocol including open-ended and semi-structured questions that were properly adapted and contextualized accordingly to the type of organization, i.e. manufacturing companies adopting one or more digital technologies, providers of digital technologies and connected services, competence centres providing specific competences and knowledge on digital technologies and involved managerial issues. Main areas of investigation were 1) the investments in I4.0 technologies or, accordingly, the support to companies' innovation capacity and competitiveness, 2) the ability in perceiving and facing the path towards digital transformation and the related challenges, 3) the mechanisms for knowledge sharing with a focus on the partnerships and the skills for transferring and implementing I4.0

technologies. The information collected was then integrated by data and internal documentation of companies, aiming to triangulation purposes for consistency of findings and mitigation of bias (Voss et al., 2002; Yin, 2013).

During the first period, the researchers performed data collection and analysis in interaction, in order to eventually review and refine the emerging findings. In the pattern-matching and cross-case analysis (Voss et al., 2002; Yin, 2013), good and best practices for a digitalization path in manufacturing companies were identified. Collected data were distinguished in first-order data, corresponding to informants' views, and second-order data, where coding was undertaken using concepts drawn from the three dimensions identified in literature (i.e. the level of investments in I4.0 technologies, the ability in perceiving the path towards digital transformation, the knowledge sharing). Following the analytic technique of pattern-matching, similarities and differences between data incidents and groups of codes were identified (Eisenhardt, 1989; Yin, 2013), and challenges and possible mistakes for the implementation of the digital technologies and the related outcomes on business processes have been also highlighted.

4. Findings

As a first step for the analysis, the level of digital implementation for the organizations selected has been assessed according to the amount of investment already undertaken in the new technologies and to the level of advancement in their implementation. The results are shown in Figure 2.

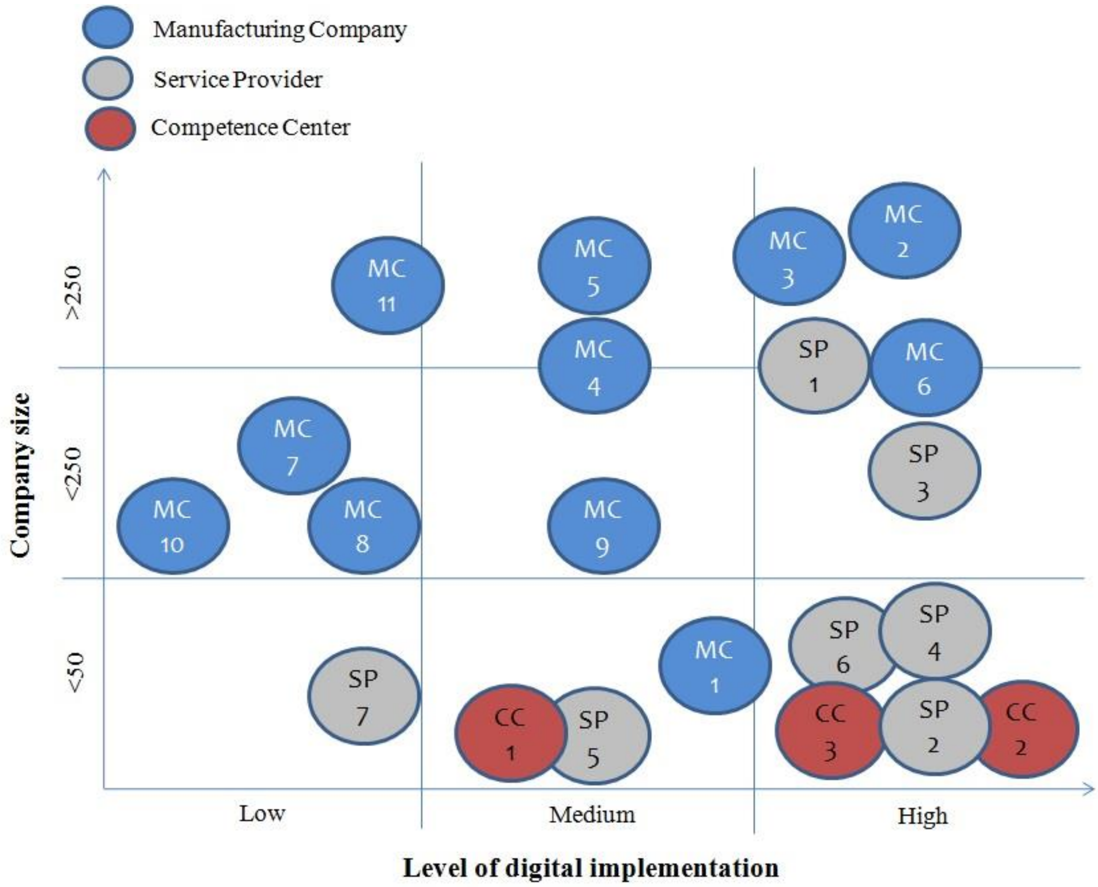

Figure 2: Positioning of case studies according to company size and level of digital implementation.

The analysis on the case studies revealed commonalities and peculiarities in terms of enablers, mistakes and practices implemented in the digital transformation path. The following subsections present the most relevant practices employed in the selected value chain actors according to the three dimensions of *investments in I4.0 technologies*, *ability in perceiving the path towards digital transformation*, and *knowledge sharing*.. From the analysis of practices, basing on a bottom-up approach, related challenges grouping specific sets of practices have been identified and classified.

4.1 Investments in I4.0 technologies

For what concerns the first dimension , one of the most important challenges emerged is to define a clear strategy in which framing investments, avoiding the "stand alone" adoption of a new solutions. The definition of a technological roadmap is thus an essential enabler to accomplish this goal, as highlighted by CC3. SP6 argues that a common error of companies is to consider the introduction of some I4.0 technologies as tactical and not strategic or impacting on the business model, while technological issues should be integrated with operational and organizational ones. Along with this line, company managers should act as receptive decision makers and be guided in implementing concrete choices for a correct use of financial investments, aligned to a clear strategy. This also relates with the importance of understanding on which relevant technologies to focus on according to the specific business addressed and company needs. For example, MC6 found out the importance of simulation and virtual reality as key drivers for the process of new product design. SP2 stresses the importance of IoT and cloud services for the areas of data storage and industrial processes monitoring.

An enabling practice underlined in the analysis is looking for the support of experts and intermediaries to invest efficiently in promising technologies and be guided in the related strategic choices, basing on specific company priorities,. From the one side, CC3 argues that manufacturing companies sometimes fail in identifying proper interlocutors, e.g. organizations playing the role of integrators of the innovation ecosystem. From the other side, actors such as SP1 are evolving from system integrator to ‘digital enabler’ to highlight the role of facilitating the transformation path and framing it as an opportunity of growth for both the provider and the customer in a win-win approach. Another challenge underlined by interviewed organizations in this context is to start the adoption of I4.0 technologies by implementing small pilot projects and facing limited investments. This is argued to support the step-by-step evaluation of the feasibility of a specific technological choice and related opportunities, considering also the scalability of many I4.0 solutions. For example, MC8 argues that many companies start from the digital control of production processes, especially to use data from sensors for predictive maintenance issues, to increase quality and ergonomics for operators, identify bottlenecks and improve integration between departments. MC6 made exploration projects to understand governance issues and at the same time deepen the emerging opportunities for further adoption of I4.0 technologies in the future. MC1 adopted and implemented the digital technologies in a modular approach, starting form small areas where testing and validating related practices before applying them to the overall process level. The initial assessment for addressing the I4.0 investments and testing specific solutions can be done also by exploiting technological demonstrators, as highlighted by CC3, or participating to case studies' sessions where to discuss business cases and evaluate critical issues, opportunities, and also the economic sustainability of the digital transformation, as reported by CC1. Similar options, which are often overlooked, should be better leveraged to enable spreading and cross-fertilizing experiences among companies. This aspect may represent a relevant barrier and is also strictly related with the need to invest – beyond targeted I4.0 technologies – in training specialists to increase focused skills on specific technologies, e.g. through a path of training activities as in MC9, also by stimulating and consolidating a digital culture. Both big companies, as MC2 and MC3, and smaller ones, as MC6 highlighted that real "digital" companies do not only make extensive use of technological innovation, but also stimulate all the human resources, at any organizational level, to be the "bearer" of a shared culture towards I4.0, conveying behaviours, skills and attitudes towards a better understanding and triggering new dynamics for the digital transformation path of the overall company.

Finally, adoption of lean management approaches before investments is recognized by most companies as an important prerequisite and enabler for the implementation of the new solutions. Both MC3 and MC5 argue that the digital transformation would have been more difficult without a clear knowledge of the processes thanks the fundamental implementation of the lean approach. The development of a lean production model resulted in a further flexibility and business expansion in MC1, which was able to become a service provider (and not only a manufacturing company), by reselling to its customers the know-how acquired along the digital transformation path and assisting them in their own one.

Figure 3 shows the main challenges encountered, and practices adopted by manufacturing companies in their transformation path concerning the *investments in I4.0 technologies*, with evidence of the level of digital implementation of cases addressed.

CHALLENGES	PRACTICES IN THE CASE STUDIES	Cases and level of implementation: Low	Medium	High
Defining a specific strategy, avoiding stand-alone implementation of a new technology	Define the company's Smart Manufacturing strategy and identify the key factors to improve market competitiveness			MC3
	Perceive the introduction of some technologies as strategic (and not only tactical), even changing the business model			SP6
	Foresee to guide the company managers in concrete choices for a correct use of financial investments			CC2
	Build a technological roadmap			CC3
	Involve all necessary actors along the value chain (or add new partners) according to the company needs for the adoption of the selected technology	MC11		
Understanding relevant technologies to focus on accordingly to the specific business and needs	Consider cybersecurity to protect sensible data generated and stored in the company and key knowledge		MC4	MC2
	Look for the support of experts to invest efficiently, increase awareness on which technologies are promising, and identify who to ask for specific advices or supply of technologies			SP4
	Start from the values that drive the strategic choices before investing in new technologies			CC2
	Focus on investment priorities (e.g. cobots) of the company	MC10		
Starting with small projects and limited investments, exploiting scalability of I4.0 technologies	Start with pilot projects to evaluate local profitability, feasibility and opportunities for further investments	MC7		MC3
	Undertake the transformation with small steps through "exploration projects" and modular approach to understand short-term dynamics and benefits		MC1	MC6
	Create case studies aimed at solving concrete business cases		CC1	SP6, CC2
	Exploit technological demonstrators to test and highlight related opportunities			CC3
	Evaluate digital control of production processes as the first and safest area of intervention	MC8		
Recognizing the need to invest also in training and culture	Develop and consolidate digital culture and digital skills over time and with different initiatives to innovate continuously			MC2, MC3
	Stimulate a new business culture towards I4.0			MC6
	Forecast higher investments on know-how		MC1	
	Foresee to develop a path of training activities for specialist, focused skills in the digital transformation		MC9	
Adoption of lean management approaches before investing in I4.0	Consider lean as a prerequisite for the digital transformation		MC5	MC3
	Move from lean to digital and from product to service		MC1	CC2
	Structure the organization in order to be leaner, even if it is already flexible and ready to face the new technology adoption			SP3
	Forecast a careful development path of lean techniques in production	MC10		

Figure 3: Challenges and practices identified for the first dimension of analysis.

4.2 Ability in perceiving the path towards digital transformation

Referring to the second dimension of analysis, the first point emerged from several case study is the need to understand how the company business model changes after technology adoption in operations.. This is of fundamental importance in order to properly address company goals and refine or eventually restructure the value proposition. Even if not radically changing the business model, MC4, for example, integrated new services enabled by the adoption of IoT in its operational processes and subsequently in the value offer, resulting in more direct relationships with customers and loyalty building. MC9 is planning to integrate the technologies it invested in to drive the company towards a holistic smart digital business model. With this aims, also resources and processes required by the business model have to be modified accordingly, considering also the implications on the organization due to the new technological solutions...

In fact, beside what concerns investments to have an adequate IT infrastructure, being aware on the changes needed to adapt an organization to I4.0 technologies can be challenging. This is particularly true for what concerns the mind-set of managers: CC3 highlights that usually attention is focused on increasing digital skills of operators without considering the criticality of having managers able to understand challenges posed by this new path. A main mistake can be overlooking the opportunities of integration at several levels, as between business processes and different business units (as experienced by MC2), into a corporate culture and vision of digital processes shared between management and executive levels, as in case of SP6, which subsequently changed the organisational structure. Moreover, the choices of new technologies must be done by considering the legal issues (e.g.: IPR, contractual constraints,…) before the operational ones, as experienced by SP5.

A further element relates with the awareness of existing implementation supporting measures and means, and their matching with real companies' needs. From the one side, MC9 argues that national programmes and policies facilitating investments, as the National Plan Industry 4.0, can be a springboard for a truly exponential growth of companies integrating I4.0 technologies in their overall strategy. MC1 highlights that its main investment has been guided by the participation to a European funded collaborative project, which represented the beginning of a virtuous cycle, leading to further opportunities of innovation and a positive attitude towards the transformation path. From the other side, SP2 observes as a common mistake of manufacturing companies has been a lacking concrete intention to invest in enabling technologies, resulting in a wrong perception of the practical relevance and benefits derived from the fiscal incentives introduced by the supporting plans. Finally, SP4 argues that being conscious of the continuous increase in the accessibility and exploitability of many I4.0 technologies allows to properly evaluate their sustainability and related potentially different applications according to specific needs and requirements. Companies lacking this kind of knowledge are hindered from a proper understanding of benefits and potentials due to the implementation of these novel technologies. For example, MC10 recognizes his low level and scope of implementation of I4.0 technologies as mainly due to the initial "blindness" towards the possible synergies with both suppliers and customers, and the use of technologies in restricted applications, limiting a widespread digital transformation. MC11 argues that involving all partners needed, or adding new partners along the value chain (e.g. for smart materials), and integrating them in the business processes according to selected technologies and strategy is a key enabler. This is strictly linked to the adoption of a proactive approach, which can be challenging for the implementation of a new digital technology. SP3 highlights that a common error of several industrial companies is not having adopted main innovative technologies, trends and management solutions due to reactive (and therefore late coming) approach and low maturity in defining involved processes and resources. This is due to a lack of interest, a problematic involvement of human resources, or the limited exploitation of many technologies. MC8 is developing an attitude towards acting as a “pioneer” in its sector in terms of digital transformation to motivate decision making, boosting implementation process and overcome the reactive or negative approach towards the internal perception of the transformation path as a “wasted effort”. MC4 mainly leveraged on the “technology enthusiasts” within the organization to start facing the transformative path.

Figure 4 summarizes the main challenges encountered, and practices adopted by manufacturing companies in their transformation path as regards the *ability in perceiving the path towards digital transformation*, with evidence of the level of digital implementation of cases.

CHALLENGES	PRACTICES IN THE CASE STUDIES	Cases and level of implementation: Low	Medium	High
Understanding how the company business model changes after technology adoption	Consider that the introduction of a digital technology widely impacts the business model, leading to several benefits in addressing mass customization trend and cost, time-to-market and new capabilities to reach new markets or create new products / services	MC10	MC9	SP6
	Understand if the business model radically changes, or the value proposition can be widened		MC4	SP3
	Integrate more digital technologies into a smart digital business model		MC9	
	Strengthen the added value to the customer without risking altering the perception of the product	MC8		
Awareness of the implications on the organization beyond IT infrastructure	Improve the transversal communication among business units			MC2
	Consider that the new technologies to analyze and integrate data (and machine learning) can modify the workflow			SP2
	Extend the vision of digital processes to the overall organization, as often they are only at disposal of the “operative” people			SP6
	Take into account the mindset of managers as a critical issue, beyond the increased digital skills			CC3
	Consider the legal issues		SP5	
Awareness of existing implementation supporting measures and means at policy level	Monitor European, national and regional funding schemes	MC11	MC1	SP1
	Develop a concrete intention to invest in enabling technologies to perceive the concrete relevance and benefits derived from the incentives and measures at policy level		MC9	SP2
	Consider the matching of the timing of the supporting measures with the real company needs for the implementation of I4.0 technologies			MC2
Awareness of the continuous increase in accessibility and exploitability of many I4.0 technologies	Consider that the cost of many technologies decreased quickly, allowing companies to benefit from a “technology democratization”			SP2
	Include the sustainability of a technology (and its potentially different applications) as the key elements in the undertaking of the digital transformation path			SP4
	Identify appropriate software and hardware vendors		MC1	
	Consider the potential synergies with the suppliers and customers already adopting I4.0 technologies, or integrate new partners in the value chain	MC10, MC11		
Proactivity rather than reactivity in defining resources, processes and procedures to adopt I4.0 technologies	Foresee the proactive involvement of the human resources into the definition of the processes, procedures and qualifications for I4.0 adoption		MC1	MC3
	Apply an integrated approach and process	MC11	MC4	
	Overcome reactive approach in adopting main innovative trends and act as pioneer	MC8		SP3
	Look for “technology enthusiasts” to face and promote the digital transformation		MC4	
	Develop the competences to understand the advantages that technological innovation can bring and the responsiveness to react quickly to changes			SP2
	Select a technology considering resources, materials and efforts in terms of time to avoid misleading results and no real applications			CC2

Figure 4: Challenges and practices identified for the second dimension of analysis.

4.3 Knowledge sharing

The third and last dimension addressed irefers both to the definition of collaborations with external sources of knowledge and the development of mechanisms for knowledge creation and sharing within the company's boundaries as a priority. External sources include different kind of actors as: universities and research centres framed within specific R&D projects aimed at adopting new technologies and implement customized methods, collaborations with analysts and reference companies to predict the technological trends, and also partnerships with other companies and vendors in order to strengthen the value network. For example, the partnership of SP1 with universities resulted in the launch of an innovative start-up. SP2 argue that collaborations with both start-ups and other companies have increased in the last years and in a future perspective these new players will may be part of the company supply network. Moreover, MC7 experienced the collaborative attitude and networking with suppliers as essential to better understand the technologies and the impact of their adoption. MC10 further highlights that networking must be done taking into account the level of guidance, the maturity and the timely response from possible partners consistently with business priorities. Exploiting connections with local ecosystem is a key challenge from which companies can benefit in different ways. Many cases (MC6, MC9, MC10, SP6 among others) built strong relationships by structuring agreements with research centres, technology parks, innovation agencies and membership with regional and national clusters and trade associations for sharing knowledge, resources and assets, but also to promote exchange of good practices, success stories and ways to overcome a negative attitude towards technological challenges. Indeed, a common mistake in this dimension is not considering relationships with the local infrastructure and sharing of skills, specialised services and mutual trust as key for the innovation development.

The importance of sharing and spreading best practices should not be underestimated in order to enable a successful implementation, e.g. by exploiting crossfertilization to learn from other sectors that already applied a specific technology, as suggested by SP5. Also the adoption of new approaches for knowledge transfer has a relevant role as enabler in the digital transformation process and is directly linked with the importance of increase knowledge base on I4.0 technologies. Examples of innovative and effective approaches are the "train the trainer" between employees of the same company, aimed also at internalizing the activity of training among key business practices, as taught by SP2, and visits to laboratories and pilot factories of I4.0, where better understanding modes and features of I4.0 technologies through learning-by-doing experiences, as offered by CC1 and CC2. A typical mistake is not considering the importance of knowledge transfer also at managerial level, to understand the advantages that technological innovation can bring and the importance of responsiveness to related changes. This can be achieved through practices such as the creation of a "digitalization committee" including managers of several departments to share ideas and improve organizational skills, as made in MC2. The increase of the knowledge base with specific skills and the talent management, aimed to properly use technologies and overcome resistance to change and lack of expertise, has to be a priority goal, especially for what concerns aging workers. Firstly, the locus of the required skills and talents, i.e. internal or external to company's boundaries, has to be identified. For example, MC9 had already in its staff the IT experts required for the new infrastructure adopted, but experienced the need to develop advanced analytical skills to properly exploit it. Secondly, as highlighted by MC7 and SP4, a great attention is needed for the transfer of knowledge to aged workers, who have matured a professional career and often need to deeply transform their skill to stay ahead of the new I4.0 technologies, especially in contexts relying on personnel highly qualified and specialized in mature and traditional technologies. Accordingly, internal know-how need to be generally improved also by promoting the integration between the digital skills and the traditional ones in order to avoid possible obstacles that may arise from fragmentation. In this sense, a common error of manufacturing companies is represented by the case of MC10, which is only recently introducing technologies such as 3D printing for supporting new product development and engineering, as R&D investments have been addressed to the integration of traditional technologies, such as electronics, to the products on which the company builds its competitive advantage.

Figure 5 shows the main challenges encountered, and practices adopted by manufacturing companies in their transformation path as regards the *knowledge sharing*, with evidence of the level of digital implementation of cases.

CHALLENGES	PRACTICES IN THE CASE STUDIES	Cases and level of implementation: Low	Medium	High
Adopting collaboration with external sources of knowledge	Adopt a virtuous collaborative attitude with suppliers and customers to integrate digital technologies along the value chain	MC7	SP5	MC3, SP1
	Undertake collaborations with universities (also at international level) for specific R&D&I projects	MC10, MC11	MC9	
	Foster partnerships with vendors through loyalty and recognition programs			SP1, SP6
	Consider networking with international analysts and relevant companies to predict the future technological and market trends and match them with customer needs			SP1, SP3
	Build partnerships with both start-ups and companies addressing different markets, strengthening and growing the supply network with new players			SP2
Exploit connections with local ecosystem (e.g. universities, innovation centers, policy makers)	Undertake focused agreements with research centers, technology parks, innovation agencies of the territory for sharing knowledge, resources, assets, good practices		MC9	MC6
	Consider membership to regional and national clusters and trade associations	MC10		MC6, SP6
	Network within the local ecosystem and establish strong partnerships (especially with universities) to cover relevant competences		MC5, CC1	
	Create "informal networks" with the companies located in the near geographical area		MC1	
Recognizing the importance of sharing and spreading best practices for successful I4.0 implementation	Promote a good communication and a description of the benefits from success stories and case studies			SP2
	Improve communication with technology providers and potential users to achieve technological alignment and exchange practices			SP4
	Resell the know-how about the transformation experience as a new business		MC1, MC4	
	Explore the opportunities to learn how other sectors are applying the interested technology and how they already faced the related issues		SP5	
Adopting new approaches for knowledge transfer	Visit laboratories and pilot factories		CC1	CC2
	Create a "digitalization committee" as a place where all the managers of the different business units can share ideas and results and develop organizational skills			MC2
	Enrich the process of digital transformation with participation to or organization of initiatives such as sharing group, digital summit, *Young Talents Hackaton*, working group, *digital roadshow*			MC3
	Consider the "train the trainer" approach to increase the competence level of few employees which will train in-house other colleagues			SP2
	Organize networking events to disseminate and spread the knowledge on the I4.0 technologies, going beyond standard formats			SP4
Increasing knowledge base on I4.0 technologies and talent management	Build work-based, interactive sessions and experiential paths through I4.0 technologies and related activities		CC1	MC2, SP3
	Give importance to lack of expertise and resistance to change of workers, especially aged ones, which need to increase their knowledge and transform their skills to stay ahead of new I4.0 technologies	MC7		SP4
	Identify the specific skills required for properly use specific technologies and if they are present within or outside company boundaries, avoiding a possible fragmentation with traditional skills	MC10	MC9	
	Look for self-learning programs through MOOC platforms			SP6
	Look for digital talents inside the company before recruiting			CC3

Figure 5: Challenges and practices identified for the third dimension of analysis.

5. Discussion

The empirical findings for both research questions are discussed in the following in terms of digital transformation paths implemented by companies adopting I4.0 technologies, with related implications on operations management.

Firstly, adopting a managerial perspective when investigating the digital transformation path of a company means taking into account the management issues deriving from the adoption of I4.0 technologies along three key dimensions: 1) the investments in I4.0 technologies, 2) the ability in perceiving the path towards digital transformation, and 3) the knowledge sharing. These dimensions of analysis have to be considered strictly interrelated and to be developed in an integrated effort to enable a digital transformation path that crosses different areas of action. Indeed, themes as the training of human resources and the implications on business strategy due to I4.0 technologies adoption appear in all three dimensions, with different aspects to be taken into account. Specifically, the discussion on these aspects contribute to answer the second research question.

Being aware of the revolutionary impact of the industrial transformation enabled by digital technologies (Agrifoglio et al., 2017), manufacturing companies are undertaking a peculiar digital transformation path, with different approaches, and related level of implementation, according to their specific needs and employed efforts. Nevertheless, patterns of adopted practices and related challenges can be identified per each dimension. Furthermore, findings from the multiple case study revealed practices that could be considered among the most useful in enabling companies to “move towards digitalization” according to their technological implementation level characterized by the the amount of investments undertaken and rate of advancement in the project, KPIs accomplishment or defined strategy for I4.0 adoption.

Reference practices Tto prioritize and optimize the quantity and quality (McAfee and Brynjolfsson, 2008; McKinsey Digital, 2015) of investments in I4.0 technologies can be mostly identified at more advanced levels of digital implementation. Recognizedpriorities also in the early stages of I4.0 technologies adoption include starting with pilot projects to evaluate the profitability of the investments, adopting a modular approach to undertake the transformation through small "exploration projects" and identify business cases, also focussing firstly on the operative areas such as production control. All these practices allow to face the challenge of exploiting the scalability of I4.0 technologies through limited investments. A widely recognised best practice in all the implementation stages is applying lean management as a requirement for adopting I4.0 technologies, especially considering the organizational perspective and the implications on the value offer. In this sense, Buer et al. (2018) argue that the effects of established lean manufacturing systems in facilitating the implementation of I4.0 represent an important research area. Focusing on practices identified as best to facilitate the digital transformation in the late implementation stages, the ones of formulating a smart manufacturing strategy by identifying key factors for competitiveness, or even a technological roadmap, and guiding the company managers in addressing the investments, allow to face the challenge of overcoming the stand-alone implementation of a I4.0 technology. Finally, the practices aimed to invest in training and culture, such as the enhancing and consolidation of a new business culture towards digital transformation, and the investments in know-how beyond technological resources, are present mainly in the more advanced stages of transformation, but have to be acquired as a reference from the first planning phases.

Secondly, the ability in perceiving the path towards digital transformation results in systematic efforts along all the stages of digital implementation, especially when its accomplishment requires to face some specific challenges, namley: to understand how the company business model changes after technology adoption, to be aware of the supporting measures and means at policy level, and to adopt a proactive rather reactive approach in defining the resources, processes and procedures involved in the process. As regards the first one, a key practice is mapping the effects and benefits of introducing digital technologies on performance (as cost and time-to-market) and on capabilities to reach new markets or create new products or services. The extend to what change and adapt the business model is a challenge itself (Schneider, 2018). Indeed, the managerial skills enabling adaptations of production systems, supply chain processes and corporate strategy for improving the use of digital technologies have a key role in digital value creation and customer demand meeting, especially in competitive environments (Dong et al., 2009; Yin et al., 2018). Best practices for enhancing proactivity rather reactivity in undertaking a digital transformation paths are: to foresee a proactive involvement of human resources into the definition of the processes, procedures and qualifications for I4.0 adoption, aimed to collect the different perspectives and experiences, especially the “technology enthusiasts”, and to apply an integrated approach, but also to act as pioneers in comparison with competitors. Finally, a challenge mainly raised in the more advanced levels of implementation is being aware of the implications on the organization when perceiving the digital transformation path. In this sense, best practices that should be considered are the ones of improving the transversal communication among business units, and extending the vision of digital processes to the overall organization beyond the operational issues, including the mind-set of managers. Indeed, digital transformation requires a different mind-set and a new culture towards new ways of working (Camarinha-Matos et al., 2017).Thirdly, the dimension of knowledge sharing presents numerous managerial challenges and best practices. These can be defined in all the different stages of digital implementation, according to company needs, in terms of new knowledge to be acquired from sources internal or external to company boundaries, or existing knowledge and experiences to be exploited. For example, the challenge of adopting collaboration with external sources of knowledge, which has been widely recognized as key for innovation purposes (Camarinha-Matos et al., 2017), requires to consider different kinds of relationship according to the sources to be involved. The adoption of I4.0 technologies itself can contribute to operations through external network, exchanging information and sharing data with the other supply chain actors (Agrifoglio et al., 2017), which are required to acquire complementary capabilities to enable the information flow for the digitalization path (Barua et al., 2004). Moreover, a virtuous collaborative attitude with suppliers and customers should be adopted along all stages to integrate digital technologies along the value chain. Indeed, digital values are generated in supply chain contexts through developing integration capability (Dong et al., 2009). This is strictly connected with the importance of exploiting connections within the local ecosystem, especially with high concentration of knowledge and expertise in digital technologies, such as service and technology providers and innovation centres. Best practices identified consist in undertaking focused agreements for sharing knowledge, resources, assets, good practices, and the formalization of memberships to regional and national clusters and trade associations, in order to remain updated on industry and technology trends. This pattern of practices is strictly related to the one aimed at increasing the knowledge base on I4.0 technologies and especially of talent management. In this sense, the organization of work-based, interactive sessions and experiential paths through I4.0 technologies and related activities, together with the prioritization of the lack of expertise and resistance to change of workers and the avoidance of fragmentation between digital and traditional skills are recognized among best practices along the entire digital transformation path. Creating acceptance for change and counteracting organizational inertia should be indeed a priority (Schneider, 2018). Nevertheless, a challenge mainly raised in the more advanced levels of implementation is the need of new approaches for knowledge transfer. In this sense, best practices that should be adopted include visits to existing facilities such as laboratories and pilot factories, the organization of structures and events aimed at share and consolidate knowledge on I4.0 technologies and trends as internal "digitalization committee", "digital roadshow", dissemination on technologies uses, and practice-based learning modes as "train the trainer". Indeed, digitalization should be educated and demonstrated in a practice-oriented way (Erol et al., 2016).

6. Conclusions

Emerged as a technology-based manufacturing paradigm, I4.0 has gained increasing interest both from academia and practitioners (Buer et al., 2018) also for its implications at managerial, organizational and strategic level (Schumacher et al., 2016). Considering the field of operations management (Schiavone and Sprenger, 2017), many aspects are still unknown and uncertain (Yin et al., 2018) and supporting practices and benefits of the I4.0 paradigm have still to be deeply investigated (Buer et al., 2018). This work aims to contribute to this stream of research and presents a first but deepened investigation into the managerial issues encountered by manufacturing companies when "moving towards digitalization", focusing on challenges encountered and practices adopted in their implementation efforts. Aiming to gain a comprehensive overview of the ways a digital transformation path can be implemented, the employed methodology is a multiple case study, with the involvement of different players of the manufacturing value chain.

Key theoretical implications relate to the discussion of enablers, mistakes and challenges encountered by manufacturing companies adopting I4.0 technologies 1) into specific dimensions of analysis, 2) considering the level of digital implementation, in terms of investments and advancements undertaken by companies, and 3) in an integrated overview that involves also strategic and organizational issues.. Practices have been investigated within a framework facing three dimensions, which have to be considered in close connection for an integrated vision of the transformation path towards I4.0. Even if the interest of this paper is mainly in challenges encountered and practices applied in manufacturing companies from the managerial perspective, i.e. the 'manageable issues that can be influenced directly by company managers' (Schneider, 2018), important implications are also at strategic and organizational level. Impacts of adoption of I4.0 technologies on strategic issues, such as the business model changes and the building of a technological roadmap, and organizational variables, as the importance of the mind-set of managers and the introduction of new forms of training, have been considered. Indeed, the investments in digital technologies has the role of platform for organizational capabilities of companies (Sambamurthy et al., 2003). Specifically, a prioritization of challenges and practices linked to the promotion of a digital culture, the growth of awareness of organizational implications of I4.0 adoption and the consequent application of new approaches for knowledge transfer should be foreseen also in the early stages of digital implementation.

Considering the implications for practitioners, the results proposed in terms of good and best practices and associated challenges emerged from the analysis represents a formalization that can support companies in understanding which are the most important issues to be addressed, in a systematic effort, when facing the adoption of digital and innovative technologies. The I4.0 topic has been in fact addressed in literature from several different perspectives but a holistic vision on the implementation side is still lacking. Moreover, the discussion of reference practices according to the level of digital implementation allows to identify the most suitable ones when the transformation is at an early or more advance stage. Companies that have recently undertaken a project or even their long-term strategy for I4.0 adoption can refer also to the practices and related challenges emerging in the late stages, aiming to learn from and anticipate them towards a smart transformation path.

This study is part of a research addressing digital transformation and manufacturing value chain networks in the regions of Alpine Space area, and analyses a set of cases within the Italian context and with a qualitative approach, resulting in possible limitations in terms of generalizability of findings. An extensive categorisation of the different challenges with a wider sample could enrich the contribution, as the early practical evidence suggests that integrating and strengthening specific actions along the three dimensions proposed can effectively support the different actors of the manufacturing supply network in enabling the implementation of this path. Nevertheless, the three dimensions of analysis, i.e. investments in I4.0 technologies, ability in perceiving and facing the path towards digital transformation, and knowledge sharing, can be applied to the investigation of companies experiences and paths in other contexts such as construction sector and services. Further research should include a wider sample of companies in different sectors and countries to test the groups of challenges identified and the adoption of practices according to the level of implementation. Longitudinal case study would also contribute to evaluate the possible implications of I4.0 adoption and related managerial practices on operational and business performance. Indeed, digital technologies play a fundamental role in enhancing the company performance through innovations in products, services and channels (Sambamurthy et al., 2003).

. Finally, future studies are required to deepen the discourse on the role, impacts and peculiarities of adopting single o more technologies, such as machine learning and IoT, on the challenges identified in terms of investments, ability in perceiving the transformation path, knowledge sharing..

Acknowledgements

This research has been conducted as part of the BIFOCAlps project (n° 510) (Boosting Innovation in Factory Of the future value Chain in the Alps), funded by the European Commission under the Interreg Alpine Space programme. The authors wish to acknowledge the Commission for their support. We also wish to acknowledge our gratitude and appreciation to all the project team for their contribution during the development of this research.

References

Agrifoglio, R., C. Cannavale, E. Laurenza, and C. Metallo. 2017. "How emerging digital technologies affect operations management through co-creation. Empirical evidence from the maritime industry." *Production Planning & Control* 28 (16): 1298-1306.

Associazione Cluster Fabbrica Intelligente. 2014. "Roadmap per la ricerca e l'innovazione - Research and Innovation Roadmap." Available at https://www.fabbricaintelligente.it/wp-content/uploads/2018/04/Roadmap-Fabbrica-Intelligente-.pdf

Barua, A., P. Konana, A.B. Whinston, and F. Yin. 2004. "An empirical investigation of net-enabled business value." *MIS Quarterly: Management Information Systems* 28 (4): 585-620.

Bessant, J. and H. Rush. 1995. “Building bridges for innovation: the role of consultants in technology transfer.” *Research Policy* 24 (1): 97-114.

Buer, S.-V., J.O. Strandhagen and F.T.S. Chan. 2018. “The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda.” *International Journal of Production Research* 56 (8): 2924-2940.

Camarinha-Matos, L.M., R. Fornasiero, and H. Afsarmanesh. 2017. “Collaborative networks as a core enabler of industry 4.0.” In *Working Conference on Virtual Enterprises* (3-17). Cham: Springer.

Chiarello, F., L. Trivelli, A. Bonaccorsi, and G. Fantoni. 2018. “Extracting and mapping industry 4.0 technologies using Wikipedia.” *Computers in Industry* 100: 244-257.

Dong, S., S.X. Xu, and K.X. Zhu. 2009. “Information Technology in Supply Chains: The Value of IT-Enabled Resources Under Competition.” *Information Systems Research* 20 (1): 18-32.

Eisenhardt, K.M. 1989. “Building theories from case study research.” *The Academy of Management Review* 14 (4): 532-550.

Eisenhardt, K.M., and M.E. Graebner. 2007. “Theory Building from Cases: Opportunities and Challenges.” *The Academy of Management Review* 50 (1): 25-32.

Erol, S., A. Jäger, P. Hold, K. Ott, W. Sihn. 2016. “Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production.” *Procedia CIRP* 54: 13-18.

Fatorachian, H. and H. Kazemi. 2018. “A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework.” *Production Planning & Control* DOI: 10.1080/09537287.2018.1424960

Gölzer, P., and Fritzsche, A. 2017. "Data-driven operations management: organisational implications of the digital transformation in industrial practice." *Production Planning & Control* 28 (16): 1332-1343.

Heavin, C., and D.J. Power. 2018. "Challenges for digital transformation – towards a conceptual decision support guide for managers." *Journal of Decision Systems* 27 (1): 38-45.

Holmström, J., M. Holweg, S.H. Khajavi, and J. Partanen. 2016. "The direct digital manufacturing (r) evolution: definition of a research agenda." *Operations Management Research* 9 (1): 1-10.

Ivanov, D., A. Das, and T.-M. Choi. 2018. "New flexibility drivers for manufacturing, supply chain and service operations." *International Journal of Production Research* 56 (10): 3359-3368.

Jardim-Goncalves, R., D. Romero, and A. Grilo. 2017. "Factories of the future: challenges and leading innovations in intelligent manufacturing." *International Journal of Computer Integrated Manufacturing* 30 (1): 4-14.

Kache, F., and S. Seuring. 2017. "Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management." *International Journal of Operations & Production Management* 37 (1): 10-36.

Khan, A., and K. Turowski. 2016. "A Survey of Current Challenges in Manufacturing Industry and Preparation for Industry 4.0." In *Proceedings of the First International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'16). Advances in Intelligent Systems and Computing*, vol 450, edited by A. Abraham, S. Kovalev, V. Tarassov, and V. Snášel, 15-26. Cham: Springer.

Liao, Y., F. Deschamps, E. de Freitas Rocha Loures, and L.F. Pierin Ramos. 2017. "Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal." *International Journal of Production Research* 55 (12): 3609-3629.

McAfee, A., Brynjolfsson, E., 2008. "Investing in the IT That Makes a Competitive Difference." *Harvard Business Review* 86 (7/8): 98-107.

McKinsey Digital. 2015. "Industry 4.0. How to navigate digitization of the manufacturing sector." Available at https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Operations/Our%20Insights/Industry%2040%20How%20to%20navigate%20digitization%20of%20the%20manufacturing%20sector/Industry-40-How-to-navigate-digitization-of-the-manufacturing-sector.ashx.

Moeuf, A., R. Pellerin, S. Lamouri, S. Tamayo-Giraldo, and R. Barbaray. 2018. "The industrial management of SMEs in the era of Industry 4.0." *International Journal of Production Research* 56 (3): 1118-1136.

Müller, J. M., O. Buliga, and K.-I. Voigt. 2018. "Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0." *Technological Forecasting and Social Change*, 132: 2-17.

Nuvolari, A., and M. Vasta. 2015. "The Ghost in the Attic? The Italian National Innovation System in Historical Perspective, 1861–2011." *Enterprise & Society* 16 (2): 270-290.

Oesterreich, T. D., and F. Teuteberg. 2016. "Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry." *Computers in Industry* 83: 121-139.

Pessot, E., C. Battistella, A.F. De Toni, A. De Zan, E. Ocello. 2017. “Shifting operations to Factory of the Future: a survey of European manufacturing companies.” Presented at the *8th European Decision Sciences Institute Conference*, Granada, Spain, May 29 – June 1.

Porter, M.E., and J.E. Heppelmann. 2015. “How smart, connected products are transforming companies.” *Harvard Business Review* 93 (10): 96-114.

Sambamurthy, V., A. Bharadwaj, and V. Grover. 2003. “Shaping agility through digital options: Reconceptualizing the role of information technology in contemporary firms.” *MIS Quarterly: Management Information Systems* 27 (2): 237-264.Schiavone, F., and S. Sprenger. 2017. “Operations management and digital technologies.” *Production Planning & Control* 28 (16): 1281-1283.

Schmidt, R., M. Möhring, R.-C. Härting, C. Reichstein, P. Neumaier, and P. Jozinović. 2015. “Industry 4.0 – Potentials for Creating Smart Products: Empirical Research Results.” In *Business Information Systems. Lecture Notes in Business Information Processing, vol 208*, edited by W. Abramowicz, 16-27. Cham: Springer.

Schumacher, A., S. Erol, and W. Sihn. 2016. “A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises.” *Procedia CIRP* 52: 161-166.

Schneider, P. 2018. “Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field.” *Review of Managerial Science* 12 (3): 803-848.

Skevi, A., H. Szigeti, S. Perini, M. Oliveira, M. Taisch, and D. Kiritsis. 2014. “Current Skills Gap in Manufacturing: Towards a New Skills Framework for Factories of the Future.” *IFIP Advances in Information and Communication Technology* 438: 175-183.

Tortorella, G.L. and D. Fettermann. 2017. “Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies.” *International Journal of Production Research* 56 (8): 2975-2987.

Voss, C., N. Tsikriktsis, and M. Frohlich. 2002. “Case research in operations management.” *International Journal of Operations and Production Management* 22 (2): 195-219.

Yin, R.K. 2013. *Case Study Research: Design and Methods (Fifth Edition)*. Thousand Oaks, CA: SAGE Publications.

Yin, Y., K.E. Stecke, and D. Li. 2018. “The evolution of production systems from Industry 2.0 through Industry 4.0.” *International Journal of Production Research* 56 (1-2): 848-861.

Zangiacomi, A., J. Oesterle, R. Fornasiero, M. Sacco, and A. Azevedo, 2017. “The implementation of digital technologies for operations management: a case study for manufacturing apps.” *Production Planning & Control* 28(16): 1318-1331.