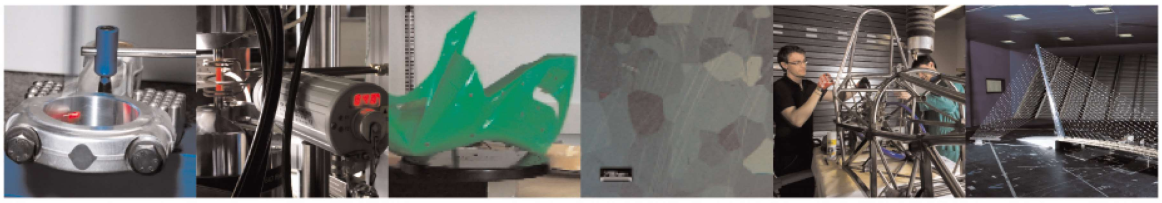

# A Hybrid Architecture for the Deployment of a Data Quality Management (DQM) System for Zero-Defect Manufacturing in Industry 4.0

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# A hybrid architecture for the deployment of a Data Quality Management (DQM) System for Zero-Defect Manufacturing in Industry 4.0

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**Abstract.** The adoption of Industry 4.0 technologies is slow and lacks homogeneity across the manufacturing landscape. Challenges arise from legacy IT systems, or a low level of digitization leading to difficult integration processes, or simply the fear of investing too much in building the necessary infrastructure versus the uncertainty of the potential benefits. The market has also become more demanding, both in terms of competition and customer requirements, so that more and more manufacturers are faced with the demand for high production flexibility, high quality, and low operating costs. This paper aims to address the implementation complexity of a cyber-physical production system for zero-defect manufacturing in dynamic, high-value, high-mix, and low-volume contexts where the level of digitalization is still low, or the IT infrastructure is rigid.

**Keywords:** Architecture, Cyber Physical Production Systems, Zero Defect Manufacturing.

## 1 Introduction

The introduction of new technologies in manufacturing is often painful [1]. Companies have launched costly, complicated initiatives to introduce digital tools and approaches across the enterprise, only to find that these programs fall short of their potential or stall altogether. A key factor in these shortfalls is the lack of a common, integrated operating model for digital and conventional IT teams. At least 60 percent of the highest value technology projects that organizations pursue require collaboration and execution across multiple technology groups in digital and IT teams. In addition, fragmented technology stacks can impact overall system stability, scalability, and resilience. Enterprises must demonstrate a willingness to test and learn, and they must design flexible, constantly evolving enterprise architectures that can support the development and delivery of new business capabilities.

In the same way, the application of cyber-physical systems (CPS) in the manufacturing environment, namely cyber-physical production systems (CPPS), are still in their infancy and we see difficulties in implementation without the collaboration of manufacturing professionals with experts in cloud and ICT solutions [2]. The ICT departments of small businesses are often more focused on solving operational tasks than implementing new technologies. An important step in digital transformation is to have a clear strategy to build a suitable architecture [3]. Leveraging knowledge developed in previous projects (IFACOM [4], QU4LITY [5]) and going beyond the state-of-the-art in zero-defect manufacturing (ZDM) approaches, we have created a blueprint for a promising system architecture to address many of the challenges faced by today's manufacturing enterprises, such as integration issues, infrastructure flexibility to support production agility, and cost containment. In the following sections, we provide an overview of this concept, a description of a CPPS for a digitally-enhanced quality management system (DQM) for ZDM, and the underlying hybrid architecture to support system deployment in production systems for different markets.

### 1.1 The use of ZDM in Quality Management

The keys to achieving ZDM are monitoring the conditions of manufacturing equipment and processes and making decisions to implement appropriate business processes and policies to ensure zero defects in manufactured products [3]. ZDM as a quality paradigm approach goes beyond TQM, Six Sigma and other traditional quality control strategies by integrating at system level defect avoidance solutions, based on IoT and other digital or artificially intelligent systems. CPPSs play a key role in addressing the various challenges of integrating data/information (process/equipment monitoring) and knowledge (decision making and feedback controlling) to achieve the key objectives of ZDM. However, the design of CPPS is extremely challenging due to the involvement of multiple disciplines such as (i) industrial engineering, (ii) computer science, and (iii) electrical engineering [6].

### 1.2 The CPPS design concept

The term CPPS [6] refers to the application of CPS in manufacturing and production, and is characterized by the following features: (i) CPPS are systems of systems; (ii) These systems include autonomous and cooperative elements and can be connected or disconnected depending on the situation, which means that the subsystems are independent and reconfigurable; (iii) The interconnection between systems affects all levels of the production life-cycle, from manufacturing to logistics; (iv) The CPPS system learns from the knowledge generated by both human resources (human-in-the-loop) and equipment during the production process, as well as from the knowledge generated by the manufactured products during their lifecycle. Building on this concept, we propose to add in a CPPS definition that (v) it includes elements to manage data sovereignty and interoperability, to enable usage control of proprietary industry data across the whole value chain (suppliers, manufacturers, customers) in a cross-organizational, shared, virtual data space.

## 2 A novel hybrid model for CPPS

Following a seminal work [7], an improved conceptual model of the DQM architecture is shown in **Fig. 1**. The improvements include the integration of cyber-security aspects for the data safety, the semantic tagging for data clustering according to data sources and functional use, as well as data integration features for advanced data fusion solutions.

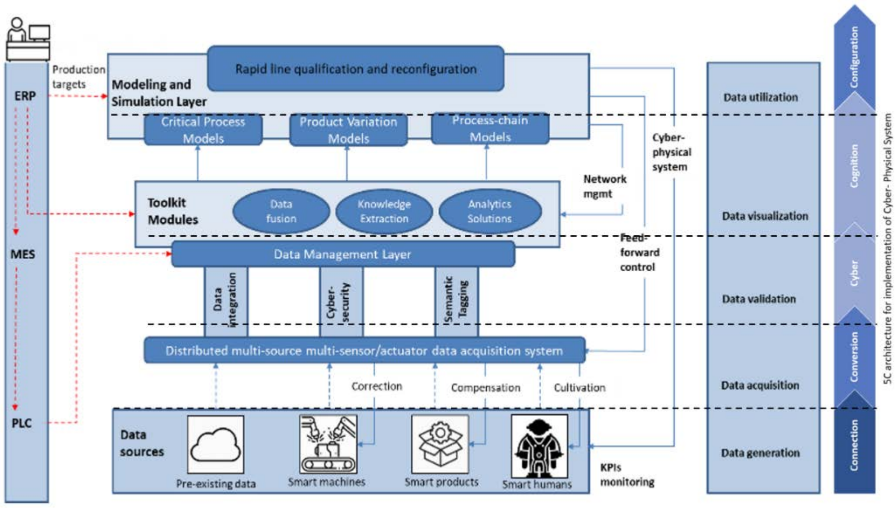


**Fig. 1.** Conceptual model of the DQM architecture

With this model we aim to use a multi-level approach for data processing and control strategies; we also aim to cover the whole path through the digitalization process by including pluggable SW and HW elements to overcome some of the prerequisites highlighted in [7] (i.e., (i) presence of a parts tracking system and (ii) machine state monitoring). The model is mapped to the CPS 5C architecture [8] to illustrate the logical path for design and development from initial data collection to final system control:

**Smart Connection - 1C)** the first layer (Data Sources) is represented by a distributed network of sensors, actuators, and other signals/data sources (e.g., HMIs, smart wearables, machines, historical company data).

**(Data to information Conversion - 2C)** the second layer (Distributed Data Acquisition Systems) will convert the signals into data and perform some pre-processing to support data integrity at the following processing stages.

**(Cyber - 3C)** the Data Management Layer will take care of Data Integration, Data Integrity, Cyber Security, Semantic Tagging and Interface with Legacy Systems (i.e. Enterprise Resource Planning – ERP, Manufacturing Execution System - MES, Supervisory Control And Data Acquisition – SCADA and Programmable Logic Controllers - PLCs), to feed the data analytics and knowledge extraction subsystem (Toolkit Modules). At this level will also be implemented a strategy for secure data sharing and traceability, using blockchain solutions and latest European standard for data sovereignty [9].

**(Cognition - 4C)** the Toolkit Modules will support data fusion of different data sets, process mining and analytics, while the Modelling and Simulation layer will manage product and process modelling, for improved decision making at the shop floor and in engineering. Appropriate data repositories will be built to support the training of machine learning techniques and the creation of process models, which will be combined with the CAD/CAE information. Additionally, specific cyber-physical systems will be considered for the feed-forward control of the manufacturing stages in the process-chain to proactively manage emerging defects and avoiding the propagation of defects along the manufacturing system.

**(Configuration - 5C)** as part of the Modelling and Simulation layer, data-driven tools (e.g., Digital Twin of the process chain) will be developed for rapid line qualification and reconfiguration, enabling learning from historical patterns and knowledge extracted in the other subsystems to reduce system ramp-up times, as well as support optimal decision making at value-chain level. In this perspective, the development of the digital twin is seen as the key to fully distributed automation, enabling the implementation of Multi-Agent Systems in the management of operations (next generation legacy systems) and in the process control of production lines, that interact and exchange information with such a digital twin.

### 2.1 A possible framework to facilitate the transition from conventional IT infrastructure to Industry 4.0 digital technology

Considering the most common design, development and deployment challenges (integration with legacy infrastructure, Real-Time Control constraints, and Company IP policy), we believe a hybrid architecture for CPPS as showed in **Fig. 2**, based on (i) mixed Cloud solutions (i.e. private and public) complemented by (ii) Edge Computing capabilities, combined with (iii) block chain solutions, adoption of (iv) High Security and Privacy Standards and (v) open-source technology, to be a promising one to implement the conceptual model previously introduced.

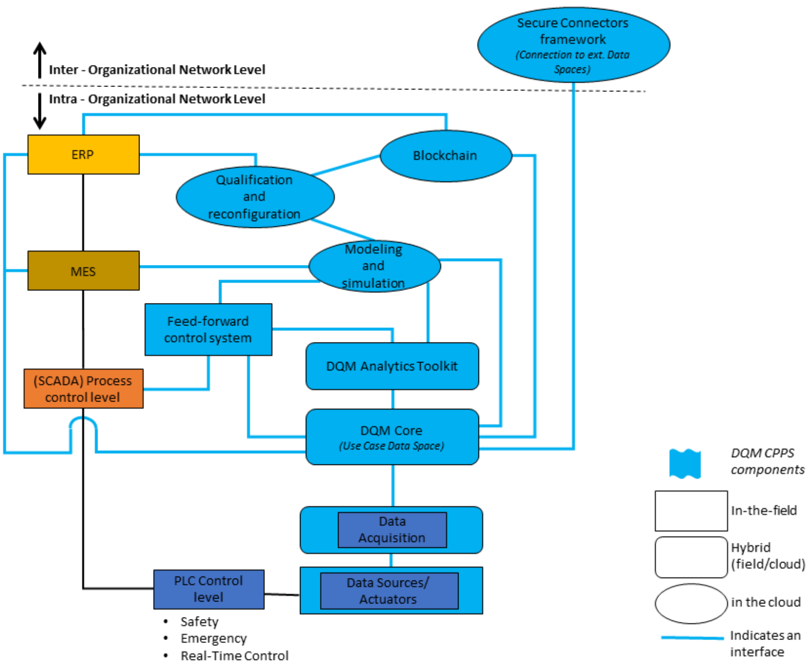


**Fig. 2.** Reference Architecture for the DQM system

This hybrid architecture (**Fig. 3**) allows to transition smoothly from the traditional automation hierarchy to a fully distributed one [10]. Indeed, each functional node is decoupled from the other ones. In this way, parallel implementation of each module is possible once the interfaces and data communication protocols and standards have been fixed.

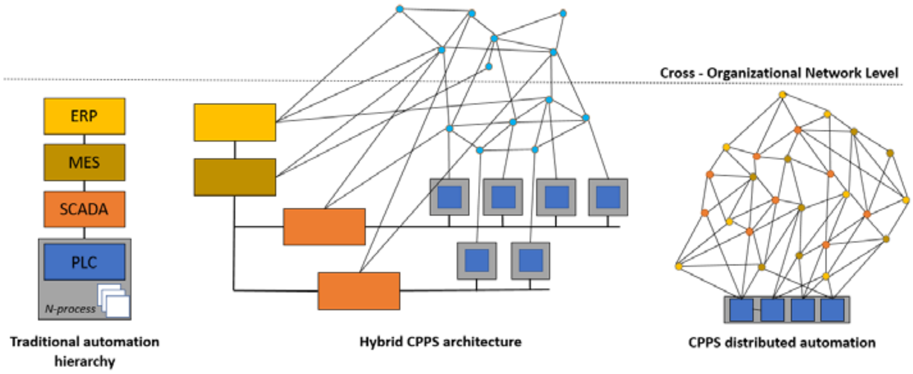


**Fig. 3.** Positioning of the hybrid architecture, as a bridge between the traditional automation hierarchy and a fully distributed one.

Such configuration should give the possibility to

**(i)** Fulfil the Real-Time Control needs as required (Edge Computing capabilities).
**(ii)** Manage the data processing workload (Cloud Computing).
**(iii)** Ensure data security along a whole value chain (block chain and secure connectors to external data spaces, mixed use of public and private cloud solutions).
**(iv)** Allow compatibility and synergy with legacy systems (interfaces to allow the required data flow between the DQM components and legacy systems).
**(v)** Exploit greater architectural flexibility and related external services offerings: the DQM components deployed in the cloud can be easily run, maintained, and replaced independently from each other, as well as accessed from anywhere; the general usage of open protocols will facilitate the introduction of new services/new hardware as developed by several providers in the value chain (no customization needed); variable data storage or computing power requirements can be addressed with hybrid cloud solutions; rapid reconfiguration techniques will be the answer to variable product demand and customer requirements.

### 2.2 Conclusion

This paper presents a hybrid architecture for a CPPS for ZDM in dynamic, high-value, high-mix, and low-volume contexts where the level of digitalization is still low, or the IT infrastructure is rigid. The reference architecture is highlighted in terms of conceptual modelling for design and development as well as software components and main interfaces. The advantages of choosing a hybrid approach to overcome implementation challenges due to the slow evolution of conventional systems towards advanced manufacturing technologies [11] are also explained. The reference architecture is implemented in the European project DAT4.Zero [12], which is only a first step towards the industrial implementation of CPPS for DQM in ZDM. Further results and considerations for successful implementation and adoption are expected from the future integration of the novel DQM in five selected pilot lines in different markets in the automation and healthcare segments.

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