THE INTELLIGENT PLANT – A NEW APPROACH FOR METALS MANUFACTURING*

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Abstract

The complexity and the number of components in production of industrial automation systems have been increasing. Data processing from these components to improve the normality and reduce heteroscedasticity to a minimum plays a significant part in transforming the digital industrial plant to an intelligent smart plant.

A systematic, flexible and an intelligent architectural design of these distributed autonomous heterogeneous systems results in the optimization of capital Investment and operational expense paving the way to smart factory.

In a Smart Factory, machinery and equipment will have the ability to improve processes through self-optimization and autonomous decision-making resulting in improvements in maintenance, refurbishment, security, remote diagnosis, real-time control, self-organized, autonomous management, transparency, predictability, effectiveness and efficiency.

In this paper, we present Danieli innovative smart approach for an intelligent plant to optimize the resources and minimize the capital expenditure using our seamless integrated interface architecture across the vertical and horizontal levels of production in the domain of metals manufacturing.
A mobile, web-based, cross-platform and responsive application for the real-time monitoring of all plant areas supporting the cloud based architecture ensures not only the visibility of the complete plant but also can access, search, control, configure, analyze complete lifecycle of a plant which enhances quality of the productivity and minimizes the capital expenditure.
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1 INTRODUCTION

The evolution of disruptive information and communication technologies (ICT) such as Big Data, Internet of Things, Cloud Technologies and Cyber Physical Systems is enabling vertical, horizontal and transversal integration of the automation systems for the manufacturing industry.These key enabling technologies can drive towards the realization of the final goal of implementing the Smart Steel Factory, which represents the intelligent, flexible and dynamic steel production of the future.

Danieli Automation (DA), the automation company of the Danieli Group, sensed this change in the first decade of 2000s, renewing its product portfolio and releasing to the market new solutions based on the results of important R&D projects. These projects aimed at providing the integrated monitoring, control and executions of sustainable manufacturing and business processes, beyond the usual plant perimeter. At the advent in 2013 in the public domain of the Industry 4.0 term, DA deeply re-analyzed its industrial approach and the relevant implementation strategy. Once again, it was not surprising to verify the large convergence between the already adopted strategy and the Industry 4.0 paradigm. The analysis confirmed also the validity of the general approach and, in particular, the importance of three main pillars at the base of the company strategy:

1. Centrality of the human factors (human-in-the-loop or HITL approach with relevant simulation, cognitive behavior, machine learning techniques, safety etc.),
2. Capital importance of data gathering and processing for extracting the embedded value, actually emphasized by the Big Data paradigm.
3. Extended development of models with complex multi-physical and through-process simplified approach for offline simulation, plant design, scenario analysis and execution practices design on one side and simplified models mostly derived from the previous ones for process control and real time applications.

The latter three points were at the base of three directions of development:
1. Extended area and through-process supervision;
2. Deployment of robots where possible to increase safety;
3. To extend the use of intelligent autonomous systems in the plant and to provide effective and in time decision support to operators through knowledge systems.

The wide and strong push modelling of steel manufacturing aimed at:
- performing the local supervision for each process and manufacturing area;
- extending supervision over the steel manufacturing process sequence to the customer order and expectations, according to the Industry 4.0 paradigm [1].

2 LITERATURE REVIEW

A Cyber Physical Systems (CPS) architecture [2] in shop floor for intelligent manufacturing aims to provide solutions from three key aspects to the configuration and operation of CPS: interconnection and interoperability among different devices, multi-source and heterogeneous data acquisition, integration, processing and visualization, and intelligent decision-making based on knowledge acquisition and learning methodology. [3] Introduces a novel cyber-physical system, where all sensors, actuators, machines and industrial robot is connected to a local network, sharing information easily with each other. The solution is achieved on the software side, with minimum hardware reconfiguration need. The flexibility of the industrial robot is kept intact, but extend its' understanding with sensor fusion on a higher decision level, rather than on low robot programming level. The system also allows remote monitoring and supervision of the production plant. [4] Introduces on technical level major challenges to shorten engineering phases and improve business process with Cyber-Physical Systems - Embedded systems with decentralized control intelligence can establish communication through open networks based on internet protocols which will lead to the replacement of classical hierarchical automation systems by self-organizing cyber physical production systems. [5] Introduces the significant impact and the value of Industrial Cyber Physical Systems (ICPSs) to empower the transformation of industry and business at large to a digital, adaptive, networked, and knowledge-based industry with long-term impact on the economy, society, environment, and citizens. [6] Identifies the key challenges in the Industrial automation sector based on CPS technologies, from four European Innovation projects (SOCRADES, IMC-AESOP, GRACE and ARUM) with the aim to increase the Technology Readiness Levels (TRL) which lead to their usage in Industrial automation environments. [7] Proposes a new manufacturing system optimization strategy through CPS and Internet of Things (IoT) creating a new paradigm shift in business and market models through new data value chains. [8] Present a concept for self-reconfiguration of real-time communication within a CPS that can be composed of sub-systems using different communication media, e.g., Ethernet and Controller Area Network (CAN). The software architecture proposed supports coordinated Plug-and-Produce functionality based on a common abstract cycle-based time triggered communication medium which ensures that adding a new component can be registered by the CPS within one cycle.

3THE INTELLIGENT PLANT ACCORDING TO THE DIGI&MET PARADIGM

Furthermore, model deployment both in the design phase and in the monitoring, control and decision-making represents fundamental aspects of the Digital Factory concept [9]. The Digital Factory has the advantage to carry out comprehensive multi-objective optimization of products, processes and systems before a new factory is built or any modification is actually carried out on an existing system, in order to improve quality and reduce time.

Extensive exploitation of data (Volume, Velocity, Veracity i.e. Big Data), complex reasoning capabilities, autonomy of Systems, are transversal functions to the existing automation landscape. Moreover, execution must be supported by supervision and forecast functions, including intelligent scheduling of resources, for which the latest MES are adequate. How to cross cut virtually the structure taking and supplying information everywhere? A new platform to cover this gap is necessary: this is the DIGItal platform for the METals industry (DIGI&MET). This layer is not a further hierarchical level in the Automation Pyramid but a way to break hierarchy when and where necessary. Furthermore, it provides the logical layer to plug services represented by logical systems of different degree of complexity. In Fig. 5, for example, systems dealing with remote or in-house maintenance, energy monitoring and optimization, support to manufacturer on process quality etc., are easy to plug and play in the upper part of the shell.

A further step was launched with the following commands: Keep Robotizing, More sensors in the field, No Man on Floor, Exploit Data. In one command: Keep Digitizing. Through the interaction between robots and systems, the development of a new generation of autonomousCyber Physical Production Systems (CPPs) have taken place; exploitation of data value adopting Big Data approach is under testing in customers plants.

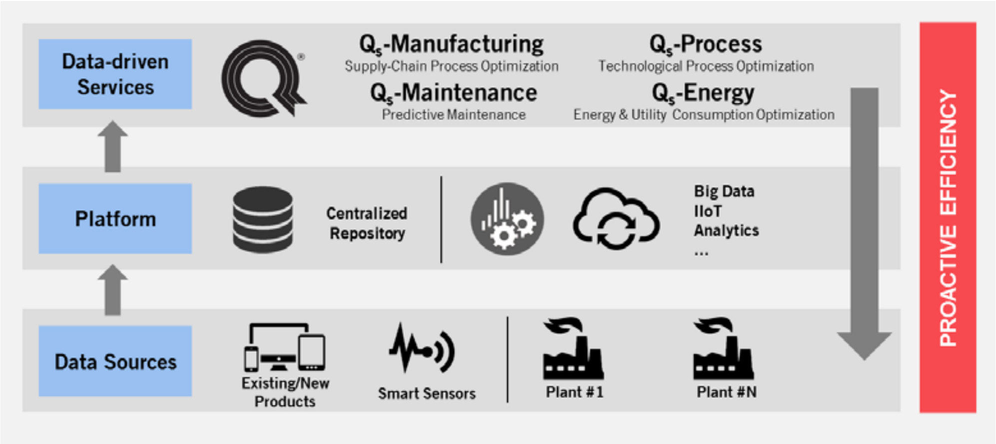


Figure 1.DIGI&MET approach for a smart plant.

Two aspects are very interesting:
1. The evolution from Descriptive to Prescriptive approach;
2. The development of the new platform.

These points summarize the process to evolve from the purely reactive approach following the recognition of events already happened to the proactive prescription of actions already processed by autonomous systems. Figure 1 shows this process with a synthetic view; the metrics combine the degree of intelligence needed to take decisions autonomously and the added value for the customer. Such approach needs an extensive development of Cyber Physical Systems (CPS) to be fast, reliable and effective, robust modelling suites for fast scenario analysis, in memory processing of large volume of data. This is also part of the approach for Condition Monitoring and Predictive Maintenance configuring a category of remote services through the deployment of the Internet of Things concept.
The DIGI&MET platform is based on five pillars, described in detail in the following paragraphs.

3.1 3Q Automation

The 3Q approachis focused on customer needs and requirements; the three Qs stand for focus on:
- Quality, for excellence in Quality and Product Quality certification,
- Quantity, for High Productivity,
- Quickness, for quick response to market demand.

From the technical point of view, the driving aspects assumed are data and data analytics, process supervision, attention to social aspects, digitalization and application of robots in the working areas. The integrated 3Q concept generated a set of three technological packages (Figure 2): OA – Operator Assistant, PPI – Plant Performance Indicator and API - Area Performance Indicator.

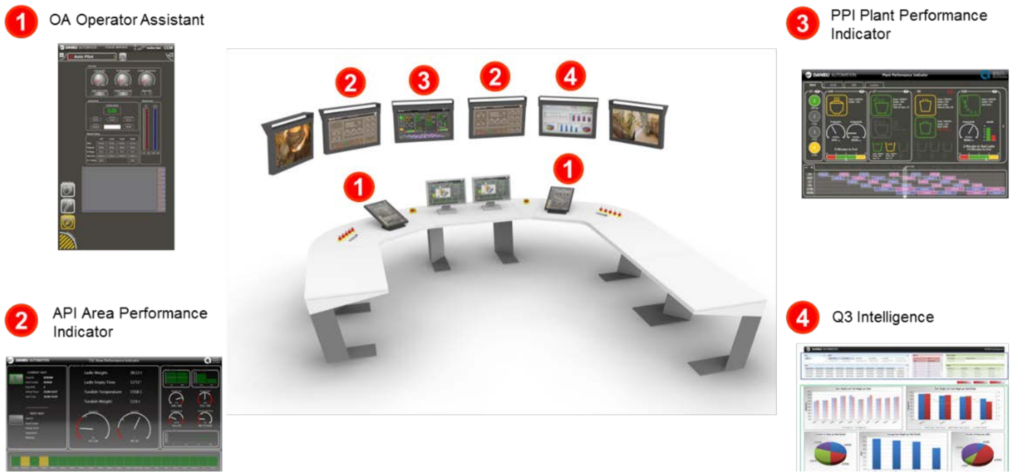


Figure 2.DA soft desk based on 3Q paradigm.

- OA –Operator Assistantis based on digital technologies like touch screen, 3D rendering and screen pages with execution digital buttons devoted to the execution of operation tasks.

OA provides interactive and knowledge-based assistance to operators for safe and intelligent plant operation. It can be part of the fully digitalized pulpit solution or synchronically can assist operators using a conventional button pulpit for command execution. It concentrates much of the intelligence needed within the automation system and reduces the number of commands that operators have to consider (Figure 3).

- PPI – Plant Performance Indicator provides overall information about the plant performance and on the status of the synchronization of the processes in the controlled areas. The PPI receives data from the plant technological areas and translates that information into a graphical overview presented to the operators. The upper virtual environment can run PPI in simulated manner using simulated or historical data and providing the same graphical vision.

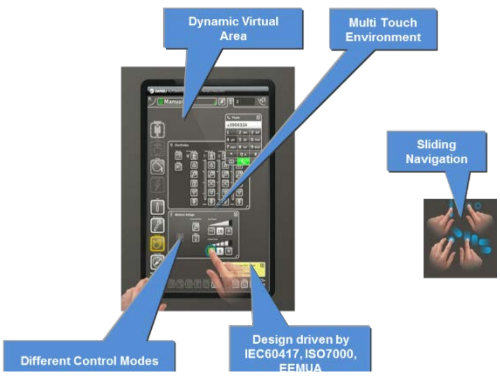


Figure 3. Example of Operator Assistant (OA).

- API –Area Performance Indicator function provides, for each technological area, overall information on the status and the quality of performance of the process in the controlled area. The API receives information from each technological area and translates that information into a graphical overview to inform and assist the operators. In analogy with PPI, API can be part of the virtual environment.

3.2 Equipment Monitor and Control

Cyber–physical systems (CPSs) (Figure 4) are distributed, heterogeneous systems connected via networks, and usually associated with the concept of the Internet of Things (IoT) [10]. The complexity and the number of components in production automation systems have been increasing [11].

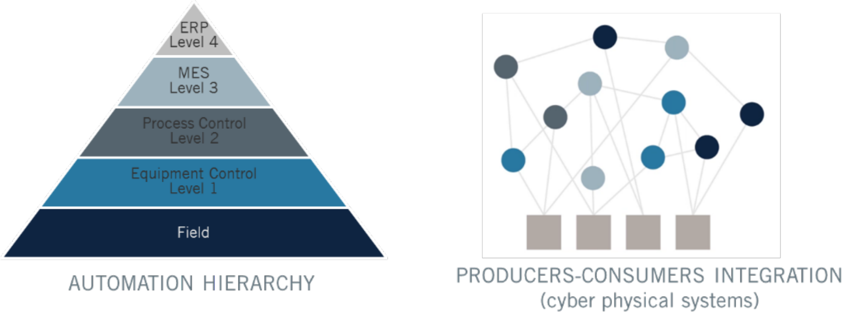


Figure 4. Automation Hierarchy and Cyber Physical Systems.

Software for controlling industrial processes or machines is commonly executed on Programmable Logic Controllers (PLCs), which are digital computers specifically designed for the use in industrial environments, that is, environments with extended temperature ranges and high electrical noise and vibrations. PLCs provide advanced functions, among which analog monitoring, control, and high speed motion control and communication over networks. PLCs satisfy requirements imposed by hard real-time applications in this domain.

The IEC 61131 standard [12], the first version of which was published in 1993, was the first attempt of the International Electro technical Commission (IEC) to define a standard language for writing software for PLC with a scope to specify syntax and semantics of programming languages for programmable controllers.IEC 61131 standardized several languages that were already used in this domain. The first two being IL (instruction list) and ST (structured text), are textual languages, and the other two, that is, LD (ladder diagram) and FBD (function block diagram), are graphical.
A higher level programming language, the sequential function chart (SFC), is defined for structuring the internal organization of programmable controller programs and function blocks. The FBD language is the one that better matches with the object-oriented and the model-driven development paradigms in software development and is widely used in industry.

The reutilization of proven automation solutions for automation systems is an essential approach to increase the profitability of engineering services. Additionally, distributed systems are increasingly important in automation systems. To address the very need, “Functional application design of Distributed Automation systems” (FAVA) focuses on the aspect of distributed systems combined with the reutilization of automation tasks and solutions in the domains of process and production automation. In the FAVA research project [13], fundamental non-functional requirements for automation systems are identified. Newly introduced design patterns as known from software engineering provide a form of assistance for ensuring the compliance of automation-system designs to these non-functional requirements.

A distributed system can be described as a composition of interacting components, such as function blocks (FBs) or port-based objects, which are mapped onto distributed devices [14].A distributed system nodes, i.e., distributed components, may have different properties [15]. Each node allows either the execution of parameterized predefined functions (in the form of a set of parameterized FBs) or free programming of control applications based on FBs, programming, and cyclic execution being based on the IEC61131 standard. Such manufacturing automation system configurations are widely used in the manufacturing industry.

This standard provides a small basis for common modelling of control programs, but platforms and tools are not able to interoperate [16]. To address these restrictions as well as the new challenges in the development of today's complex industrial automation systems, the IEC has assigned to its Technical Committee 65 (IEC TC65) the task of developing a common model for the use of FBs [17].

The result of this activity was the IEC 61499 standard [18], which is considered as an extension of the IEC 61131 Functional Block Diagram (FBD) language. At the same time, to overcome these restrictions, several research groups, for example, [19–21], have proposed approaches that exploit best practices from the desktop application domain. Object orientation, component-based development, and model-driven engineering are among these widely accepted best practices.

Our novel architecture based on IEC 61131-3, has been developed to enable intelligent automation through the distribution of software components such that the metal industries will benefit through its adoption from the promise of the intelligence automation research results such as portability, interoperability, code modularity, reusability, and re-configurability as well as determinism and the event-driven execution.

Q3-BBox is the Off the shelf edge computing solution for DIGI&MET platform: it is the combination of standard hardware and software solutions capable to gather, analyze and present the information extracted from data.

The purpose of such system is to be able to collect data from heterogeneous sources (Figure 5: I/O – Instruments, PLCs (Automation Controllers), PCS(Process Control System), MES(Manufacturing Execution System), ERP(Enterprise Resource Planning), TP (Technological Packages) and to publish information, ready to be used by external subscribers (e.g. higher level analysis tools, other DA packages like DCMS(Distribution Center Management System), the cloud ..).It has been designed to be fully configurable: in fact, it is possible to create several communication channels among heterogeneous sources with different communication protocols or I/O, defining related variables freely combinable to create data messages.Q3-BBOX is key to move from pyramid to Producer consumer paradigm: an efficient solution data interchange require the participants to be producer and consumers of information, overriding the classical CIM (Computer Integrated Manufacturing) [22] pyramid data flow.

The classic automation pyramid model shows a series of well-defined layers structured in such a way that information flows upwards from devices to enterprise via levels of control, supervision and management.

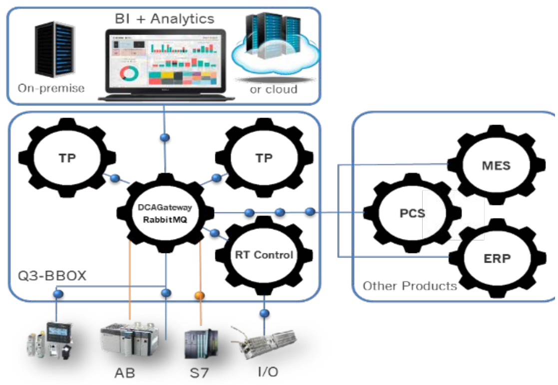


Figure 5. Q3-BBox collocation and interfacing capabilities.**Figure 6**Q3-BBox Acronyms

Although the model is well-established, this flow of data is by no means smooth. At each layer of the pyramid there are differing functional requirements, this has led to the development of task-specific communication methods which offer little compatibility between the layers.This issue is particularly acute at the lower end of the model. For field level devices with real-time and safety requirements, the lack of a single suitable communication standard has led to a multitude of competing proprietary protocols. This means that there is incompatibility not only between layers but also within the device and control layers. As a result it is not uncommon for automation devices to support five or more different industrial protocols in order to be compatible with the system favored by the end user.

Although OPC UA breaks down some of the barriers between automation and IT, it does not solve the issue of the proprietary and isolated networks used for real-time and safety sub-systems. These networks are now addressed with the advent of a Publish/Subscribe model for OPC UA, and the Time Sensitive Networking (TSN) extension which adds real-time functionality to IEEE 802 Ethernet. The combination of OPC UA Publish/Subscribe with TSN enables the exchange of data from one-to-many and many-to-many in real-time over standard Ethernet. OPC UA TSN therefore provides an open, standard and real-time communication platform which supports the principles of the Internet of Things whilst fulfilling the strict requirements of traditional automation.

The common scenario usually found in existing plant (but also in new installation) is the segregation of information into localized islands. The challenge is to find the proper solution to allow the harvesting of available data providing the possibility of data normalization to create uniform communication flow using standards such as an Advanced Message Queuing Protocol (AMQP).

In this way, any new data consumer can rely on a known and safe Application Programming Interface (API) by means of which it can enter into the communication flow.Moving from CIM hierarchical pyramid to a producer-consumer data circulation allow easy and quick implementation of distributed logic and data analysis.

Faster CPU’s and lower costs of memory and storage are creating a new breed of powerful low cost devices that are produced by many new vendors and that use modern communication protocols.

The systems base data management lies on a producer-consumer logic where they coexist with the machine ecosystem, implementing a widespread and continuous data collection, equipping the machines with the sensors and the necessary instrumentation or directly from the automation systems. Taking into account the cyber security of data circulation. In turn the systems are information providers for advanced data analysis and collection systems.

3.3KPI Monitoring

Danieli has developed Q3Intelligence to centralize the information of the entire steel plant, giving the end users a unique source to retrieve and analyze it.The Q3Intelligence platform delivers information through a real-time, Web-based application and offline and long-term data analysis. The Web-based application, Web Dashboard Module (Figures 7-8), is a real-time user interface with a graphical presentation of the status and historical trends of each specific steel plant area. Thanks to the full integration with Microsoft tools (Excel and SharePoint), the learning curves are remarkable shorter, making the users autonomous in the data access and retrieval.

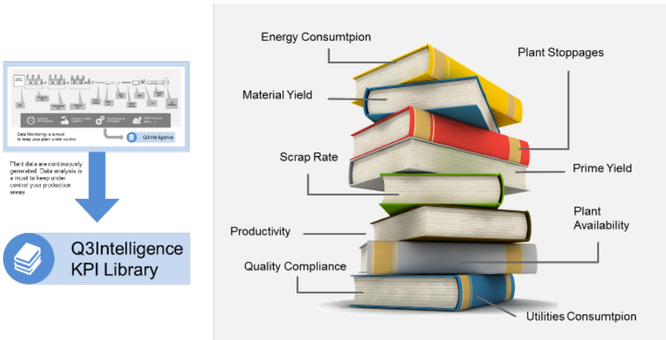
Figures 7-8.Q3-Intelligence.

A typical structure of a Q3Intelligence OLAP data structure brings together groups of measurements and variables arising from multiple sources into a consistent and unified model. Typically, a data model includes measures relative to chemical analyses, production quantities, process times, process variables and quality control assessments, as well as classification perspectives such as dates, heats, grades, practices and product features. This gives the users the ability to perform multiple analyses using the same source scheme within the same spreadsheet. Along with the data models, a set of advanced statistical Excel Workbooks are available making it possible to rapidly investigate correlations, distributions, outliers and patterns.

The Data Warehouse is the core of Q3Intelligence Platform and it is developed to store large volumes of historical data. Data related to different plant areas are stored in the DWH in order to easily analyze data related to the entire production process. This is a database completely designed to support analysis rather than transaction processing. Quality control procedures are used to ensure the accuracy and consistency of the data loaded into the Data Warehouse.

Data warehouse (DW) is a system used for reporting and data analysis, and is considered a core component of business intelligence. DWs are central repositories of integrated data from one or more disparate sources. They store current and historical data in one single place that are used for creating analytical reports for workers throughout the enterprise. Data rigidity, as it has to be transformed and cleansed and their processing speed is low.Data Integration or importation into warehouse is not always done resulting in loss of information. There is no flexibility as majority of the store static and difficult to get tuned to processing speed.

Process Information Management System (PIMS) is a client/server application for the acquisition, display, archiving and reporting of information from a wide variety of control, plant and business systems. A critical component in a manufacturing enterprise's application architecture for creating a common repository of plant information that can be effectively leveraged in enterprise and supply chain management applications. PIMS, a central repository for all things related to product data- both structured and unstructured. A PIMS provides a single repository for storing all outgoing product data. A central repository system of record gives a single view of the product data to the entire enterprise so everyone sees the same information.Data quality and data consistency are naturally improved by reducing the need to manage redundant information in multiple systems. They improve control and management of the product data through system defined workflows, automated formatting of data and auto triggering of business rules and flags.



Figures 9.Q3-Intelligence KPI library.

Data stored into the DWH are used in order to build the data model (used in Q3Analytics module). This multidimensional model gives faster performances during data analysis, with the capability to support complex queries on business data. Based on Danieli Automation's metals-making knowledge and experience, data model is designed to be highly flexible and to provide very informative KPIs.
The KPI Library is the repository of Key Performance Indicators and metrics related to the productive process managed by the PCS system. The Q3Intelligence solution has its default complete and exhaustive KPI Library, which can be completely customizable to the customer needs (Figure 9).

3.4 Mobility

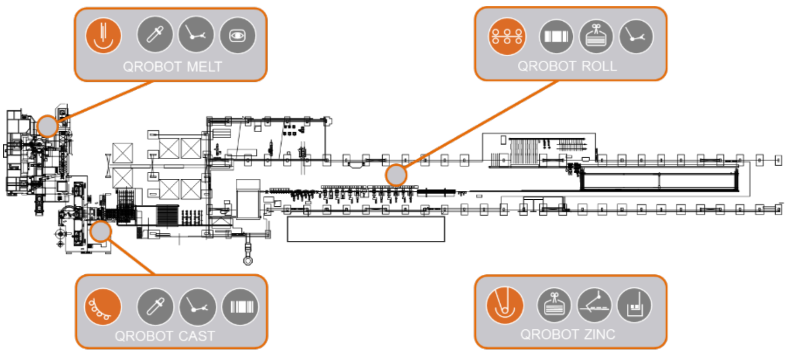
Thanks to the native Mobile functionality, all the monitoring capabilities are available by accessing the system with tablets and smartphones, giving the plant personnel immediate access to information on operations in real-time, allowing them to track the production chain efficiently and react rapidly in the case of anomalies or critical situations.Q3MobileIntelligence is a web-based application for the real-time production monitoring of all plant areas. It brings the full power of mobile devices into the metals industries with clear and concise, focused on content, which makes any user, easy to understand (Figure 10).It ensures a secure Internet and Intranet connection to production data with the End-user customization and filtering capabilities along with the Integration with reports and access to IBA and FDA files (from desktop version) and finally, sharing of multi-media content (photos, videos).

Figures 10.Q3-Mobile Intelligence.

It ensures enhanced productivity from continuous interaction among users at the workplace by creating a collaborative awareness of plant status and performances with the capability to react promptly and by setting a benchmark of the current plant performances compared to set targets.

3.5 Autonomous and Robotic Systems

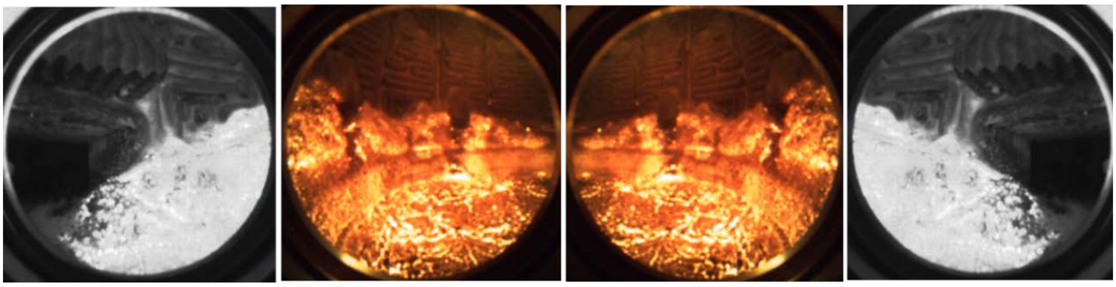
Q-ROBOT is the result of the most advanced alliance between industrial robotics and process automation. A set of solutions for each production area allow the introduction of flexible automation in dangerous places where human intervention is still necessary to finalize the production.
As shown in the below Figure 11 the cast ladle sampling and measurement is used to perform all measurements on tundish.



Figures 11.Q-Robot Application areas.

Q-Robot Melt Scan is endowed with a camera tool that is used for visual inspection of the EAF. It focus on vital factors such as miniaturization of the scan tool (enclosure + 360 camera), automatic clamping system on the existing measurement tool and development of images navigation system.

The camera tool in figure 12 (4 industrial cameras with 360° FoV) enters the slag door and in few seconds grabs a complete view of the inner part of the furnace. The obtained images are stored and can be analyzed by means of zoom and pan functions by the operator in any time.



Figures 12.Q-Robot Melt Scan Image analysis.

Thus no more manual operations in front of slag door are required and helps in the reduction of operators exposure to high temperatures, high-noise and high-pollution levels. The reliability of the sampling operation is guaranteed maintaining a constant depth and tilt of the lance, which can be set from the HMI and the repeatability of the sampling operation.
Q-Robot zinc in figure 13 helps in automatic detection of zinc dross on the liquid zinc surface thorugh a vision system. A constant use of the robot avoids the formation of “dross slab” - pieces of coalesced dross. It operates in the continuous, repetitive and flexible efficient zinc dross removal from zinc pot and helps in best line operators’ focusing on galvanizing process, because the dross skimming operation is fully automatic, and linked to the line speed variations.

Figures 13.Q-Robot Zinc in action.

The Q-Robot Roll Deburring is a stand-alone robotic cell designed to remove burrs or corner defects on billets, blooms or slabs.
The cell is equipped with an artificial vision package that allows the robot to identify the bar profile and automatically generate the robot part program.

4 CONCLUSION

In this paper, we successfully presented a systematic, flexible and an intelligent architectural design of a plant with various features, which can be seamlessly integrated resulting in the optimization of capital Investment and operational expense

paving the way to smart factory. We described and presented the various features, of integral packets of the autonomous systems, their feasibility and purpose.
Once the Minimum Digitalization Level is reached, the step to move into the Smart Plant is short and the application of Danieli methodology become easier because the access to the data and the infrastructure enable the Smart Approach.

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