# DIGITAL FACTORY ALLIANCE

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## A Reference Architecture for digital Zero-Defect Manufacturing

Position Paper

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# Executive Summary

The Industry 4.0 initiative proposed the digital transformation of European factories towards smart digital production systems through intense vertical and horizontal integration, with the objective to increase operational efficiency, scrap reduction, prescriptive quality management, energy efficiency, defect avoidance and improved smart product customer experience, fostering new digital business models.

This demands for the definition of reference models and system architectural approaches that could help to manage the complexity of this revolution.

Within the QU4LITY Project, one of the challenges in implementing Autonomous Quality (AQ) processes and solutions is the development of the **QU4LITY Reference Architecture (Q-RA)** for digital Zero-Defect Manufacturing (ZDM) solutions for smart manufacturing, based on relevant sector standards and adopting the most mature innovative technologies for digital manufacturing.

The foreseen Q-RA inherits most relevant outcomes of other Research and Innovation activities, at the same time it is fully compliant with the most recent releases of major standard reference architectures for digital industries, industrial IoT and edge computing - namely those from the Plattform Industrie 4.0 initiative (RAMI 4.0), the Industrial Internet Consortium (IIRA and OpenFog RA), or the Chinese Industrial Internet Architecture (IIA) - to support digitalization of European industry not only the Smart Factory dimension, but tackling also the Smart Product and Smart Supply Chain dimensions.

# 1 INTRODUCTION

One of the challenges in implementing Autonomous Quality (AQ) processes and solutions is the development of the QU4LITY Reference Architecture (Q-RA) for digital Zero-Defect Manufacturing (ZDM) solutions for smart manufacturing, based on innovative technologies and on relevant sector standards such as RAMI 4.0.

Q-RA (Figure 1) consists of a **Four-Tier design**, where the main Tiers (Field, Line, Factory and Ecosystem) are hierarchically stacked according to their scope with respect to the physical processes in the factory, and one Sovereign Digital Infrastructures providing common services such as connectivity and distributed processing capabilities. Moreover, the Q-RA groups system functionality into three distinct Functional Domains (Adaptive Digital Shopfloor Automation, Multiscale ZDM Cognitive Processes and Human-Centric Collaborative Intelligence), which are orthogonal to the Tiers, and three Crosscutting Functions (Security, Sovereign Digital Infrastructures, and Digital Models and Vocabularies) that are domain-agnostic. Overall, QU4LITY-based system populates Tiers, Functional Domains and Crosscutting Functions with Components: self-consistent software modules, also known as Digital Enablers, that play a well-defined role and interact with each other and with the outside world through interfaces.

QU4LITY has developed a range of Digital Enablers that enable the implementation of ZDM systems that comply with the Q-RA. Specifically, these digital enablers empower the functionalities of the QU4LITY systems at different levels of the three-tier architecture pattern, including several cross-cutting functions that are applicable to all functional domains of the Q-RA:

- **Scalable, Reliable and High-Speed Connectivity for ZDM**: All elements of a ZDM platform should be able to benefit from high bandwidth access to devices, CPS systems and other data sources. Apart from several wired technologies, the digital enabler leverage also 4G and 5G technologies in order to ensure seamless connectivity and access to data sources for all components of the Q-RA compliant system.
- **Customization of HPC and Cloud Infrastructures for Digital Quality Management**: Cloud resources are essential for the implementation of the three-tier architecture pattern of the Q-RA, as the platform tier is essential cloud based. Likewise, HPC resources in the cloud enable high performance computations as part of the industrial analytics cross-cutting functions.
- **AI and Big Data Analytics for ZDM**: This task comprises two distinct sets of digital enablers for Big Data and AI: Big Data infrastructures (such as streaming middleware and data lakes) and data analytics algorithms. The Big Data infrastructures implement cross-cutting functions associated with data routing and industrial analysis. These functions are provided by the range of Big Data platforms that have been customized as part of this task.
- **Fog/Edge Computing Technologies Adaptation and Cyber-Physical Systems Integration**: The Fog/Edge computing enablers of the project map directly to the edge tier of the Q-RA three tier implementation pattern. They are specialized edge nodes that address ZDM and Quality Management requirements.

- **QU4LITY Cybersecurity, Privacy and Trust Framework**: The digital enabler of this task adheres to the main principles of the IIRA/IISF (Industrial Internet Reference Architecture/Industrial Internet Security Framework). They offer functionalities for protecting the various endpoints of Q-RA, including horizontal cross-cutting functionalities.
- **Blockchains for Secure Decentralized State Management in ZDM**: The QU4LITY blockchain enablers will implement the secure data sharing and state synchronization across multiple systems in the manufacturing value chain.
- **Digital Services Interoperability, Packaging and Integration**: This digital enabler provide interoperability functions that will be implemented/provided at the enterprise and platform tiers of the QU4LITY systems. They will ensure interoperable access and interpretation of quality management and ZDM information by different components, systems and stakeholders. Hence, interoperability will be a cross cutting functions that links different functional domains of the Q-RA.

In the following pages, four Digital Enablers, among the many developed within QU4LITY project, will be analysed more in-depth to offer the read a more comprehensive view of the capabilities of the QU4LITY Platform.

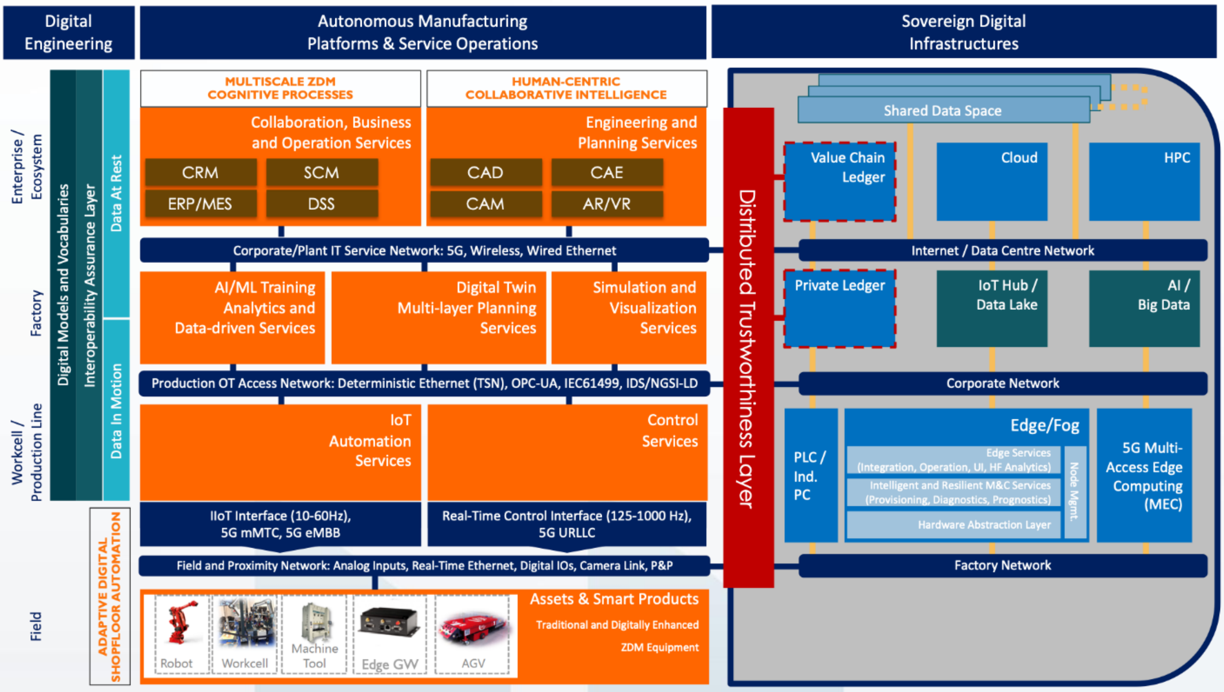


*Figure 1 - QU4LITY Reference Architecture*

# 2 HPC AND CLOUD RESOURCES FOR ZDM

Today's major drawback in adopting Cloud and HPC Solutions is network latency which, in manufacturing environments, is critical to satisfy production needs. Congested networks, in fact, make impossible to reprocess salient information in a short period of time forcing plant and IT managers to rely on on-premises ad-hoc network solutions. Along with network performances, interoperability across multiple data models is crucial for building a comprehensive ZDM ecosystem for AQ as different solutions/assets, from different vendors, have to interoperate and communicate seamlessly.

Moreover, fog/edge computing seems an interesting topic to the pilots as it enables to run AI models locally, boosting production and improving KPIs, without relying on the Cloud to close the loop. As a matter of fact, when speaking about fog/edge computing we also refers to hybrid Cloud Platforms where training of models is performed on high performance computing infrastructure and predictive and prescriptive analysis are run locally.

Addressing these needs, QU4LITY HPC Infrastructure and QU4LITY Cloud Solutions have been built keeping in mind two key factors: responsiveness and simplicity. The former will address the easing the design and deployment of resource intensive solution on a HPC cloud (once trained the model, it may be pushed back at the edge for fast processing close to the data generation). The latter, instead, goes behind the cloud services provisioning, enabling an easy interoperable mechanism for ZDM processes and solutions based on QU4LITY data models and approach.

## 2.1 QU4LITY Cloud Solutions

QU4LITY Cloud Solutions provide a seamless solution to exchange data using the QU4LITY Ontology Model (based on the R-MPFQ model), enabling a semantic enriched data exchange from on-premises data lakes to QU4LITY Cloud Data Storage using a time-based approach. Among the different needs and requirements that QU4LITY Pilots have highlighted, two solutions stand up for their interoperability and simplicity: QU4LITY Cloud Bridge and Q-Ontology Enabler. The former, the QU4LITY Cloud Bridge, eases the exchange of data across existing on-premises data lakes and QU4LITY Cloud Data Storage by the means of REST API. The latter, the so-called Q-Ontology Enabler, delivers a powerful set of scripts to enable semantic interoperability between legacy data and newly engineered QU4LITY R-MPFQ Ontology.

The **QU4LITY Cloud Bridge** is built on top of Node.js, an event-driven, non-blocking I/O, JavaScript runtime, specifically designed for building fast and scalable network applications, perfect for data-intensive real-time applications that run across distributed devices. On top of that, Sequelize has been chosen to handle database connection at application level. Sequelize is an open-source ORM Object/Relational Mapper) that provides easy access to MySQL, MariaDB, SQLite or PostgreSQL databases by mapping database entries to objects and vice versa. It has very powerful migrations mechanism that can transform existing database schema into a new version. It also provides database synchronization mechanisms that can create database structure by specifying the model structure.

The **Q-Ontology Enabler**, instead, consists of a set of tools/script built with Python, an interpreted, interactive object-oriented programming language suitable (amongst other uses) for distributed application development. Python makes the Q-Ontology Enabler a very versatile set of tools as every adjustment at code level does not require any compilation but a simple re-execution of the python interpreter to restart migration of existing on-premises data lakes towards QU4LITY Relational Ontology Model.

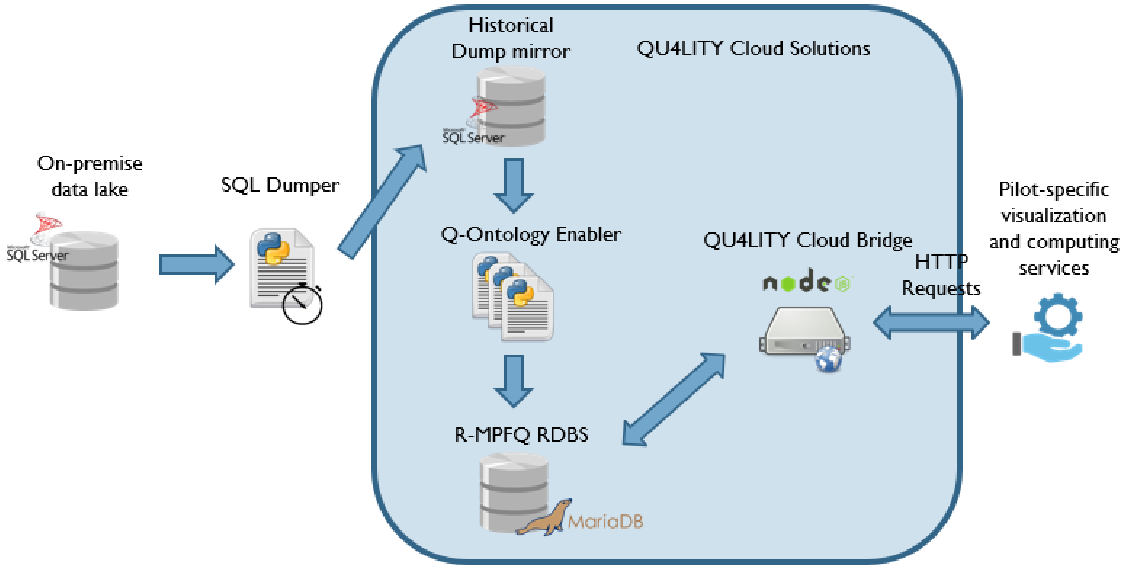


*Figure 2 2 - QU4LITY Cloud Solutions Reference Implementation*

## 2.2 QU4LITY HPC Infrastructure

QU4LITY HPC solution provides the possibility of leveraging High Performance Computing (HPC) for training of models for ZDM processes. The models are implemented as deep neural networks, which have the computational power to model complex nonlinear transformations. For example, they can use production process parameters and sensory data to predict failures. HPC will play an increasingly important role in helping ZDM achieve the next level of innovation fueled by deep neural network models.

As part of the realization process, QU4LITY has provided a blueprint for seamless utilization of the HPC. The main issue is to help the customer define the models, install the necessary software libraries on HPC infrastructure, transfer the data to the HPC infrastructure, and encapsulate the computed models within the docker containers, which can be run on the edge.

The development and training of new neural network models cannot be fully automated and must thus be realized as a service that involves interaction between the client and the service provider. This is because the data and the neural network models are process-specific. For training on the HPC infrastructure, the client data needs to be processed and the network architecture should be adapted to the specific use case. The preparation of data involves its normalization and weighting so that different types of data provided in different units can be correctly interpreted by the training process. Different network architectures with different cost functions can then be tested until the desired performance is reached. The HPC infrastructure provides the computational power to accelerate this process.

The main effort on client side is to provide the necessary input and output data for neural network training. Numeric data should be provided in a file with comma-separated-values (.csv), with each row a new data instance, and each column a different data parameter. The input and output data should both be provided in the same file, with input and output data marked in the header line. Any image data should be provided separately in a folder. To securely transfer the data, the cybersecurity measures require proper certification and identification prior to every access to the HPC.

Th training of deep neural networks on the HPC infrastructure is based on PyTorch deep learning library. PyTorch is open-source and has been released under the modified BSD license. A GUI is provided to monitor the training and evaluate the performance of the trained models. After training, the trained neural network model is encapsulated in a Docker container and sent back to the client, who can utilize the model at the edge without installing any additional software.

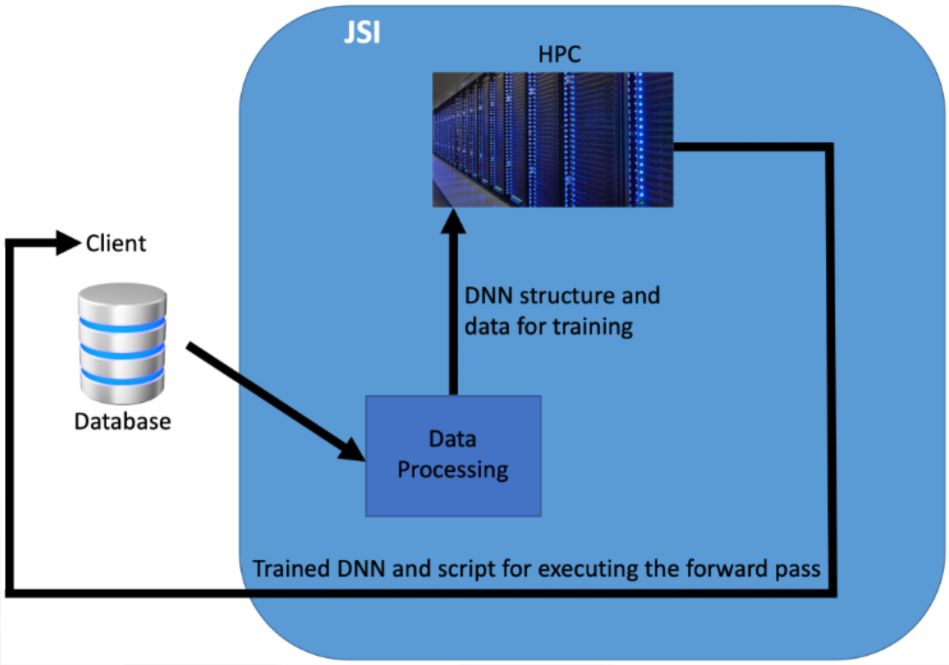


*Figure 33 - HPC service schematic*

# 3 Big Data and Analytics Infrastructure

The QU4LITY project has developed Big Data management and analytics solutions for prominent Zero Defect Manufacturing (ZDM) and Quality Management (QM) use cases. The solutions are provided in the form of reusable building blocks that comply with the Reference Architecture (RA) of the project, which are conveniently characterized as enablers of ZDM and QM use cases. Specifically, the project has developed 10 enablers for Big Data analytics in ZDM and QM, including:

- **Three Big Data and Industrial Internet of Things (IIoT) platforms**. These platforms provide the means for collecting and managing large volumes of quality data from production lines, including data streams with high ingestion rates. They also support functionalities such as analytics and visualization of ZDM and quality data. In QU4LITY they have been deployed and used for the on-line collection, management and visualization of industrial data in the context of the project's pilots. Specifically, they have been used to support pilot deployments in sites and production lines that did not have readily available data collection and data management platforms.
- **Seven Machine Learning (ML) systems for quality management**. These systems cover different ZDM and quality management use cases and tasks, including calculation of assets' Remaining Useful Life (RUL), failure detection, failure identification, testing of products for defects, identification of process parameters that must be avoided and more. As such these systems can be used to implement various maintenance, logistics and process control mechanisms, as part of wider and holistic ZDM strategies. From an ML perspective, the presented systems employ a wide array of machine learning techniques, including deep learning, classical supervised machine learning, rules mining, model based reinforcement learning, and unsupervised learning. The models employed combine state of the art approaches (e.g., popular deep learning techniques), and novel approaches developed by the project's partners (i.e., home-grown approaches).

## 3.1 ZDM Use Cases Supported by QU4LITY Analytics Solutions

Leveraging the analytics enables of the QU4LITY project, manufacturers and providers of industrial automation solutions can implement the following classes of ZDM and QM use cases and related processes:

- **RUL (Remaining Useful Life) Calculation**: The calculation of the RUL of an asset provides a foundation for implementing effective preventive and predictive maintenance towards avoiding failures and unplanned downtime. Avoiding failures leads to avoidance of defects as well. In most cases, RUL calculation leverages sensor data readings from a machine (or tool) on various parts made before the machine (or tool) breaks towards determining the End of Life for the machine (or tool) on any new (unseen) sensor readings.
- **Fault Detection and Fault Identification**: The goal of these detection and identification processes aims at identifying the faulty status of a product or process towards taking remedial actions against future failures or defects.

- **Determination of associations between production variables**: The analysis of these associations aims to determine associations of input production variables that lead to certain outputs. This knowledge enables the tuning of production variables in ways that avoid faulty or defective outputs.
- **Determination of process parameter settings to avoid**: As part of this analysis a set of values for various process parameters are constrained towards ensuring that the percentage of products that do not pass quality testing is below a specific threshold.
- **Anomaly Detection**: The aim of anomaly detection processes is to distinguish the products that deviate from normal products leveraging on properties of the products such as their shape, thickness, surface and quality of materials.
- **Product Testing**: The goal of product testing processes is to audit certain characteristics of produces (e.g., volume, geometry) against predefined threshold values provided by the machine vendor.

## 3.2 QU4LITY Data Analytics Platforms

QU4LITY has developed and provides three Big Data platform solutions for data management in industrial ZDM and QM Scenarios. They are listed in the following table.

| Platform Name | Overview Description |
|---|---|
| DataCrop DDA | Data Analytics platform that Supports Configurable Routing, Pre-processing and Analytics of Heterogeneous Data Streams in Industrial Environments. It consists of two main engines: (I) The Edge Processor Engine (EPE) that enables processing of low-level data streams close to the field, i.e. at the edge of the network; and (II) The Distributed Processor Engine that resides within the Cloud tier and is responsible in processing data coming from many different Edge Processor Engines. |
| Open VA | Supports Analytics and Visualization of IoT Data in Industrial Environments. It consists of various software components that are used as building blocks of visual analytics tools, including: (I) A database that stores the application data in a standard domain independent form; (II) An extendable analysis and visualization library providing a selection of analysis and visualization methods; (III) Embedded R and Python environments for statistical computing; and (IV) A web user interface where the user can select variables for analysis and explore the data with the help of visualizations. |
| ikCloud+ ML Platform | Supports ZDM related analytics by means of ML algorithms. It adds data analytics capabilities by providing different ML tooling managed together by Machine Learning Operations (MLOps) solutions. It enables the development and deployment of end-to-end development of simple ML models that are orchestrated by the platform. |


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## 3.3 QU4LITY Library of ML Algorithms

The QU4LITY ML enablers includes a wide array of machine learning models and algorithms that can extract ZDM related insights and support different use cases. They are listed in the following table.

| Algorithm / Use Case | Overview Description |
|---|---|
| RUL Calculation | These algorithms perform Remaining Useful Life Estimation based on RNN (Recurrent Neural Networks) and LSTM (Long Short Term Memory) Deep Learning Techniques. |
| Failure Detection and Identification | This is a collection of Supervised and Unsupervised Learning Techniques for Detecting and Identifying Faults in Production Lines. |
| QARMA | QARMA (Quantitative Association Rule Mining) is a data mining approach that produces quantifiable and explainable rules based on the sets of features that appear frequently together in the training dataset. |
| Anomaly Detection in Production | Detection of anomalies in production using repetitively trained auto encoder and unsupervised learning techniques. |
| Image Analyzer for Surface Inspection | ML models for quality Inspection of products using Deep Learning and Model Based Reinforcement Learning. It analyses images. |
| Improved Failure Classification in Solder Paste Inspection (SPI) | Models for ML based powered inspection of the volume and geometry of the solder paste against predefined threshold values provided by the machine vendor to identify and classify failures. |
| Anomaly Detection at Machine Level | Inspection of Failures using Deep Learning Techniques AutoEncoder Networks |

As evident in the table, the QU4LITY ML systems provide a very representative coverage of ML techniques that can be used for ZDM and quality management, including supervised learning and reinforcement learning, as well as classical machine leaning and deep learning. Each one of the ML enables of the QU4LITY project exhibits innovative characteristics beyond conventional machine learning techniques found in the literature. The algorithms have been validated and evaluated based on real life datasets from the production lines of the manufacturers of the project. They have been found to yield very good performance that is appropriate for industrial deployment and use in the target use cases.

# 4 Fog Nodes and Edge Gateways for ZDM Deployments

One of the main important factors of realizing Zero Defect Manufacturing (ZDM) is to have the data quickly available, potentially directly at the source, which means the manufacturing line of machines. The QU4LITY project proposes data-driven, digitally enabled mechanisms for ZDM. To make data directly available at the machines (or so-called edge of the network), the QU4LITY project provides different fog and edge solutions, enabling the hosting of applications at the edge for faster handling of data to enable ZDM. The advantage of having the ZDM technologies at the edge is that a more direct access to data can be guaranteed, without any delay of data transfer into the cloud. Additionally, applications that are interacting with the machines (e.g., perform control operations) can even do this in (semi) real-time as there is hardly any delay in sending data back to the machine.

The following table provides an overview of the three edge solutions that have been developed/provided within the project and that have been deployed in QU4LITY pilots and experimental facilities.

| Platform | Description | IP Owner |
|---|---|---|
| Nerve Blue | A radically open edge computing platform that promotes vendor independence and flexibility, allowing users to deploy their own software, or applications developed by third parties. | TIAG |
| Danobat Box | The Danobat Box is the solution used by Danobat for the monitoring and provision of associated services related to their machines. It is a robust solution that enables heterogeneous data acquisition and provides a safe channel to send this information to the cloud. | IDEKO |
| FOOTPRINT | The Fog Node that supports data acquisition from an arbitrary number of sensors and use the available data to create a set of profiles for each pair of machine/part to monitor the production quality and automatic detect and identify problems or defects during manufacturing. | UNP |

## 4.1 Nerve Blue

Nerve Blue is a versatile software that enables machine builders to deliver data and offer services to their customers from machines installed anywhere in the world. For plant owners, Nerve Blue can be used to optimize the processes running in the plant, enabling faster access to data, as data can be used directly at the edge of the network and no latency is created by sending all the data to the cloud.

Nerve provides connectivity to multiple PLCs or remote I/O modules using Ethernet fieldbuses, such as PROFINET and EtherCAT and allows users to collect, store and analyse machine data direct on the edge of the network. The data collected from the I/O modules is then modelled in OPC UA, which allows information to be shared in a standardized way.

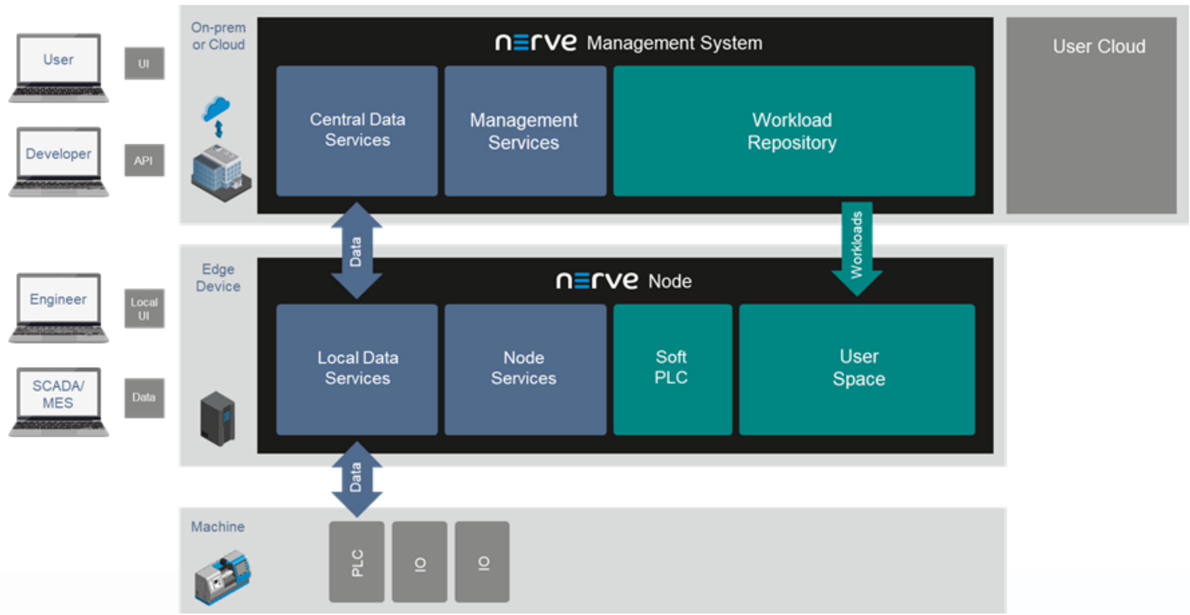


*Figure 4 4 - Nerve System Architecture*

The Nerve System consists of two parts, where one part is located at the edge device and the other part runs in the cloud, which could be any specific cloud solution. The edge device host different services, which are:

- **Data Services:** a collection of services and interfaces, compliant to different I/O protocols, that enable the system to collect, store, analyse, visualize and distribute data.
- **Node Services:** a set of services, running locally on the node, that enable user to access and control the node.
- **Management Services:** a set of services hosted by the Management System in the Cloud or on-premises, that offer monitoring (and logging) of nodes, deployment and control of workloads to the registered nodes and the management of workloads
- **Remote connection:** direct connection into a node located at a factory or a machine or even a direct connection into a virtual machine on the edge device
- **Virtual/Soft PLC:** Nerve Blue can be used to host and manage multiple virtual/soft PLCs on one edge device, enabling convergence of control on the plant floor.

## 4.2 Danobat box

The Danobat Box is a "Plug & Run" system, easy to install and compatible with a big number of industrial automation protocols that allows information sharing across third party systems and software providing a safe channel to send this information to the cloud. It is a non-intrusive system as it works in parallel avoiding overloading the CNC or PLC of the machine.

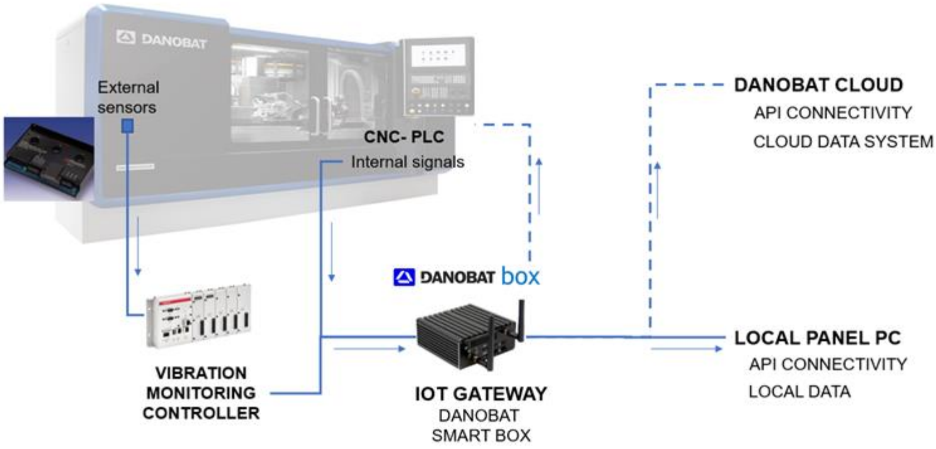


*Figure 5 5 - Schema of installation of the Danobat Box*

The Danobat box allows to deploy software in the edge through a dockerized system. Because of the volume of data in IoT environments, some processing and management functions have to be pushed closer to the devices in order for them to scale. That extension to the edge requires more complex operational management – another layer must be integrated into the operational model, and the IoT platform needs to have the architectural support for it. Functions such as identity validation and data processing can be projected out to edge elements to distribute the work required to operate at IoT scale.

Even though the cloud computing paradigm seems ideally suited for addressing the increased demand for computation power at the edge, this comes at the expense of an additional abstraction layer that imposes significant overhead to the software stack. Danobat Box edge computing offers computation and storage at the very edge of the network where data is produced, reducing latency and limiting the load that is carried to higher layers of the infrastructure hierarchy.

## 4.3 FOOTPRINT

FOOTPRINT is an edge device that enables a high-level monitoring of the production quality, automatic detection and identification of problems or defects during manufacturing. It uses voltage and current sensors to create energy profiles, for a machine doing a specific job.


*Figure 66 - Footprint edge device deployed on-site*

The edge device provides energy monitoring and detection of the machine's job or action based on the energy profiles used to train the model. Additionally, automatic detection and identification of problems or defects during manufacturing and maintenance forecasts can also be supported. The measured parameters (Current, Voltage, Power (Active, Reactive, Apparent), Energy Consumption. Energy Production, Power Consumption, Power Production, Frequency, Power Factor) are read out every second and sent to the configured MQTT broker, for persistent storage of historical data in an external database. The data is also stored in an internal database every minute, which is convenient in case of offline usage. The measurement periods can be configured if needed, to match the requirements of the specific application scenario.

A dashboard, built with Grafana, is provided to view real time and historical data. The dashboard can be customized to display the most relevant info, as needed by the user, and alerts can be defined, to notify the user when a parameter exceeds a threshold or certain conditions are met. The dashboard also supports exporting the historical data as CSV files, for chosen time frames, to allow usage of the datasets with other tools.

# 5 QU4LITY SPT FRAMEWORK

The objective of the SPT (Security, Privacy and Trust) is to provide cybersecurity, privacy and trust functionalities to the QU4LITY platform and the different industry scenarios using it. This way, the SPT provides, on the one hand, a framework for integrating the information coming from the systems and, on the other hand, a set of tools that can be deployed or used in the target system in order to provide a cybersecurity characteristic or functionality.

The SPT provides functionality in the QU4LITY reference architecture in both the scenarios ("Assets & Smart Products") and the communication component between the systems and digital infrastructures ("Sovereign Digital Infrastructures"). The way it provides its services are in the following way, according to the functionality of the cybersecurity solutions:

1. **Access control:** the cybersecurity solution of access control integrated in the SPT allows for users to define and specify how and who can access the target system, specific resources, etc., being able to create specialized roles for accessing unique functionalities or the whole system. This way, it would be possible to create roles that can access only the needed parts of the system instead of having everyone with full access. Apart from being a good way of protecting the system against external malicious hackers it would also protect against internal attacks or leaking of user/password, as only specific and necessary users/roles would have access to critical aspects of the system.
2. **Monitoring:** the cybersecurity monitoring solution is able to monitor, analyse and inform users about cyber incidents in the network of the systems, being the end-point with the assets or in the digital infrastructure (or both). This way, the monitoring solution could be deployed in the necessary system/network and provide information of cybersecurity status together with recommendations for reacting to cyberattacks. The information can be accessed via the user interface and integrated with the SPT access control solution, so the role management and access to the information is done by only the necessary or specific users/roles of the whole system. This solution requires an integration of an agent in order to compile the information of the system, which has to be deployed according to the specific technology of the system.
3. **Data protection:** this SPT solution is a library/API that provides access to an anonymization functionality which can be used for both storing information or sending over an untrusted network. This can be used both by the end-systems (assets) for sending information or by the digital infrastructures for communication with external systems or storing the information in order to increase its security. The data protection component can be used easily in different scenarios for satisfying different constraints and deployed in any environment.
4. **Security-by-design:** this tool covers the design phase of the SPT for the creation of security and privacy systems. The modelling solution can be used at the designing of the whole system or some parts of it. It includes a library of cybersecurity components in order to integrate them with the normal system so the development/testing phase can be done with security integrated naturally in the system. This way, the library of cybersecurity models can be extended in the future with more elements so it can cover more scenarios and environments as the digital industry domain grows or

evolves. This solution can be used both by the end-users for the design of their system or at QU4LITY for providing cybersecurity-oriented design of the target system, in order to enhance it with functionality and components integrated from the beginning in the target system instead of being an addon used when the system is already created and running.

These tools are the initial ones we have developed in QU4LITY but, as abovementioned, can be extended in the SPT with more tools as necessary. This is a required characteristic as the industry 4.0 scenario will continue evolving digitally and the cybersecurity aspect has to continue growing at the same level.

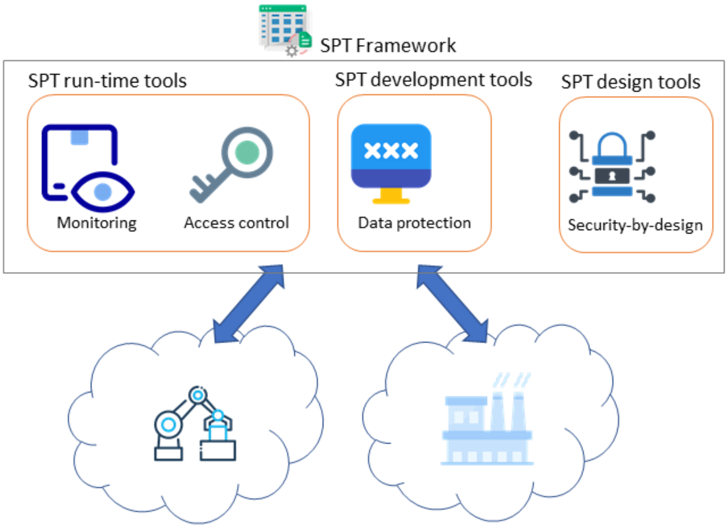


*Figure 77 - SPT Reference Architecture*

As we can see in the figure of above, the SPT is composed of three different components that cover the different life cycle of digital components in order to provide cybersecurity. The objective of each one is:

- **SPT run-time tools:** solutions that aim to protect, monitor, analyse, react, etc. against cyberattacks for running systems. These solutions could range from a honeypot to a malware protection solution. These solutions can also be integrated between them in order to provide a more complex functionality.
- **SPT development tools:** these tools provide cybersecurity protection when developing industry systems. These solutions can provide different characteristics such as encryption, sanitization of data, key generation or storing, etc.
- **SPT design tools:** this component provides tools oriented at design time. These ones can support requirement elicitation, tracking and definition, system design, etc. This way the system would be created as secure by design, being able to integrate cybersecurity functionalities or characteristics in the target system naturally.

The three sub-components provided tools and solutions in their own, although they could be related for supporting specific functionalities. This way, the run-time solutions could monitor variables or scenarios that are defined as critical at the design time. Also, each tool provides its own data storage and user interface, if possible, so they can provide to the users the status of the system together with remediation actions.

The tools are deployed and used in the system according to their specification and way of working. This way, there is not a unique way of deploying the tools, configuring and using them but they follow special steps. As an example, the data protection (anonymization) solution is an API that can be downloaded and used when developing software while the monitoring solution requires to deploy the agent in the system to be monitored and a server for the analysis and interface.

## 5.1 Roles and usage of the SPT

Due to the complexity and number of cybersecurity solutions of the SPT, we have identified different roles that can take advantage of them. We thought it was necessary to provide an overview about this topic because cybersecurity is a complex area and in order to take full advantage of it, users should have a minimum level of expertise. Figure 4 shows the different roles we have identified.

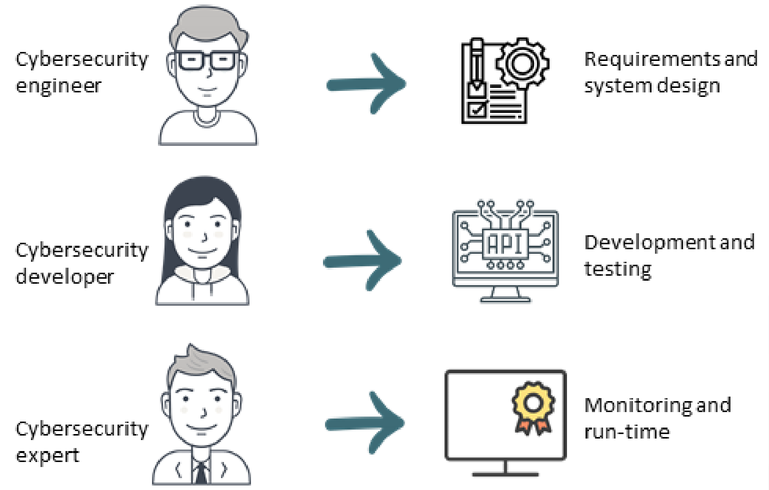


*Figure 88 - SPT roles and usage of the platform*

**Cybersecurity engineer:** this role focuses on the identification of cybersecurity requirements and needs in the target system, integration of cybersecurity at design time and understanding the impact of the cybersecurity solutions and components in the whole system. This is very important for identifying how cybersecurity solutions would impact in the system in order to add the necessary extra components or policies. This role would use the tools of the component "SPT design".

**Cybersecurity developer:** this role is the one working on the development of systems and any digital component of industry 4.0. The developer uses cybersecurity solutions for either integrating in the system or taking advantage of the provided functionalities (such as an API) for providing resilience or privacy characteristics to a system. This role works with the tools provided by the component "SPT development".

**Cybersecurity expert:** this role is the one that can work and analyse the results of the run-time tools. This implies working in the deployment and configuration of the tools and understanding their results. This cybersecurity expert can be either a member of the organization or working in a third-party, providing cybersecurity services and informing the organization about the cybersecurity status of the company or any cyberattack that is detected. This role works with the tools provided by the component "SPT run-time".

# 6 Conclusion

Based on the specification of the Autonomous Quality (AQ) concept and related properties for a ZDM manufacturing, this white paper presents the QU4LITY Digital Sovereign Infrastructure of Q-RA for cognitive AQ solutions. This conceptual architecture has been designed to serve as a blueprint for structuring and implementing cognitive manufacturing systems for excellent quality in different domains, providing AI-based and data-driven added value solutions to both manufacturing and customers of the most various sectors and activities, such as the ones tackled in the project: White goods & Appliances, Plastic injection, Metal machining, Ceramic pressing, Aerospace, Automotive & Electronics, Additive manufacturing.

Q-RA, and its Digital Sovereign Infrastructure, has been adopted in several Large Businesses and SMEs and has been already demonstrated in some relevant success stories, such as:

1. SIEMENS, involved in the printing of circuit boards and soldering of electronical components, now uses a DSS system at edge level to detect systematic failure root cause detection thanks to data analytics capabilities and enhanced data acquisition pipelines.
2. PRIMA, a company leader in additive manufacturing, now benefits from an autonomous quality assurance system which decides whether to cancel or continue the production process, relying on real-time processing and machine-learning algorithms, based on HDR imaging combined with CNNs and model-based RL for inter-layer quality optimization of LPBF processes, to find structures and pattern related to the required key quality indicators.
3. KOLEKTOR, known as the world's largest manufacturer of commutators, with the introduction of AQ control loops at the operational level and the optimization of the machine vision control with machine vision cameras and predictive models has drastically reduced the number of defective units produced.
4. FAGOR, a company leader in hot stamping industry, has improved waste reduction up to 10% with the help of Open VA, a real-time data acquisition system, relying on a private Cloud, which performs data analytics on sensorial data coming from production line and triggers alarms in case of KPI deviations.
5. WHIRLPOOL, a company leader in white goods & appliances, has reduced the number of defective products on the market and has successfully moved as much as possible decision steps from the line operators to machines thanks to the QU4LITY Cloud Infrastructure in conjunction with the achievements made on the definition of R-MPFQ Ontology model.

Overall, the Q-RA has been shown to drastically improve cost per production ratio and wastes per production ratio, bringing every organization closer to the Autonomous Quality paradigm for ZDM defined in QU4LITY.

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