13

Migration Strategies towards the Digital Manufacturing Automation

Ambra Calà[1], Filippo Boschi[2], Paola Maria Fantini[2], Arndt Lüder[3], Marco Taisch[2] and Jürgen Elger[1]

[1]Siemens AG Corporate Technology, Erlangen, Germany
[2]Politecnico di Milano, Milan, Italy
[3]Otto-von-Guericke University Magdeburg, Magdeburg, Germany
E-mail: ambra.cala@siemens.com; filippo.boschi@polimi.it;
paola.fantini@polimi.it; arndt.lueder@ovgu.de; marco.taisch@polimi.it;
juergen.elger@siemens.com

Today, industries are facing new market demand and customer requirements for higher product personalization, without jeopardizing the low level of production costs achieved through mass production. The joint pursuit of these objectives of personalization and competitiveness on costs is quite difficult for manufacturers that have traditional production systems based on centralized automation architectures. Centralized control structures, in fact, do not guarantee the system adaptability and flexibility required to achieve increasing product variety at shorter time-to-market. In order to avoid business failure, industries need to quickly adapt their production systems and migrate towards novel production systems characterized by digitalization and robotization.

The objective of this chapter is to illustrate a methodological approach to migration that supports decision makers in addressing the transformation. The approach encompasses the initial assessment of the current level of manufacturing digital maturity, the analysis of priorities based on the business strategy, and the development of a migration strategy. Specifically, this chapter presents an innovative holistic approach to develop a migration

strategy towards the digital automation paradigm with the support of a set of best practices and tools. The application of the approach is illustrated through an industrial case.

13.1 Introduction

In recent years, lot of research has been devoted to the improvement of control automation architectures for production systems. Latest advances in manufacturing technologies collaborate under the Industry 4.0 paradigm in order to transform and readapt the traditional manufacturing process in terms of automation concepts and architectures towards the fourth industrial revolution [1]. The increasing frequency of new product introduction and new technological development leads to more competitive, efficient and productive industries in order to meet the volatile market demands and customer requirements.

The Industry 4.0 initiative promotes the digitalization of manufacturing in order to enable a prompt reaction to continuously changing requirements [2]. The envisioned digitalization is supported by innovative information and communication technologies (ICT), Cyber-Physical Systems (CPS), Internet of Things (IoT), Cloud and Edge Computing (EC), and intelligent robots. The control architecture is a key factor for the final performance of these application systems [3]. Therefore, new automation architectures are required to enhance flexibility and scalability, enabling the integration of modern IT technologies and, consequently, increasing efficiency and production performance.

For this purpose, within the last years, a lot of decentralized control architectures have been developed in different research projects highlighting the benefit of decentralized automation in terms of flexibility and reconfigurability of heterogeneous devices [4]. However, after years of research, the reality today shows the dominance of production system based on the traditional approach, i.e. the automation pyramid based on the ISA-95 standard, characterized by a hierarchical and centralized control structure.

The difficulty in adopting new architectural solutions can be summarized in two main problems:

- Enterprises that are reluctant to make the decision to change;
- Projects that fail during the implementation or take-up.

Manufacturers are reluctant to adopt decentralized manufacturing technologies due to their past large investments on their current production

facilities, whose current lifetime is long and, therefore, the required changes are sporadic and limited. In addition, methods and guidelines on how to integrate, customize, and maintain the new technologies into the existing ICT infrastructure are unclear and often incomplete. Nevertheless, with the advent of future technologies and with current market requirements, changes during the whole life cycle of the devices and services are necessary.

These changes lead to the transformation of the existing production systems and their migration towards the digital manufacturing of the Industry 4.0 paradigm. The term "migration" refers to the changing process from an existing condition of a system towards the desired one. Here, specifically, the migration is considered as a progressive transformation that moves and the existing production system towards digitalization. Migration strategies are thus essential to support the implementation of digital technologies in the manufacturing sector and the decentralization of the automation pyramid, in order to achieve a flexible manufacturing environment based on rapid and seamless processes as response to new operational and business demands.

Aligned to this vision, the aim of the EU funded project FAR-EDGE (Factory Automation Edge Computing Operating System Reference Implementation) [5] is twofold: it intends not only to virtualize the conventional automation pyramid, by combining EC, CPS and IoT technologies, but also to mitigate manufacturers' conservatism in adopting these new technologies in their existing infrastructures. To this end, it aims at providing them with roadmaps and strategies to guarantee a smooth and low-risk transition towards the decentralized automation control architecture based on FAR-EDGE solutions. Indeed, migration strategies are expected to play an essential role to the success of the envisioned virtualized automation infrastructure. To this end, FAR-EDGE is studying and providing smooth migration path options from legacy-centralized architectures to the emerging FAR-EDGE-based ones.

This chapter aims at describing the migration approach developed within the FAR-EDGE project. After this brief introduction, the state-of-the-art migration processes, change management approaches and maturity models are presented in Section 13.2, providing the founding principles of the FAR-EDGE migration approach presented in Section 13.3. An industrial use case application scenario is presented in Section 13.4, which is assessed and analyzed in Section 13.5, providing an example of migration path alternatives. Finally, Section 13.6 gives an outlook and presents the main conclusions.

13.2 Review of the State-of-the Art Approaches

13.2.1 Migration Processes to Distributed Architectures

There are several other migration processes that have been developed in other projects that allow for a smooth migration between different systems. The work developed in the IMC-AESOP project [6] focused mainly on the implementation of Service Oriented Architecture (SOA) to change the existing systems into distributed and interoperable systems. The migration of systems towards SOA has four major steps, such as Initiation, Configuration, Data Processing, and Control Execution. This migration process makes use of the mediator technology to communicate with the legacy systems, i.e. the old systems. The four steps aim at maintaining the perception of conformity between the several systems' interfaces.

Similarly, the SOAMIG project [7] developed a migration process towards SOA, which is developed as an iterative process and is represented by four phases: Preparation, Conceptualization, Migration and Transition. This migration process aims at a single specific target solution, which is derived step-by-step.

The SMART project [8] performed the analysis of the legacy systems by determining if they can be "linked" to SOA. SMART is an iterative process of six steps: Establish migration Context, Define Candidate Services, Describe Existing Capability, Describe Target SOA Environment, Analyze the Gap, and Develop Migration Strategy. This migration process is mostly used for migrating legacy Information Technology (IT) to SOA.

The MASHUP [9] is another technique for migrating legacy systems into service oriented computing. This migration process proposes a six steps process: Model, Analyze, Map and Identify, Design, Define, and Implement and Deploy. This technique is mainly used to overcome some SOA difficulties, such as the Quality of Service.

The Cloudstep [10] is a step-by-step decision process that supports the migration of legacy application to the cloud, identifying and analyzing the factors that can influence the selection of the cloud solution and also the migration tasks. It comprehends nine activities: Define Organization Profile, Evaluate Organizational Constraints, Define Application Profile, Define Cloud Provider Profile, Evaluate Technical and/or Financial Constraints, Address Application Constraints, Change Cloud Provider, Define Migration Strategy, and Perform Migration.

The XIRUP [11] process aims at the modernization of component-based systems, in an iterative approach. This method comprehends

four stages: Preliminary Evaluation, Understanding, Building, and Migration. The ultimate goal of the XIRUP process is to provide cost-effective solutions and tools for modernization.

The different migration processes found in the literature present some similarities, regardless of the domain and target of migration. Generally, following a stepwise approach, first the legacy system and the target system are analyzed and the requirements defined, and then the target system is developed and finally the migration is defined and performed. Processes like SOAMIG and IMC-AESOP focus mainly on the technical constraints and characteristics of the migration, while SMART, MASHUP, and XIRUP pay attention also to business requirements and involved stakeholders, and Cloud-step includes legal, administrative and organizational constraints. In addition, most of the described processes analyze the migration iteratively, but only the XIRUP process considers the integration of the possible new features after the successful validation of the migrated components.

The existing migration processes or methods are all target based, taking only in consideration a specific goal, e.g. service-oriented architectures. While the described processes try to migrate and transform only technologies, now it is fundamental to start considering changing business paradigms. For the implementation of a new business paradigm, in this case Industry 4.0, it is necessary to have a migration process that allows for holistic and continuous improvement. A process that supports the lean approach for continuous improvement, adaptation to change and system's innovation is the migration process proposed by Calà et al. [12] within the PERFoRM project, which constitutes the baseline for the migration strategy towards the digital manufacturing automation presented in this chapter.

13.2.2 Organizational Change Management

Architectures and information systems represent the backbone of enterprises, and their transformation is a part of the comprehensive process of an organizational change. There is a rich management literature addressing the theme of how to introduce, implement, and support changes that impact the role and work of people in the organizations. In his seminal work, Lewin has highlighted how social groups operate in a sort of equilibrium among contrasting interests and that any attempt to force a change may stimulate an increase in opposing forces [13]. Changes have implications on the employees, who, in most cases, show reactions such as concern, anxiety and uncertainty, which may develop into resistance [14]. In order to prevent and overcome

resistance, Lewin proposed a three steps process: (i) unfreezing, (ii) moving, and (iii) freezing. The first step aims at destabilizing the equilibrium correspondent to the status-quo, so that current behaviours become uncomfortable and can be discarded, i.e. unlearnt, opening up for new behaviours. In practice, unfreezing can be achieved by provoking some emotional feeling, such as anxiety about the survival of the business; the second step consists in a process of searching for more acceptable behaviours, in which individuals and groups progress in learning; the third steps aim at consolidating the conditions of a new quasi-stationary equilibrium [15].

Lewin's work, by providing insight about the mechanisms that rule human groups and operate within the organizations, and by delivering guidance about change management strategies, has opened the way to following studies. In the last decades, several frameworks and approaches have been defined in order to successfully undertake transformation processes and overcome possible resistance. Starting from the analysis of why change effort fails, Kotter [16] has identified a sequence of eight steps for enacting changes in organizations: (i) creating a sense of urgency, e.g., by attracting the attention on potential downturn in performances or competitive advantage and discussing the dramatic implications of such crisis and timely opportunities to be grasped; (ii) building a powerful guiding coalition, i.e., forming a team of people with enough power, interest and capability to work together for leading the change effort; (iii) creating a vision, i.e., building a future scenario to direct the transformation; (iv) communicating the vision, including teaching by the example of the new behaviours of the guiding coalition; (v) empowering others to behave differently, also by changing the systems and the architectures; (vi) planning actions with short term returns, limited changes that bring visible increases in performances and, through acknowledgment and rewarding practices, can be used as examples; (vii) consolidating improvements, developing policies and practices that reinforce the new behaviours; and (viii) institutionalizing new approaches, by structuring and sustaining the new behaviours. Another quite famous framework for managing changes is the Prosci ADKAR Model [17], which suggests to pursue changes through a sequence of five steps corresponding to the initial letters of ADKAR, i.e. (i) awareness about the need for change; (ii) desire to support the change; (iii) knowledge about how to change; (iv) ability to demonstrate new behaviours and competencies; and (v) reinforcement to stabilize the change.

The focus of some researchers and practitioners has shifted from an episodic to a continuous change.

This type of approach includes the continuous improvement of Kaizen [18], with its three principles: (i) process-orientation, as opposed to result-orientation: (ii) improving and maintaining standards, as opposed to innovations that do not impact on all the practices and are not sustainable; and (iii) people orientation as opposed to an involvement of the employees limited to the higher levels of management.

The concept of a learning organization, capable to build, capture, and mobilize knowledge to adapt to a changing environment has been introduced by Senge in 1990 [19]. The basis for the development of a learning organization consists of five disciplines: (i) mental models, (ii) personal mastery, (iii) systems thinking, (iv) team learning, and (v) building shared vision [20]. Other recent literature supports the theory of an organization that continuously changes through engaging and learning.

The case discussed in this chapter, the migration from conventional centralized automation (e.g., ISA-95) to distributed architectures for the digital shopfloor, concerns a major transformation in which the enterprise information systems play a crucial role for realizing the business vision and converting the strategy into change [21]. The theories and strategies of change management can thus provide some guidance about the path to be followed and the mistakes to avoid for the migration. However, organizations participate in a process of continuous change through engagement and learning [22], which involve the continuous transformation and integration of Enterprise Information Systems [21]. Therefore, rather than targeting the final state of a successfully deployed digital automation model, the migration roadmap should aim at incorporating further continuous transformation of distributed automation architectures in the continuous learning and improvement of the organization, in a never-ending process.

13.2.3 Maturity Models

In order to understand what maturity models are, the basics concepts of maturity models are given. To this aim, it is appropriate to provide some definitions, since the notion of maturity concepts might not be one and the same [23].

Maturity can be defined as "*the state of being complete, perfect or ready*". Adding to this definition, there is another point of view of maturity concept given by Maier et al. in 2012 [23], who believe maturity implies an evolutionary progress from an initial to a desired or normally occurring end stage [24]. This last consideration, which stresses the process toward

maturity, introduces another important concept, which is the one of *stages of growth* or *maturity levels*.

The concept of stages of growth started to appear in literature for the first time around the 1970s. In particular, the authors who used these concepts for the first time are Nolan and Crosby in 1979 [25, 26]. The first one published an article where maturity model is seen as a tool to assess in which stage of growth the organization is, assuming it evolves automatically over the time, passing all the stages due to improvements and learning effects [25]. Simultaneously, Crosby [26] proposed a maturity grid for quality management process, as a tool which can be used to understand what is necessary to achieve a higher maturity level, if desired.

From this consideration, it is possible to state that in the same year, two concepts of maturity model have been proposed. On the one hand, Nolan proposed an '*evolutionary model*' that sees the stages of maturity as steps through which every company will improve, and on the other hand, Crosby introduced the "*evolutionist models*" that consider the maturity as a series of steps towards progressively more complex or perfect version of the current status of a company.

Therefore, it has been noticed that, in literature, there is not a general and clear classification of maturity models because of the different interpretation of the maturity concept, of the different approach with which the models (evolutionist/evolutionary) were conceived and according to the different sectors in which they are applied. Nevertheless, Fraser et al. [27] presented a first clear classification per typology of maturity models. In their paper, they distinguish three typologies of maturity models that are, respectively, Maturity grids, Likert-like questionnaires, CMM-like models.

The maturity grids typically illustrate maturity levels in a simple and textual manner, structured in a matrix or a grid. As mentioned before, the first type of maturity grid was the one of Crosby [26], and its main characteristic is that it is not specified what a particular process should look like. Maturity grids only identify some characteristics that any process and every enterprise should have in order to reach high-performance processes [23].

The Likert-like questionnaires are constructed by "questions", which are no more than statements of good practice. The responder to the questionnaire has to score the related performance on a scale from 1 to n. They can be defined as hybrid models, since they combine the questionnaires approach with the definition of maturity. Usually, they have only a description of each level, without specifying the different activities that have to be performed to achieve a precise maturity level.

Finally, there is the Capability Maturity Model (CMM). Its architecture is more formal and complex compared to the first two. They are composed of process areas organized by common features, which specify a number of key practices to address a series of goals. Typically, the CMMs exploit Likert questionnaires to assess the maturity. These models have been improved successively by the Capability Maturity Model Integration (CMMI) [28].

Although Nolan and Crosby have been the pioneers of the maturity assessment tools, as stated by Wendler [29], the maturity models field is clearly dominated by the CMM(I)'s inspired models. For this reason, FAR-EDGE approach is based on this model and, therefore, its relevant features will be described in this chapter.

The CMM was developed at the end of the 1980s by Watts Humphrey and his team from the Software Engineering Institute (SEI) in Carnegie Mellon University. It was used as a tool for objectively assessing the ability of government contractors' processes to perform a contracted software project. Although the focus of the first version of the CMM lies on the software development processes, successively, it has been applied in other process areas [30]. CMM decomposes each maturity level (shown in the Figure 13.1 [38]) into basic parts with the exception of level 1, which is the initial one. These levels define a scale for measuring process maturity and evaluating process capability. Each level is composed by several *key process areas*. Each key process area is organized into five sections called *common features*, which in turn specify *key practices.*

The key process areas specify where an organization should focus on improving processes. In other words, they identify a cluster of related activities, which, if performed collectively, achieve a set of goals considered important for improving process capability.
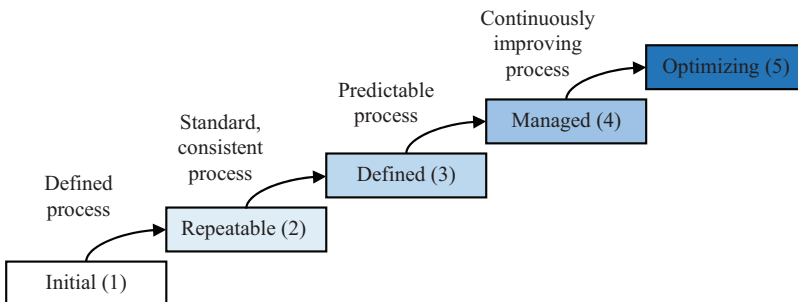
Figure 13.1   CMM's five maturity levels (from [38]).

The practices that describe the key process areas are organized by common features. These are attributes that indicate whether the implementation of a key process area is effective, repeatable and lasting.

Finally, each process area is described in terms of *key practices*. They define the activities and infrastructure for an effective implementation and institutionalization of the key process area. In other words, they describe what to do, but not how to do it.

In 2002, the CMMI was proposed [28]. It is considered as an improvement of the CMM model, but in contrast to this model that was built for software development, the purpose of CMMI has been to provide guidance for improving organizations' processes and their ability to manage the development, acquisition, and maintenance of products or services in general [28]. Furthermore, the focus of this model lies on the representation of the current maturity situation of the organization/process (coherently with the evolutionary model) and on giving indications on how a higher maturity level can be achieved (as proposed by evolutionist model). For these reasons, considering also the FAR_EDGE purposes, the CMMI can be considered as the most appropriate to be taken as a reference model to implement a blueprint migration strategy.

13.3 The FAR-EDGE Approach

The envisioned cyber-physical production and automation systems are characterized by complex smart and digital technology solutions that cannot be implemented in an existing production system in one step without considering their impact on the legacy systems and processes. Only a smooth migration strategy, which applies the future technologies in the existing infrastructures with legacy systems through incremental migration steps, could lower risks and deliver immediate benefits [4]. Indeed, a stepwise approach can mitigate risks at different dimensions of the factory by breaking down the long-term vision, i.e. the target of the migration, in short-term goals. This approach, as represented in Figure 13.2, is based on the lean and agile techniques, such as the Toyota Improvement Kata [31], to implement the new system step-by-step and support the continuous improvement, adaptation to changes and innovation at technical, operational and human dimensions.

The methodology adopted in FAR-EDGE to define a migration approach is described in [32]. Workshop and questionnaire results led to the identification of the important impact aspects of the FAR-EDGE reference architectures to the existing traditional production systems. Considering the identified factory dimensions of impact, an assessment tool has been realized
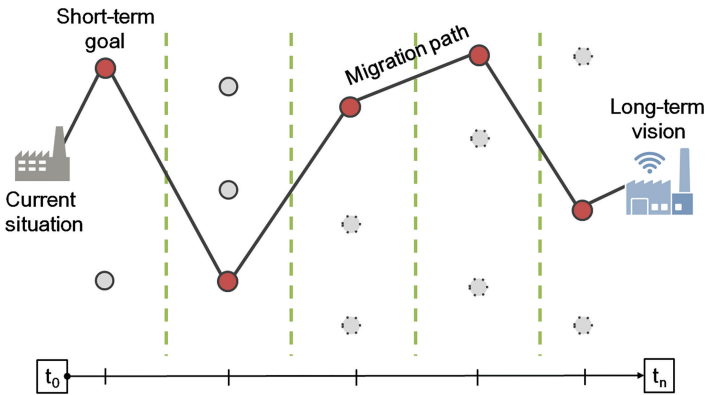
Figure 13.2 Migration path definition.

to support the analysis of the current situation and the desired ones of the manufacturing systems before defining their migration path.

Inspired by the migration process defined in [12], a methodology to define and evaluate different architectural blueprints has been defined within the FAR-EDGE project to support companies in investigating the possible technology alternatives towards the digital manufacturing automation with a positive return on investments.

First, there is a preparation phase [12] that aims at analyzing the current domain of the company, as well as the business long-term vision. Through questionnaires and workshops with people involved in the manufacturing process (i.e. production and operation management, IT infrastructure, and change management), the migration goal and starting point are defined, as well as the possible impact and the typical difficulties that the FAR-EDGE solution can have.

The scope of this phase is to have a clear picture on what should be changed in a company's business by investigating the technology and business process points of view simultaneously and deriving the implication at technical, operational and human dimensions in a holistic approach. In fact, it is important to keep in mind that the implementation of smart devices, intelligent systems, and new communication protocols has a big impact not only on the technological dimension of the factory but also on system's performance, work organization, and business strategy [32]. Therefore, a questionnaire of circa 60 questions about the technical, operational,

		Level 1	Level 2	Level 3	Level 4	Level 5
	TECHNICAL					
	OPERATIONAL					
	HUMAN					

Figure 13.3 FAR-EDGE Migration Matrix.

and human factory's dimensions has been defined within FAR-EDGE to holistically analyze the current condition of the production system.

Based on the answers of this questionnaire, different migration scenarios according to the possible technology options are investigated [12] in order to identify the migration alternatives to go from the identified AS-IS situation to the TO-BE one. To this end, a tool called Migration Matrix (Figure 13.3) has been developed within the FAR-EDGE project to identify all the necessary improvements in the direction of the Industry 4.0 vision of smart factory, splitting the digital transformation in different scale levels. Thus, the matrix represents the three impact dimensions, aiming at providing a snapshot of current situation of companies and suggesting which steps should be achieved in order to reach the FAR-EDGE objective in a smooth and stepwise migration process.

The migration matrix is structured in rows and columns. The rows represent the relevant application fields selected during the preparation phase with a high potential of improvement by FAR-EDGE concepts implementation on the architecture. They refer to technology innovations, factory process maturity, and human roles. The columns describe the development steps for each application field towards a higher level of production flexibility, intelligent manufacturing, and business process in the direction of the FAR-EDGE platform implementation. As shown in Figure 13.3, the five columns represent five levels of production system's digital maturity.

These levels are based on the integrating principles of both the CMMI (Capability Maturity Model Integration) framework [24, 33, 34] and DREAMY model (Digital REadiness Assessment MaturitY) [35], which are:

- Level 1 – The production system is poorly controlled or not controlled at all, process management is reactive and does not have the proper organizational aspects and technological "tools" for building an infrastructure that will allow repeatability and usability of the utilized solutions.
- Level 2 – The production is partially planned and implemented. Process management is weak due to lacks in the organization and/or enabling technologies. The choices are driven by specific objectives of single projects and by the experience of the planner, which demonstrates only a partial maturity in managing the infrastructure development.
- Level 3 – The process is defined thanks to the planning and the implementation of good practices, management and organizational procedures, which highlight some gaps/lacks of integration and interoperability in the applications and in the information exchange because of some constraints on the organizational responsibilities and /or on the enabling technologies.
- Level 4 – The integration and the interoperability are based on common and shared standards within the company, borrowed from intra- and/or cross-industry de facto standard, with respect to the best practices in industry in both the spheres of the organization and enabling technologies.
- Level 5 – The process is digitally oriented and based on a solid technology infrastructure and a high potential growth organization, which supports business processes in the direction of Industry 4.0, including continuous improvement processes, complete integrability, organization development, speed, robustness and security in information exchange.

The main reason of this choice is that the CMMI provides a defined structure, specifying what are the capabilities, the characteristic, and the potentiality a company has at each level. Based on [35], as the five-scale CMMI provided a generic model to start from, the maturity levels have been readapted in order to be compliant and coherent with the dimensions considered by domains previously defined.

Therefore, the Migration Matrix provides a clear map of the current and desired conditions of a factory, revealing different alternatives to achieve the first short-term goal in the direction of the long-term vision. These alternatives are then evaluated according to the business strategy, considering also strengths and weaknesses points. Since FAR-EDGE aims

at providing a holistic overview of the impact of edge and cloud computing solutions on the existing production environments, the developed approach supports the identification of the areas in which improvement actions are required, matching the needs of the organization and the estimation of the overall benefit of the innovative solution for the industry.

Based on the results of these phases, a migration path is defined and the solution to execute the first migration step is designed, implemented, and deployed following the migration process of [12]. In parallel, a set of guidelines and recommendations for the implementation of the FAR-EDGE solution are defined and documented.

13.4 Use Case Scenario

The industrial application example provided here describes a simple scenario in the automotive industry. The manufacturer aims to decentralize the current factory automation architecture and introduce cyber-physical system concepts in order to flexibly deploy new technologies and maximize the correlation across its technical abilities to support mass-customization. Target of the implementation of the FAR-EDGE platform is the reduction of time and effort required for deploying new applications by the automatic reconfiguration of physical equipment on different stations, according to the current operation, and its automatic synchronization among different information systems (PLM, ERP, and MES).

The factory currently presents an automation architecture compliant to ISA-95 standards with three layers: ERP, MES, and SCADA with Field devices. However, the integration of new applications at the MES level to obtain new functions at the shopfloor is very expensive because of highly dependent on the centralized control structure of the architecture. Moreover, it requires a long verification time and, consequently, a long delivery time to customers.

The factory envisioned by FAR-EDGE, according to the Industry 4.0 paradigm, is a highly networked CPS in which the modules are able to reconfigure themselves and communicate with each other via a standard I4.0 semantic protocol. As there is no central control, the system modules can identify and integrate new components automatically, negotiate their services and capabilities in some sort of social interaction. The modules have the abilities of perception, communication and self-explanation. In this way, the new modules can be integrated into the system quickly in a "Plug and Produce"

fashion, and the system can reconfigure itself in the event of changes and continue the production process without additional adjustments of the overall control.

Applying this vision to the considered use case, the single physical equipment becomes a single "Plug-and-Produce" module able to configure and deploy itself without human intervention. The plugging of the module could be implemented at the edge automation component of the platform (Ref to CHAPTER 2 e chapter 4). An adapter for controlling and accessing information about the single equipment should be developed as part of the communication middleware. Data will flow to the edge automation component, which will interact with the CPS models database of the platform in order to access and update information about the location and status of the single equipment. The synchronization and reconfiguration functionalities of the platform will trigger changes to the configuration of the stations, which will be reflected in the CPS models database. The ledger automation and reconfiguration services could also be used for automating the deployment and reconfiguration of the shopfloor.

13.5 Application of the Migration Approach

13.5.1 Assessment

Table 13.1 presents the main fields of application to be considered from technical, operational and human points of view for the automation. The assessment represented in the Migration Matrix provides an overview of the current (AS-IS) situation of the factory with reference to the automation. The AS-IS situation of the considered industrial use case is depicted in red within the matrix of Table 13.1. From this Migration Matrix, it is immediately clear which are the less developed areas of a specific factory's use case, towards the implementation of digital technologies, i.e. "Plug-and-Produce" modules.

Currently, the automation control has a centralized structure that allows the vertical integration of the different architectural levels, by providing automation and analytics capabilities to entities that work in parallel. The production equipment is networked through vendor-specific API, and data can be shared from different systems. In this way, the production data can be monitored and analyzed from a MES system and the order processing, which is fully automated, and production processes are being developed to be fully integrated. However, the production system has only a very basic security and local access control. The main issue in this use case is the reconfiguration

Table 13.1 AS-IS situation of the use case for the automation functional domain

AS-IS	Level 1	Level 2	Level 3	Level 4	Level 5
	Equipment/Machinery connectivity and communication protocols				
	N.A.	Basic connectivity (RS232-RS485)	Local network through LAN/WAN	Networked with vendor specific API	Networked with standard communication protocols
	Security and access control mechanisms				
	N.A.	Basic security or local access control	Basic security and local access control	Vendor based access control for each system	Full security and global access control
	Production Data Monitoring and Processing				
	N.A.	Locally, per station / equipment / machinery	Centrally available through SCADA	Available and analyzed through MES at Factory level	Available and analyzed through the Cloud
	3D layouts, visualization and simulation tools				
	CAD systems not related to production data	CAD systems manually feed with production data	CAD systems interfaced with other design systems	CAD systems interfaces with intelligent systems for fast development	Fully integrated CAD systems with intelligent tools for interactive design process
	Reconfiguration of production equipment and processes				
	Manual	Locally managed at machine level (PLC)	Centrally managed from SCADA	Centrally managed by MES	Centrally managed according to ERP
	Product Optimization				
	N.A.	Rare offline optimization	Offline optimization based on manual data extraction	Manual optimization based on simulation data	Automatic optimization based on simulation services
	Availability of production process models				
	N.A.	Models defined (Excel based) with limited use	Models defined with limited specific functions	Models defined and integrated with business functions	Models defined and integrated with several different functions
	IT Operator				
	N.A.	External service provider	Internal for traditional IT systems	Internal for specific digital systems	Internal for all systems from field to cloud
	Impact on Operator, Product Designer and Production Engineer				
	Still unclear	Identified in general terms	Analyzed	Defined	Implemented in continuous improvement

of the production equipment that is performed per equipment by configuring it at PLC level. Moreover, time-consuming reconfiguration operations can stop the production. From a human perspective, the main role to be considered in this use case is the IT Operator, who has a strong knowledge on the current IT infrastructure of the factory but not on the digital systems and Industry 4.0 concepts. Within the factory, the implications of digital technologies on IT Operator have not been addressed because they are still unclear. Furthermore, other roles are involved in the transformation: the Operator, Production Manager, Product Designer, and Production Engineer. Their tasks will change as a consequence of the automatic reconfiguration of the physical equipment, of the novel devices in the field, for the need to encompass all the necessary information within product design and production planning. However, these roles are currently performing according to the current tasks and procedures, unaware of the prospected transformation.

The manufacturer could benefit from the implementation of the FAR-EDGE architecture and components in terms of modularity and reconfigurability capabilities of the shopfloor. In fact, the implementation of Edge Nodes on the single equipment enables the identification of new entities in the shopfloor and their instantiation at Cloud level, thus being directly accessible for all IT systems that require their definition (i.e. PLM). Moreover, the decentralization of the automation architecture through the Edge and Ledger layers could increase the flexibility and reconfigurability of the architectural assets, enabling future modifications and improvements.

13.5.2 Gap Analysis

Of course, to migrate the current traditional automation system to the FAR-EDGE architecture and components, different aspects of the factory need to be evaluated to guarantee a smooth transformation of the factory at minor impact on the current production system.

13.5.2.1 Technical aspects

FAR-EDGE supports automated control and automated configuration of physical production systems using plug-and-produce factory equipment in order to enable fast adjustments of the production processes according to requirements changes. To integrate plug-and-produce capabilities within an existing shopfloor equipment, a bidirectional monitoring and control communication channel with the shopfloor equipments is required, thus not only via sensors and actuators but also with active actors (e.g. PLC) equipped

with a significant processing power and with a good network connection capability, namely the Edge Nodes of the FAR-EDGE architecture that are described in earlier chapters of the book.

The connection of digital and physical worlds will also support gathering and processing Field data towards a better understanding of production processes, for example, to change an automation workflow based on changes detected in the controlled process. This requires Edge Gateways, i.e. computing devices connected to a fast LAN to provide a high-bandwidth field communication channel. Edge Gateways can execute edge processes activity, namely the local orchestration of the physical process monitored and operated by Edge Nodes. In addition, Cloud services running in a virtualized computing environment can act as entry point for external applications and provide centralized utilities to be used internally or perform activities for archiving analysis results.

The introduction of the Cloud within the production control entails full security and global access control mechanisms, which need to be increased immediately, as soon as the production information will be available at cloud level for different stakeholders in order to prevent data security and privacy issues. In addition, the automatic reconfiguration of physical equipments can be enhanced by the integration of simulation tools that provide an interactive design process leading to the optimization of the production processes. In order to improve the optimization, 3D layouts and CAD systems must be fully integrated in a common digital model by means of intelligent tools that automatically feed the simulation systems with the real production data and derive optimized solutions.

13.5.2.2 Operational aspects

Plug and Produce capability could be seen as a crucial solution to reduce the time and costs involved in not only manufacturing process (e.g. new machine/equipment/resources deployment) but also process design and process development. For this reason, it presumes the need of building an agile enterprise application platform which helps a company to be proactive in carrying out its core activities. To facilitate such tight and effective improvement in a modern enterprise, the (information and operational technology (IT/OT) integration is needed. This means, first, the integration of ERP applications, MES and shopfloor systems (i.e PLCs, SCADA, DCS) along the levels defined by ISA-95 and, second, the integration of PLM systems and MES (Level 3 and Level 4) when it comes to the transition of a ready-to-market product into production.

The latter consideration enables the integration between design and production, in terms of processes and systems, increasing product quality and process efficiency. This convergence is the source of not only product but also process definition. On one side, the Bill of Process (BoP) provides traceability to the Bill of Materials (BoM) to leverage PLM's configuration and effectiveness controls, defining the correct sequence of operations to guarantee a high level of product quality. On the other side, the Manufacturing process management carries out the documentation and the follow-up of processes in the MES, which reshapes theoretically designed processes to make them fit the reality on the shopfloor, ensuring the process efficiency. Considering this, the proper integration of systems is vital, otherwise data related to the new machine introduction or the process adjustment would "manually" be passed to MES (that coordinate and monitor the process execution).

From this consideration, the evolution to a Plug and Produce production system has to go through the information harmonization between engineering and manufacturing, coherently with a stepwise approach. To this aim, the first step is to realize an overall data backbone for all processes and products. This means to centralize the DBs and the information systems in order to integrate the information flow between manufacturing and engineering domain. Within the next step, the MES will automatically provide execution data to ensure holistic and reliable product information that, being documented and available in both systems, can be considered as a strategic asset to improve the maintenance, repair, and optimization process.

In this context, the deployment of event-driven architecture ('RT-SOA' or Real-Time Service Oriented Architecture) could facilitate the information exchange and, therefore, the seamless reconfiguration of machinery and robots as a response to operational or business events.

13.5.2.3 Human aspects

The migration towards digital manufacturing automation implies changes in the behavior of the production systems as well as in the information flows. The implications impact the work of the employees under different points of view.

The health and conditions of the operators are usually modified by the introduction of automation. In most cases, the ergonomic effort is reduced, but in some cases, additional factors, such as the introduction of robotics, have to be included in the risk management plans. The autonomy and privacy of the employees may change because of a more accurate and real-time monitoring of the operations and tracking of products and tools.

These implications need to be carefully analyzed with all the stakeholders and managed.

The role of employees can be affected by the new technological and operational landscape: on the one hand, some manual tasks or scheduling decisions are taking over by the systems; on the other hand, some new tasks are added to supervise the systems, monitor the KPIs, and address the problems. The workplace, the HMIs, the workflow, and the instructions change in several cases. It is important that the operators stay in the loop of control of the process and are aware of the states and activities of the technological systems.

The deployment of the new technologies is expected to impact not only the Production Operators, but also the Product Designers, the Production Engineers, and obviously the IT Operators. Overall, the skills requirements for each role have to be updated on the basis of the TO-BE scenario and compared with those available in the AS-IS situation, in order to identify and address the gaps, through up-skilling or recruitment initiatives. Furthermore, the job profiles and training plans need to be updated to ensure the incorporation in the standard procedures.

Although the need for these changes is perceived, they are still unclear and the size of the gap has not been evaluated yet.

13.5.3 Migration Path Alternatives

Considering the current situation of the industrial use case and the long-term vision of digital manufacturing enabled by the FAR-EDGE reference architecture, different migration path alternatives can be identified. The identified alternatives are generated on the basis of technical constraints, investment capabilities, and organizational structure. Considering different priorities and required improvements on part of the production system, these migration alternatives lead to the achievement of the first short-term goal of the migration path towards the Industry 4.0 vision.

Two main migration path (MP) alternatives have been derived according to the specific business goal of the represented factory. The first alternative (MP 1) focuses on the implementation of plug-and-produce equipment to enhance the production system reconfigurability (Table 13.2), while the second alternative (MP 2) focuses on the real-virtual automatic synchronization of the single equipment based on simulation tools to optimize the production process (Table 13.3). Both alternatives will enable the factory to improve different parts of the system towards the long-term vision of "digitalization" by implementing step-by-step some of the FAR-EDGE solution components. The manufacturer will then select the adequate solution according to the enterprise's needs, interests and constraints.

Table 13.2 MP for the implementation of reconfigurability

					FAR-EDGE
MP 1	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
	Equipment/Machinery connectivity and communication protocols				
	N.A.	Basic connectivity (RS232-RS485)	Local network through LAN/WAN	Networked with vendor specific API	Networked with standard communication protocols
	Security and access control mechanisms				
	N.A.	Basic security or local access control	Basic security and local access control	Vendor based access control for each system	Full security and global access control
	Production Data Monitoring and Processing				
	N.A.	Locally, per station/ equipment/ machinery	Centrally available through SCADA	Available and analyzed through MES at Factory level	Available and analyzed through the Cloud
	Reconfiguration of production equipment and processes				
	Manual	Locally managed at machine level (PLC)	Centrally managed from SCADA	Centrally managed by MES	Centrally managed according to ERP
	IT Operator				
	N.A.	External service provider	Internal for traditional IT systems	Internal for specific digital systems	Internal for all systems from field to cloud
	Impact of digital technologies on IT Operator				
	Still unclear	Identified in general terms	Analyzed	Defined	Implemented in continuous improvement

Color legend: red = AS-IS, yellow = intermediate step, green = TO-BE

The migration matrixes depicted for the two MPs represent two specific improvement scenarios and not the production system as a whole. In both matrixes, the maturity levels of the current situation are represented in red, while the migration steps are represented in yellow (the intermediate migration step) and in green (the final step).

MP 1: Implementation of reconfigurability. According to the business strategy, the deployment configuration should give priority to the Cloud, since the factory already planned to implement cloud technologies in the production automation control. The collection and integration of information through the Cloud will support the reconfigurability of plug and produce equipment. In fact, PLM provides the planning information about how the product will be produced and the MES serves as the execution engine to realize the plan and BoP. As a second step, the information provided by PLM

Table 13.3   MP for the implementation of simulation-based optimization

MP 2	Level 1	Level 2	Level 3	Level 4	Level 5
	3D layouts, visualization and simulation tools				
	CAD systems not related to production data	CAD systems manually feed with production data	CAD systems interfaced with other design systems	CAD systems interfaces with intelligent systems for fast development	Fully integrated CAD systems with intelligent tools for interactive design process
	Production Optimization				
	N.A.	Rare offline optimization	Offline optimization based on manual data extraction	Manual optimization based on simulation data	Automatic optimization based on simulation services
	Availability of production process models				
	N.A.	Models defined (Excel based) with limited use	Models defined with limited specific functions	Models defined and integrated with business functions	Models defined and integrated with several different functions
	Impact of digital technologies on Product Designers and Production Engineers				
	Still unclear	Identified in general terms	Analyzed	Defined	Implemented in continuous improvement

Color legend: red = AS-IS, yellow = intermediate step, green = TO-BE

needs to be reshaped. It is important to increase the amount of detail included in product information to cover machine programming, operator instructions and task sequencing. In this way, work plans, routing and BoP will serve as bridge elements between PLM and the MES [36]. In order to integrate the production systems information to the Cloud, a first improvement of the access control for each system must be immediately considered, which will be enhanced to a full security system in a second step. Moreover, because of the number of different stakeholders involved, in terms of third-part vendors and system developers, the second migration step should include also the introduction of open API to enable the standard communication among heterogeneous systems. Following this change in production systems and operations, the IT Operators must be trained in order to be able to manage the new automation control system, from the field level to the Cloud. The implications for the other roles should be analyzed in order to prepare the following steps.

MP 2: Simulation-based optimization. The virtual representation of the physical objects in cyber space can be used for optimization of the production processes. For example, the cyber modules have the ability to avoid getting

stuck in local optimization extremes and are able to find the global maximum and minimum which results in high performance. Therefore, additionally to the migration steps described in MP 1, the integration of digital models must be considered. Firstly, the existing CAD systems will be interfaced to each other, and secondly, they will be fully integrated to enable the optimization of equipment reconfiguration through intelligent simulation tools. In the same way, the production will be optimized based on the integrated information derived from the CAD designs and then it will be automatically implemented through the intelligent tools. To this end, the production process models and their different layout versions will be first integrated with business functions, in order to align the process parameters with cost deployment and profitability measures. From an organizational perspective, the main implications affect the roles of product designers and production engineers: they need to increase their level of cooperation to model all the relevant aspects of the manu-facturing processes into the CAD. Furthermore, the production engineers have to see that the models of the CAD are connected to the models of the actual production facilities, so that the production can be simulated, planned and monitored. Therefore, the competences of the above mentioned roles require to be enhanced with new skills concerning digitalization, modeling and simulation. Furthermore, the tasks and responsibilities of these roles have to be updated accordingly.

The migration matrixes support manufacturers by providing them with a holistic view of the required steps for migration towards the Industry 4.0 vision at different dimensions of the factory, i.e. technical, operational, and human. Based on this information and according to the business goals, the manufacturer will select the optimal scenario as first step of migra-tion towards the long-term goal of complete digitalization of the factory. The solution identified within the selected scenario will be then designed in detail, implemented and deployed according to next process phases described in [12].

13.6 Conclusion

In conclusion, this chapter shows how the FAR-EDGE migration approach can lead a manufacturing company to achieve an improvement towards a new manufacturing paradigm following a smooth and no risk transition approach with a holistic overview.

In fact, the use case scenario points out that every part of an orga-nization – including workforce, product development, supply chain and

manufacturing – has been considered to reach more flexible and reconfigurable aspects in order to rapidly react to both endogenous and exogenous drivers that are affecting the current global market [37].

In this context, the IT/OT convergence can be seen as a first implementation of operational aspects needed to obtain a solid manufacturing layer based on the encapsulation of production resources and assets according to the existing protocols, in order to facilitate the plug-and produce readiness, and therefore, to achieve a flexible manufacturing environment.

As far as the technical dimension is concerned, the Edge Nodes and the ledger implementation can enable the realization of the overall system architecture based on information systems integration needed to obtain the seamless system reconfiguration avoiding scrap and reducing time to market and cost.

Finally, the human aspect is crucial to ensure the operation, management, and further development of the highly digitalized and automated production system. The methodology illustrated in this chapter guides manufacturing in considering the implications for skills and work organization within their migration strategy.

Only by jointly considering the technical, operational, and human aspects can a migration strategy anticipate the possible hurdles and lead to a smooth transformation towards an effective new production paradigm.

Acknowledgements

References

[1] Acatech - National academy of science and Engineering, "Recommendations for implementing the strategic initiative INDUSTRIE 4.0-Final report of the Industrie 4.0 Working Group". pp. 315–320.

[2] Acatech - National academy of science and engineering-, "Cyber-Physical Systems Driving force for innovation in mobility, health, energy and production".

[3] U. Rembold and R. Dillmann, *Computer-Aided Design and Manufacturing,* 1985.

[4] M. Foehr, J. Vollmar, A. Calà, P. Leitão, S. Karnouskos, and A. W. Colombo, "Engineering of Next Generation Cyber-Physical Automation System Architectures", in *Multi-Disciplinary Engineering for Cyber-Physical Production Systems*, Springer International Publishing, pp. 185–206, 2017.

[5] "FAR-EDGE – Factory Automation Edge Computing Operating System Reference Implementation". 2017.

[6] J. Delsing, J. Eliasson, R. Kyusakov, A. W. Colombo, F. Jammes, J. Nessaether, S. Karnouskos, and C. Diedrich, "A migration approach towards a SOA-based next generation process control and monitoring", in *IECON Proceedings (Industrial Electronics Conference),* pp. 4472–4477, 2011.

[7] C. Zillmann, A. Winter, A. Herget, W. Teppe, M. Theurer, A. Fuhr, T. Horn, V. Riediger, U. Erdmenger, U. Kaiser, D. Uhlig, and Y. Zimmermann, "The SOAMIG Process Model in Industrial Applications", in *2011 15th European Conference on Software Maintenance and Reengineering,* pp. 339–342, March 2011.

[8] S. Balasubramaniam, G. A. Lewis, E. Morris, S. Simanta, and D. Smith, "SMART: Application of a method for migration of legacy systems to SOA environments", *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics),* vol. 5364 LNCS, pp. 678–690, 2008.

[9] S. Cetin, N. I. Altintas, H. Oguztuzun, A. H. Dogru, O. Tufekci, and S. Suloglu, "A mashup-based strategy for migration to Service-Oriented Computing", in *2007 IEEE International Conference on Pervasive Services, ICPS,* pp. 169–172, 2007.

[10] P. V. Beserra, A. Camara, R. Ximenes, A. B. Albuquerque, and N. C. Mendonça, "Cloudstep: A step-by-step decision process to support legacy application migration to the cloud", in *2012 IEEE 6th International Workshop on the Maintenance and Evolution of Service-Oriented and Cloud-Based Systems, MESOCA 2012,* pp. 7–16, 2012.

[11] R. Fuentes-Fernández, J. Pavón, and F. Garijo, "A model-driven process for the modernization of component-based systems", *Sci. Comput. Program.,* vol. 77, no. 3, pp. 247–269, 2012.

[12] A. Calà, A. Luder, A. Cachada, F. Pires, J. Barbosa, P. Leitao, and M. Gepp, "Migration from traditional towards cyber-physical production systems", in *Proceedings - 2017 IEEE 15th International Conference on Industrial Informatics, INDIN 2017,* pp. 1147–1152, 2017.

[13] T. Newcomb and E. Hartley, *No TitleGroup decision and social change,* Holt. New York, 1947.

[14] S. Z. A. Kazmi and M. Naarananoja, "Collection of Change Management Models – An Opportunity to Make the Best Choice from the Various Organizational Transformational Techniques", *GSTF J. Bus. Rev.,* vol. 2, no. 4, pp. 44–57, 2013.

[15] B. H. Sarayreh, H. Khudair, and E. alabed Barakat, "Comparative study: The Kurt Lewin of change management", *Int. J. Comput. Inf. Technol.,* vol. 02, no. 04, pp. 2279–764, 2013.

[16] J. P. Kotter, "Leading change: why transformation efforts fail the promise of the governed corporation", *Harward Bus. Rev.,* no. March– April, pp. 59–67, 1995.

[17] J. Hiatt, *adkar.* Prosci Inc., 2006.

[18] A. Berger, "Continuous improvement and *kaizen*: standardization and organizational designs", *Integr. Manuf. Syst.,* vol. 8, no. 2, pp. 110–117, 1997.

[19] S. Yadav and V. Agarwal, "Benefits and Barriers of Learning Organization and its five Discipline," *IOSR J. Bus. Manag. Ver. I,* vol. 18, no. 12, pp. 2319–7668, 2016.

[20] P. M. Senge, "The fifth discipline: the art and practice of the learning organization", *5th Discipline. p. 445,* 2006.

[21] D. Romero and F. Vernadat, "Enterprise information systems state of the art: Past, present and future trends", *Comput. Ind.,* vol. 79, pp. 3–13, 2016.

[22] C. G. Worley and S. A. Mohrman, "Is change management obsolete?", *Organ. Dyn.,* vol. 43, pp. 214–224, 2014.

[23] A. M. Maier, J. Moultrie, and P. J. Clarkson, "Assessing organizational capabilities: Reviewing and guiding the development of maturity grids", in *IEEE Transactions on Engineering Management,* vol. 59, no. 1, pp. 138–159, 2012.

[24] T. Mettler and P. Rohner, "Situational maturity models as instrumental artifacts for organizational design", *Proc. 4th Int. Conf. Des. Sci. Res. Inf. Syst. Technol. - DESRIST '09. Artic. No. 22,* pp. 1–9, May 06–08, 2009.

[25] R. L. Nolan, "Managing the crises in data processing", *Harv. Bus. Rev.,* vol. 57, pp. 115–127, March 1979.

[26] P. B. Crosby, "Quality is free: The art of making quality certain", *New York: New American Library.* p. 309, 1979.

[27] P. Fraser, J. Moultrie, and M. Gregory, "The use of maturity models/grids as a tool in assessing product development capability", in *IEEE International Engineering Management Conference,* 2002.

[28] C. P. Team, "Capability Maturity Model{\textregistered} Integration (CMMI SM), Version 1.1", *C. Syst. Eng. Softw. Eng. Integr. Prod. Process Dev. Supplier Sourc. (CMMI-SE/SW/IPPD/SS, V1. 1),* 2002.

[29] R. Wendler, "The maturity of maturity model research: A systematic mapping study", *Inf. Softw. Technol.,* vol. 54, no. 12, pp. 1317–1339, 2012.

[30] M. Kerrigan, "A capability maturity model for digital investigations", *Digit. Investig.,* vol. 10, no. 1, pp. 19–33, 2013.

[31] N. Rother, "Toyota KATA - Managing people for improvement, adaptiveness, and superior results", 2010.

[32] A. Calà, A. Lüder, F. Boschi, G. Tavola, M. Taisch, P. Milano, and V. R. Lambruschini, "Migration towards Digital Manufacturing Automation - an Assessment Approach".

[33] M. Macchi and L. Fumagalli, "A maintenance maturity assessment method for the manufacturing industry", *J. Qual. Maint. Eng.,* 2013.

[34] M. J. F. Macchi M., Fumagalli L., Pizzolante S., Crespo A. and Fernandez G., "Towards Maintenance_maturity assessment of maintenance services for new ICT introduction", in *APMS-International Conference Advances in Production Management Systems,* 2010.

[35] A. De Carolis, M. Macchi, E. Negri, and S. Terzi, "A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies", in *IFIP International Federation for Information Processing 2017,* pp. 13–20, 2017.

[36] Atos Scientific and C. I. Convergence, "The convergence of IT and Operational Technology", 2012.

[37] F. Boschi, C. Zanetti, G. Tavola, and M. Taisch, "From key business factors to KPIs within a reconfigurable and flexible Cyber-Physical System", in *23rd ICE/ITMC Conference- International Conference on Engineering, Technology,and Innovationth ICE/IEEE ITMC International Technology Management Conference w,* Janurary 2018.

[38] M. C. Paulk, B. Curtis, M. B. Chrissis, and C. V Weber, "Capability Maturity ModelSM for Software, Version 1.1", *Office.* 1993.