Digitalization of Manufacturing Execution Systems: the core technology for realizing future Smart Factories

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Abstract: In recent years manufacturing companies have been faced with different challenges, in particular with an increasing level of variability. The variability implies different set of dimensions such as demand, volume, process, manufacturing technology, customer behaviour and supplier attitude, transforming industrial systems engineering domain. This trend is now even accelerating with a direct impact on the value chain and related physical supply chains as well as factory design and management. Several national strategy and new technological roadmaps, such as the German high tech strategy “Industrie 4.0” or the Italian cluster “Fabbrica Intelligente”, aim at approaching this transformation enhancing the flexibility and re-configurability of current manufacturing systems among many other competitive dimensions; new emerging and potential enabling technologies could allow a next generation of manufacturing systems towards real implementation of smart factories. This paper introduces technological concepts of Industry 4.0 and related enabling technologies (such as Cyber-Physical Production Systems (CPPS), the Internet of Things, and the Internet of Services) that could support decentralization and manufacturing flexibility. Their application allows to orchestrate and execute manufacturing and production processes with the aim of supporting individualized production, small lot sizes, small batches and provide advanced decision support. The final research aim is to identify and define digitalized opportunities for specific type of flexibility that has an impact on the manufacturing system starting from an analysis of potential improvements of current Manufacturing Execution Systems (MES). For each flexibility type (variant spectrum, expansion, scheduling and volume), the scope is to demonstrate the principal contributions expected by using specific use cases described in terms of process improvement. The identified flexibility type in manufacturing systems are discussed and contrasted with the various reconfiguration use cases, which include specifically the planning, orchestration, and optimization of production processes within MES. Finally, the use cases presented by these manufacturing paradigms are discussed in order to demonstrate how far decentralization and self-organization can be driven to the achieving Industry 4.0 key requirements.

Keywords: Smart Factory; Manufacturing Execution Systems; Industry 4.0; Flexibility; Re-configurability;

1.Introduction

In the current competitive scenario production requirements are rapidly changing. To face these challenges of customized products and shorter product lifecycles, production systems needs to be more flexible and reconfigurable (Scheifele *et al.*, 2014). Flexible and reconfigurable manufacturing systems represent nowadays one of the key responses towards the new era characterized by driving trends as *Mass customization*, *Complex supply chain*, and *Globalization*. These trends are now even accelerating with a direct impact on production processes, *mass customization* bring to the management of a high number of product variants, *globalization* is responsible of the location change of a production system several times within the life cycle of a product, furthermore *complex supply chain* is caused by the uncertainty derived by demand levels and supplier lead times (El Maraghy, 2006). Thus, manufacturing systems should reconfigure its strategies and process very fast, in order to provide great product variety, while at the same time maintaining excellent product performance at low costs (Brettel, Klein and Friederichsen, 2016). It is in this specific context that the German high tech strategy “Industrie 4.0” (Industry 4.0) arose, which aims at exploiting the high innovation and economic potential resulting from the continuing impact of rapidly advancing information and communication technology (ICT) in industry. Accordingly, key challenges for improving supply chains are seamless digital workflows throughout the product lifecycle, highly flexible and adaptive processes in particular manufacturing processes, the capability to create and to produce individualized products and new business models to increase the attractiveness of enterprises’ performance. To face these challenges technological concepts of Industry 4.0 and related enabling technologies such as Cyber-Physical Production Systems (CPPS), the Internet of Things, and the Internet of Services, which could support decentralization and manufacturing flexibility. These new emerging and potential enabling technologies could help to realize this vision allowing a next generation of manufacturing systems towards real implementation of smart factories. The final research aim is to identify and define reconfiguration use cases, which supported by digitalized opportunities allow achieving specific type of flexibility (variant spectrum, expansion, scheduling and volume) that has an impact on the manufacturing system and therefore propose an analysis of potential improvements of current Manufacturing Execution Systems (MES). The paper is structured as follow, in the next section a short background is presented. In section 2 a literature review is conducted in order to define the state of the art of this topic. Section 3 describes the methodological approach adopted for this study, Section 4 presents the Industry 4.0 core technologies applied in MES, while Section 5 shows a practical view of such technologies' application. Section 6 introduces the specific reconfiguration requirements for the development of smart factory. Finally, in Section 7 final consideration and future developments are discussed.

1.1 Background and related work

Related works in the context of this paper starts from the previously work based on the identification of a specific set of flexibility types (Burger *et al.*, 2017). As described by Burger at al., different flexibility manifestations in manufacturing, that have an impact on the complete system, have been identified through an accurate literature review, these flexibility types are: *i) Variant spectrum:* it does not only aim at the flexibility to produce similar parts but also new parts within a production line without the requiring major setup effort; *ii) Expansion flexibility:* focuses more on the trend of plug and produce, since it is described as the flexibility that enables the system to easily exchange capabilities in terms manufacturing technologies; *iii) Scheduling flexibility*: which is tightly connected to prioritization and delivery time as well as efficiency and utilization optimization topics; *iv) Volume flexibility*: this flexibility characterizes a system which is capable of producing efficiently even though the output can vary between different levels. Starting from these flexibility types the scope of this work is to understand what enabling technologies could support the crossing of these issues. In this section is presented a mapping between the aforementioned manufacturing trends, which are supposed to be the cause of these flexibility types (Table 1). Thus, this mapping allows understanding and contextualizing each flexibility types with respect to its feature of variability. The first trend is *Complex supply chain* which can be defined as the detailed and dynamic complexity that derives from the products and processes as well as relationships within a supply chain (Bozarth *et al.*, 2009). Furthermore, this complexity even increases when considering the digitalization and the resulting interconnectivity between the product and business processes. Another influence factor, which challenges manufacturing companies, are shorter product lifecycles. Supply chain complexity in this case is created to the faster exchange of products and all the process that needed to introduce the product. Then this trend is mapped with the all flexibility types. The second trend to be considered is *Globalization,* as due to the globally distributed value creation a dependency between different countries arises and strong economies such as China, United States of America, and Europe have a strong impact on the global economy. Currently the vertical range of manufacture decreases and the value creation is provided by platforms instead of a local factory, since the components of a product are produced in different parts of the world. These relationships also lead to more complex process within the supply chain of globally acting companies. Thus, this trend has been mapped with variant spectrum, scheduling and volume flexibility. Finally the last analysed trend is *Mass Customization* as one of the solutions for providing a more diversified portfolio to the customers, since it offers individualized products or services to a customer (El Maraghy, 2006). Therefore, this trend has also a stronger focus on the customers. Customer satisfaction can be reached by a more diversified production mix, can increase when a company creates capabilities that bring an added value to the customers (Zhang, Vonderembse and Lim, 2003). Another solution in this context, which also shows a high customer orientation, is adaptive manufacturing, where the complete value creation is adapted to customer wishes and requirements. This trend has been mapped with variant spectrum, expansion and volume flexibility. Table 1 shows the aforementioned mapping between external trends and flexibility types.

Table 1: Mapping between trends and flexibility types

Trends	Variant spectrum Flexibility	Expansion Flexibility	Scheduling Flexibility	Volume Flexibility
Complex supply chain	x	x	x	x
Globalization	x		x	x
Mass customization	x	x		x

2. Literature review

This section of the paper adopts a qualitative methodology based on a literature review in order to understand which is the level of digitalization in the Manufacturing Execution System (or Manufacturing Operations Management) from the scientific point of view. In this context the aim is to investigate and define the state of the art of the enabling technologies adopted by manufacturing company at MES/MOM level. As a result, a literature review was carried. Academic papers were selected through a computer search from two databases: ScienceDirect and Scopus. Authors chose these databases for their ample covering of articles in the field of manufacturing flexibility. They offer search combinations using "AND" and the possibility to search for keywords. Authors' strategy used to search was to identify articles that included "manufacturing flexibility", "manufacturing execution system", "manufacturing operations management", "smart factory", "industry 4.0" as main subject headings or text words in the title or in the paper. The literature search identified 52 empirical academic papers that were published between 2000 and

2016. Their titles, abstracts were reviewed in detail for relevance to the study. This organization of the papers provided a summary of the recent state of the art about the digitalization in MES/MOM. The earliest paper included in the dataset was published in 2002 and the most recent in 2016. The distribution of publications over years shows that in 2006 a peak is reached and then the interest decreases until 2014. After 2014, the same time, in which "Industrie 4.0" was fully widespread on the market, the amount of publications increases again and reached its maximum in the last two years (2015 and 2016). In terms of geographical distribution, the publications contributing to this research area originate from many different countries around the world, based on the main author's university affiliation. One country stands out: Germany. Hence, it might be argued that this topic is primarily rooted in this country, and partially in countries throughout the rest of Europe and China. What emerges from the literature review is an overview of the current technologies applied to the MES level, in particular Brettel et al., highlight the essential role of additive manufacturing which is considered a keystones of Industry 4.0, and in combination with iterative development processes, allows to employ manufacturing flexibility both as reactive and proactive manufacturing strategies (Brettel, Klein and Friederichsen, 2016). However, Hänel et al. pay specific attention to the role of data analytics as a key technology of Industry 4.0, with a specific focus on the integration and analysis of production data, it is also underlined that this data integration allows combining multidimensional views on flexibility requirements of production process (Hänel and Felden, 2016). Diverse authors promote the concept of Cyber Physical Production Systems (CPPS), in the Michniewicz's work, for example, the focus is established on industrial robots which have a great inherent flexibility due to their kinematical degrees of freedom and the versatility of manageable tools, sensors and other periphery devices. In this context the Plug&Produce approach was introduced in order to facilitate the reconfiguration of robot cells. The robot cell components and the product to be manufactured are defined as CPPS, which allow to store data, to process data intelligently, to interact and to communicate with each other (Michniewicz and Reinhart, 2014). Also Scheifele et al., identify CPPS as a core technology for smart factory, "the use of CPPS provides added value for smart factories like optimized production of customized products and resource-efficient production". Besides, they pay attention on the self-reconfiguration concept, the production will organize itself, each part "knows" its requirements and each machine "knows" its capabilities (Scheifele *et al.*, 2014). Other technologies connected to the CPPS concept are Industrial Internet of Things and Cloud Manufacturing. Recently, benefitting from the Industrial Internet of things (IIoT) and CPPS, the industry-relevant items such as materials, sensors, machines, products, supply chain, and customers, are able to be connected, which means these necessary objects are going to exchange information and control actions with each other independently and autonomously (Qin, Liu and Grosvenor, 2016). However, cloud manufacturing provides a shared environment of manufacturing capability, computing power, knowledge and resource. It can contribute with innovative robotic technologies to factories of the future. It offers an environment to connect the computing and service resources in the cyber world to the machines and robots in the physical world, thus forming a cyber-physical system (Wang *et al.*, 2015). For Wieland et al., a smart factory is defined as a factory that is context-aware and assists people and machines in execution of their tasks by using context. Besides the focus is established in order to improve failure management by coordinating and supporting the repair process with context-aware workflows (Wieland *et al.*, 2010). Repair process and in particular the maintenance management could be covered also by virtual and augmented reality (VR/AR). In fact, Turner et al., claim that a fundamental aspect of Smart Factory is virtual manufacturing, whereby the process of manufacturing is simulated from product design to final production; each stage of the production process is simulated and explored in a VR setting (Turner *et al.*, 2016).

In conclusion, analysing these results, it is possible to say that the topic of the digitalization at the MES/MOM level starts to be studied deeper over the last two years. Furthermore, the current enable technologies that characterize the MES/MOM level could be recognized as CPPS, which has been great consideration, Data analytics, Cloud manufacturing, IIoT, Additive manufacturing, VR/AR and simulation techniques.

3. Research methodology

The logic behind the research methodology is to investigate the relationships between different type of flexibility and new emergent technologies, and also the relationships between flexibility types and derived reconfiguration use cases. The design is conceptually depicted in Fig. 1. The model distinguishes three main source factors of flexibility, four type of flexibility that have an impact on the production system, and seven core technologies, which could allow to reconfigure and reorganize the MES level. Through this framework is also highlighted the main parts of the purpose of this study.

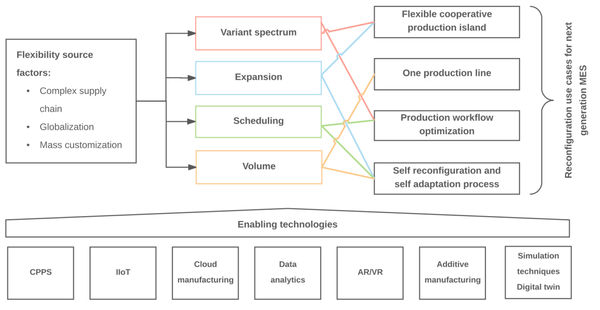

Figure 1: Conceptual model describing the relationships between flexibility source factors, flexibility types and reconfiguration use cases

Authors start by investigating the source factors, which implicate different flexibility types, then identify and analyse the current core technologies, and finally compare the aforementioned technologies with respect to different reconfiguration flexibility use cases, which represent the requirements for improving MES. According to the hierarchical structure of the conceptual model the identified use cases respond to specific challenges from the manufacturing environment that make necessary a factory to go through new ways of production configuration.

4. The key paradigm of Industry 4.0

As mentioned in the previous section, the performed literature review allows identifying what the core technologies of Industry 4.0 could drive the development of next generation of manufacturing systems. Particularly this section explains how the Authors analysed the aforementioned technologies respect to their applications and practical implementation at MES/MOM levels. The key and representative technologies are:

Cyber Physical Production Systems (CPPS): it is a key technology for realizing smart factory, and it is being studied in close relationship with such technologies as:

- Plug and produce: A plug and produce system can be described as a collection of stations or modules for assembling or checking parts. Modules can be replaced with others having similar functionality and interfaces in case of breakdown or to adapt to a new process. Also, new modules can be added to increase production volumes (Weyer et al., 2015). The concept follows a product-centric approach, in fact the product is the driver of its own production, there is no need for central coordination. Production systems are composed of intelligent production units that are able to configure themselves, execute a defined set of production skills autonomously, or in cooperation with other units (Jatzkowski, Adelt and Rettberg, 2016). A production unit is aware of its production skills, capabilities, state, and its physical and virtual environment. Different production units could be identified such as machines, robots and conveyors.
- Smart products: Smart products are products that are capable to do computations, store data, communicate and interact with their environment. To this end, it is necessary to develop chips and microprocessors as well as embedded systems (Abramowicz, 2015)

Industrial Internet of Things (IIoT): IIoT is the industrial or the manufacturing version of the Internet of Things. It can be seen as a systematic expansion of automation and a progressive improvement of how machines communicate to each other at the manufacturing sites. IIoT mainly relates to human-object interaction. This helps users to track the sequel of events and activities as and when they occur (Almada-Lobo, 2016).

Cloud manufacturing (CM): CM is the cloud computing technology that is applied to the manufacturing area. In this context, manufacturing resources and capabilities are virtualized and coordinated in a cluster, as a result, all components within the CM can perform real-time and collaborative manufacturing task (Hao and Helo, 2015).

Data Analytics (DA): The increasing volume of data, generated also by CPPS and IIoT, needs to be stored and processed and analysed in real-time. Big data has emerged as a tool which is able to provide data analysis, knowledge extraction, and advanced decision-makings (Zhong *et al.*, 2016).

Augmented and virtual reality(AR/VR): Augmented-reality-based systems can support a variety of services, such as selecting parts in a warehouse and sending repair instructions over mobile devices. VR applications have been well reported in virtual prototyping, web-based virtual machining, assembly, fault diagnosis and learning, and various types of manufacturing operations (Nee and Ong, 2013).

Additive Manufacturing (AM): the implementation of AM for technical prototyping, pre-production series and short series production can bring benefits in terms of cost reduction and shorten of the time-to-market in product development (Ituarte *et al.*, 2015).

Simulation techniques-Digital twin (ST): simulation techniques such as the discrete event simulation of a manufacturing plant could allow studying the factory production and it is expected to avoid problems of robustness of adopted meta-models with proper methodologies (Cassettari *et al.*, 2013). In this context is arranged the Digital Twin which is a virtual model of process, product or service. This pairing of the virtual and physical worlds allows analysis of data and monitoring the whole system. From a simulation point of view the Digital Twin approach is the next wave in modelling, simulation and optimization technology (Rosen *et al.*, 2015).

5. Practical application of enabling technologies

In this section a practical view with respect to the application of the Industry 4.0 enabling technologies is provided in order to understand the actual consistency resulting from the adoption of the proposed model and the related technologies. As previously mentioned Industry 4.0 embraces various technologies and presents different application fields, many of these will influence planning criteria of next generation production systems. Table 2 shows the mapping between enabling technologies and the related application field. The proposed mapping allows comprehending the relevance of CCPS, IIoT, AR/VR and simulation techniques for the development of next generation of production systems. In this direction through the machines connection, the product and components traceability, an intelligent network is built with the aim of control autonomously production processes in quantitative and qualitative terms. One evident objective of industry 4.0 is to translate information not only for humans but also for machine and robots. An additional application is that the product itself is a collector of data and information and it should be able to transfer these data to production processes, controlling and improving them. The aim is to achieve a new paradigm in which real and digitalized' world can interact. This combination is very complicated, but advantages can be huge because the digitalization of the whole production systems can affect the economic sector. In the next section a list of reconfiguration use cases is provided in order to analyze better the application of such technologies with respect to MES.

Table 2: Mapping between enabling technologies and production application field

Application field	CPPS	IIoT	CM	DA	AR/VR	AM	ST	Level of Interest
Design of industrial systems	x	x	x	x	x		x	High
Design of production processes	x	x	x	x	x		x	High
Logistics		x	x	x	x		x	Medium
Management of production systems	x	x	x	x	x	x	x	High
Maintenance	x	x			x		x	Medium
Safety of production systems	x	x		x	x	x		Medium

6. Reconfiguration use-case for next generation MES

In this section specific requirements for the next generation of MES are derived. Starting from the flexibility source factors and the flexibility types, reconfiguration use cases are extracted thanks to the performed literature review, which portrayed the state of the art of the MES respect to the Industry 4.0 principles and the application of flexible paradigm such as Plug&Produce, decentralized and individualized production. In fact, the reconfiguration use cases are developed with the aim of realizing the decentralized and self-organizing Industry 4.0 principles. As emerged by the qualitative literature review the main technology, which could drive these challenges, is CPPS. For these reasons the following use case are based on this paradigm and supported by advanced IT services such as data analytics, simulation and the whole cloud computing technologies. The decentralized and self-organized production are based on the integration of different elements which all are intelligent, therefore each production element know its skill, capabilities, position and needs, there is no need of central coordination (Essers and Vaneker, 2016). Summarizing, the advantages of this production paradigm are: i) reduction of breakdown, therefore installation and maintenance costs; ii) reduction of engineering, reprogramming or rescheduling activities; iii) increase in flexible placement production; iv) continuous production optimization and v) customer centric approach, which supports the highly individualized and small production. The benefits of decentralized and self-organized production can be evaluated through the development of flexible and reconfiguration use cases which are: 1) Flexible and decentralized production islands; 2) One production line; 3) Production workflow optimization and 4) Self-reconfiguration and self-adaptive processes.

Flexible and decentralized production islands

The aforementioned shift from mass-production to mass-personalization, is one of the key drivers for flexible and decentralized production system. The aim is to organize production in cooperative and flexible islands. Each unit in this path is able to cooperate with human or robot, specifically, production islands can interact with one to another and can do specific job within the production processes. This flexible layout allows producing many different product variants, and changes in production modules are possible in a short time (Variant spectrum and expansion flexibility). Advantages of using decentralized systems make all elements to be intelligent. In fact, each element is aware of their state, capabilities and needs. There is no need to reprogram, reroute, or reschedule tasks. Another advantage is the reduction of single point of failure. In large complex systems a small failure at a high level can shut down an entire factory. When a production island fails, other production island will take over its task without any notable delay. This significantly reduces the effect of failures of part of the production system (Essers and Vaneker, 2016). This use case requires several technologies: AM, CM, CPPS, IIoT. Clearly, the CPPS application is essential in order to create a cooperation and interaction between production islands, equipment and components. Besides, with the aim of knowing state, capabilities and skills on each unit, it is necessary a massive use of CM and IIoT technologies which allow the integration and sharing of information between different factory levels. Finally, the AM when considering low-volume production, may offer an alternative that could result into shorter lead times and decreased total production costs. In addition, the introduction of AM in a production line can increase flexibility, reduce warehousing costs and assist the company towards the adoption of a mass customisation business strategy.

One production line

Due to the current trends in manufacturing systems, an increasing demand for multiple models and variants of products have been shown. It is necessary the development of one production line for product variants, each variant in the desired volume could be produced on the line matched to customer specifications (variant spectrum, volume flexibility). Therefore, longer production life cycles with highly flexible and agile manufacturing systems are necessary. It is also important of an early product influence in order to integrate a new product variant on an existing production system. Furthermore an approach of virtual product integration is necessary in order to show the virtual rump commissioning (J. Hesselbach, 2011). This use case requires various technologies: AM, CM, CPPS, Digital twin, IIoT and VR/AR. Also in this use case is fundamental the contribution of technologies as AM, CPPS, IIoT and CM which as in the previously case allow cooperation and interaction between not only physical unit but also the information flow. Moreover, it needs also tools as Digital twin which provide information in order to schedule and control material flow, update changes that have been applied to the plant and simulate the alternatives and visualize the effect of each alternatives. Finally, VR/AR allows reducing costs by virtual tests, which analyse the effective integration between new product variants and the existing production line.

Production workflow optimization

Production processes need to be adapted due to the turbulences caused by customer demand and individualized production. The CPPS application enables the use of well-adopted process modelling and execution workflow in the context of manufacturing companies and tracking of activity flows in the real world (Sungur *et al.*, 2016). These workflows allow modelling production processes in terms of route, processing times and transportation time (scheduling flexibility). Optimizations in the production workflow are then derived from the information collected from CPPS, IIoT, CM and Digital twin. This process of integration and information sharing allows on one hand self-optimization of production workflow and on the other hand a self-learning of production units. This optimization use case needs several technologies: Data analytics, CM, CPPS, Digital twin and IIoT. The CPPS units can execute data analytics functions during production operation, make diagnostics, prognostics decisions and control optimization in real time. The analytics results in large amounts of data, that are stored in the Digital twin, such that additional analytics can be executed at a later point of time. This integration of technologies allows the optimization of production processes which thanks to the match action of CPPS which send information through the CM and IIoT technologies, and the data analytics produced both real time and offline (Digital twin) production workflow are updated continuously.

Self-reconfiguration and self-adaptation process

The production process could be stopped by several events such as equipment failure and delivery of material. The scope of this specific requirement, is to develop self-reconfiguration and self-adaptive production systems which allow to respond to such occurrence (variant spectrum, expansion, scheduling, volume flexibility). Self-reconfiguration and self-adaptation concepts such as the Plug and produce capabilities and Digital Twins enable faster reconfiguration of production lines and fast replacement of production modules in case of failure, with savings in costs. Self-reconfiguration and self-adaptation of production equipment and production workflows during production can be achieved by the information collected from the CPPS units or by information captured from factory-level systems (Jatzkowski and Kleinjohann, 2016). Also this use case requires several technologies: CPPS, IIoT, CM, Data analytics and Digital twin. In this use case, CPPS unit is an independent and intelligent production resource that is able to execute a set of production skills autonomously, or in cooperation with other units. A CPPS offers its production skills as a service to other technologies, all necessary reconfigurations are handled automatically without manual engineering, in fact, CPPS units are able to configure themselves. This is possible through the application of other sharing technologies such as IIoT, CM and Data analytics, which allow the information sharing and this process of self-reconfiguration and self-adaptation. Activities in this context could be considered such as optimize orders' scheduling, control production performance, self- monitoring respect to the necessity of maintenance diagnostics, learning new skills carried out in simulation (Digital twin). In table 3 is shown the mapping between the just analysed reconfiguration use cases, flexibility types and enabling technologies.

7. Conclusions

The purpose of the paper was to identify and define reconfiguration use cases, which supported by digitalized opportunities allow achieving specific type of flexibility (variant spectrum, expansion, scheduling and volume) that has an impact on the manufacturing system and therefore propose an analysis of potential improvements of current MES/MOM. In order to define the core characteristics of this production system a literature review has been performed with the scope of investigate the state of the art of MES/MOM level at the Industry 4.0 era. Indeed, the review of the literature allows on one hand to know the level of digitalization of manufacturing company and its relevant technologies and, on the other hand analyse the current state of production capabilities adopted in order to respond to the current challenges of individualized production, short product lifecycle and the increasing variability. This has been resulted in the development of four flexible reconfiguration use cases, which are designed starting from the aforementioned state of the art provided by the literature review and also in response of four type of flexibility identified in the previous work. The scope in the development of future core requirements for MES is to achieve the capabilities own of decentralized and self-organized production. In fact, the decentralized and self-organizing production aims at achieving rapid reconfiguration and individualized production by design the manufacturing system and its machine and resources through the implementation of specific emergent technologies. Therefore, the requirements identified bring to a high level of integration between machines, humans and processes, which reflect to a high level of complexities justified by huge advantages.

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Appendix

Table 3: Mapping between flexibility types, reconfiguration use cases and enabling technologies

	Reconfiguration use cases			
Flexibility types	Flexible decentralized production islands	One production line	Production workflow optimization	Self-reconfiguration and self-adaptation process
Variant spectrum	x	x		x
Expansion	x			x
Scheduling			x	x
Volume		x		x
Core Technologies				
CPPS	x	x	x	x
IIoT	x	x	x	x
Cloud manufacturing	x	x	x	x
Data analytics			x	x
AR/VR		x		
Additive manufacturing	x	x		
Simulation techniques Digital twin		x	x	x