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Industry 4.0: Machinery integration with supply chain and logistics in compliance with Italian regulations

Diego Sinitò[a,b], Vito Santarcangelo[a], Filippo Stanco[b], Massimiliano Giacalone[c,*]

[a] iInformatica Srl, Corso Italia 77, Trapani TP, Italy
[b] Department of Mathematics and Informatics, University of Catania, Catania CT, Italy
[c] Department of Economics, University of Campania "Luigi Vanvitelli", Capua CE, Italy

REVIEW HIGHLIGHTS

- An overview about automated integration of 4.0 systems within the supply chain or logistics in two companies in the southern Italian territory is presented.
- An exhaustive analysis of the Italian legislation and the strict requirements in order to assess which investments are part of Industry 4.0 take in account the business risk.
- The paper shows the additional features such as remote maintenance and the presence of cyber-physical systems as they are normally satisfied in the real contexts analyzed.

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ABSTRACT

This paper shows a real overview of the interconnection and automated integration of 4.0 machinery within the supply chain or logistics of two companies in the southern Italian territory. The authors provide an exhaustive analysis of the Italian legislation and the strict requirements in order to assess which investments are part of Industry 4.0 with a focus on business risk. The work also shows the potential of a new framework developed that allows using OPC-UA and Modbus protocols to access the functional variables of the 4.0 machinery in a bidirectional way, directly from cloud applications. The proposed solutions help companies to develop more efficient production processes and to fulfil the requirements imposed by Italian regulations in order to benefit from Industry 4.0 financial aid.

Specifications table

Subject area:	Computer Science
More specific subject area:	Big Data in Industry 4.0
Name of the reviewed methodology:	Open Platform Communications Unified Architecture
Keywords:	Industry 4.0, machinery interconnection, industrial data exchange, Internet of Things, Big Data

(*continued on next page*)

* Corresponding author.
E-mail address: massimiliano.giacalone@unicampania.it (M. Giacalone).

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Resource availability:	https://modmes.it/ Lu, Y., 2017. Industry 4.0: A survey on technologies, applications and open research issues. Journal of industrial information integration 6, 110. Shin, S.J., 2020. An opc ua-compliant interface of data analytics models for interoperable manufacturing intelligence. IEEE Transactions on Industrial Informatics.
Review question:	What are the approaches for integrating 4.0 systems into the supply chain and logistics? What is the connection between industry 4.0 and business risks? Are there any Cyber-Physical systems in the analyzed context?

Introduction

The world of Industry 4.0 today represents an important scenario for economic and technological growth in the European context [13]. Introducing concepts such as cybersecurity, internet of things [5], internet of machines, industrial automation, robotics, smart manufacturing, simulation, artificial intelligence [38], virtual and augmented reality and Big Data are now necessary to innovate traditional companies in order to introduce a new vision in an increasingly dynamic competitive context [15,18,20,21].

As early as 2015, a law was passed in Italy that allowed financial subsidies to be used for the modernization of industries and production processes. In particular, for the purchase of capital goods that could be considered 4.0. The decision on which of these assets could be considered 4.0 was made the following year, when the legislator provided a precise list of the characteristics that new equipment had to have in order to take advantage of the financial subsidies.

Given the considerable confusion in the resolutive approach to these constraints, the paper, therefore, addresses the possibilities of bidirectional interconnection via the OPC-UA and Modbus protocols and the automatic integration of the 4.0 plant with the supply chain or the logistics processes using a new framework, developed by iInformatica Srl, that allows the integration of data coming from machinery PLC's (programmable logic controller) into web application such as Manufacturing Execution System (MES) software.

In section five a set of KPIs (Key Performance Indicators) are defined in order to rationally determine the ”Business risk”, which means that the plans of a company or an organization may not turn out as originally planned or that it may not meet its target or achieve its goals. Anything that threatens a company's ability to achieve its financial goals is considered a business risk. There are many factors that can converge to create business risk, which the authors summarized with the four KPIs: Production efficiency $P\epsilon$, Level of technological obsolescence (Lto), Compliance (C), and Production quality level (PQ).

Finally, in the last section a group of case studies of some brilliant companies from the south of Italy [19], on the automated integration carried out with the factory logistics system (L'Antincendio Srl and Derado Srl) and with the supply chain (Matera Inerti Srl).

Industry 4.0: State of the art of Italian legislation

A great opportunity for growth for Italian companies is also provided by the possibility to exploit incentives for the modernization of industries and production processes. In this case, the Italian government has been farsighted and the Parliament, in 2016, had already passed measures for the modernization of Industry 4.0 to encourage the purchase of new capital goods. The Parliament has precisely defined which categories of investment and which assets could be considered recipients of the incentives. In addition, the legislature defined a precise list of the characteristics that each new tangible equipment should have in order to be considered 4.0 capital goods.

According to Annex A to Law No 232/2016, in order to be considered capital goods for the purposes of the legislation, machinery must belong to one of the categories specified in the document:

- machine tools for removal;
- machine tools operating with lasers and other flow processes of energy (e.g., plasma, waterjet, electron beam), EDM, electrochemical processes;
- machine tools and equipment for making products by processing materials and raw materials;
- machine tools for plastic deformation of metals and other materials;
- machine tools for assembly, joining, and welding;
- wrapping and packaging machines;
- de-manufacturing and repackaging machine tools for recovering materials from industrial waste and end-of-life return products (e.g., machines for disassembly, separation, shredding, chemical recovery);
- robots, collaborative robots, and multi-robot systems;
- machine tools and systems for conferring or modifying the surface characteristics of products or functionalization of surfaces;
- additive manufacturing machines used in industry;
- machines, including traction and operating machines, instruments and devices for loading and unloading, handling, weighing and automatic sorting of parts, automated lifting and handling devices, AGVs and flexible conveying and handling systems, and/or equipped with part recognition (e.g. RFID, viewers, vision systems);
- automated warehouses interconnected to factory management systems.

All of the above machines must be equipped with the following features:

1. control by CNC (Computer Numerical Control) and/or PLC (Programmable Logic Controller);
2. interconnection with the factory computer systems with remote loading of instructions and/or part programs;
3. automated integration with the factory logistics system or with the supply network and/or with other machines in the production cycle;
4. simple and intuitive human-machine interface;
5. conformity to the most recent parameters of safety, health, and hygiene at work;

The requirements above are mandatory (MR) and all five must be present. In addition, a machine must have at least two of the optional requirements (OR):

- remote maintenance and/or remote diagnostics and/or remote control systems;
- continuous monitoring of working conditions and process parameters by an appropriate set of sensors and adaptability to drifts of the process;
- feature of integration between the physical machine and/or model of the plant and/or system of simulation of the machine itself (cyber-physical system);
- devices, instrumentation, and intelligent components for integration, sensing and/or interconnection, and automatic process control also used in the modernization or revamping of existing production systems;
- filters and systems for treatment and recovery of water, air, oil, chemical and organic substances, and dust with systems for reporting filter efficiency and the presence of anomalies or substances that are unrelated to the process or hazardous, integrated with the factory system and capable of alerting operators and/or stopping machine and plant operations.

Therefore, it is often and willingly easy for a machinery manufacturer to comply with points OR1, OR4, and OR5 of the mandatory requirements. On the other hand, it is particularly difficult to concretely satisfy those of the bidirectional interconnection (sending instructions or partial programs in both directions) or the fulfilment of automated integration without knowing the place where the machinery will be installed and without knowing the systems in use. The responsibility of fulfilling requirements OR3 and OR4 is usually left to the company that purchases the machinery. In this case, we can refer to this machinery as ready for Industry 4.0 but not already usable for the purpose of collecting the benefits provided for Industry 4.0 in terms of financial aid provided by the Italian government.

We will not discuss optional requirements (OR) at this time because they are strictly related to the manufacture of the machinery and therefore their fulfilment is deferred to the machinery manufacturer, who will decide which ones to implement.

Considering the OR2 of Annex A, which requires bidirectional interconnection with the factory informative system, it is essential to consider the use of international standard communication protocols such as the Modbus TCP/IP or OPC-UA that are used by a large part of machinery PLCs or the API REST (Representational State Transfer) for machinery that provides a cloud.

To satisfy the OR3 of Annex A, which requires automated integration, we have several options. The case of M2M (machine to machine) is the simplest to imagine for production processes that require multiple processing steps carried out by different 4.0 machinery which are able to communicate and work in a synchronized manner with respect to the various production phases, using an internationally recognized protocol for communication. Instead, if we want to integrate the machinery into the company workflow, it is necessary to analyze the processes in order to develop an integration solution based on the company's needs. The new process should introduce a benefit for the company and/or the customers. Considering the integration with the logistic processes, an example is represented by referring to identifiable incoming lots with a barcode that allows tracing the entry of the single lot and the various processing phases carried out by 4.0 machinery and using it to track the positioning of the output semi-finished product or of the finished product in a specific position in the warehouse. This tracking, therefore, allows making correct use of 4.0 in an automated integration key of the logistics process. In the absence of this flow, for instance, it is possible to carry out an evaluation of the integration of the machinery within the supply chain; this means that both the customer and the supplier who use a 4.0 automaton as an intermediary for their workflow are automatically informed of the start of the specific activity phase until the end of the activity.

Therefore, automated integration with the logistics factory system takes place through access to the machinery interconnected to the factory's computerized system. In this case, we can use the term Manufacturing Execution System (MES) to refer to a computerized system whose main purpose is to manage and control the productive function of a company. Thanks to the connection with the machines and by using the information they transfer, it is possible to further improve the communication of orders, the advancement of quantities and time, the storage in the warehouse, as well as collecting process data to be analyzed from a Big Data perspective.

Compliance analysis of a group of industrial machinery

Considering a dataset of 25 4.0 investments analyzed with a relative declaration of conformity issued by the manufacturer, it was found that there was a high non-compliance of the same with the interconnection requirements. The machinery was analyzed with regard to the characteristics required by Italian regulations for Industry 4.0 compliance: the presence of PLC/CNC, the presence of HMI, the CE mark, the presence of communication protocol, and the system for automatic integration. Most of the machines are equipped with PLCs and HMI devices. In addition, all machinery sold in Italy has received the CE mark. The most frequent problems concern the communication protocols and interconnection systems on board; often these machines can only communicate with proprietary software and do not adhere to open standards.

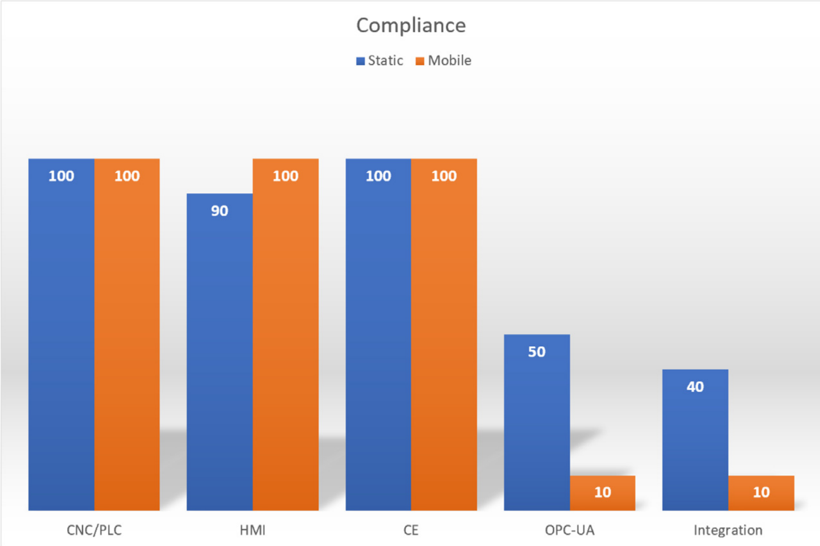

Fig. 1. Results of the analysis of machinery's characteristics.

Bidirectional interconnection

In this paragraph, we will try to shed some light on the wide range of industrial communication protocols, which is a prerequisite for interconnection and data exchange. Indeed, at the basis of the interconnection between a machine and software or another machine (M2M, machine to machine), there is necessarily a communication protocol [1,24]. In most companies (whether small, medium, or large), the machinery pool is extremely diverse, meaning that machines of different ages, suppliers, and technologies have to be working in the same company. This heterogeneity often requires the use of different communication protocols, making the interconnection operation both complicated and not immediate. It is easy to understand that this complexity leads to further complexity of the software, which has to exchange information with the various machines in production and which must therefore act as an interpreter, knowing all the languages used by the interconnected machines. A further problem, in some cases not too isolated, may arise from the fact that the machinery uses a non-standard protocol, created by the manufacturer of the machinery itself. It is as if the machine were speaking a language or dialect that no one else knows. Additionally, in this case, the interconnection software will have to be aware of the new protocol in order to communicate with the specific machine. It is evident that at this point the factory software (MES) will have to be flexible enough to allow it to interface with new machines and heterogeneous data (Fig. 1).

In the following sub-paragraphs, we will analyze two of the most popular communication protocols today.

Modbus TCP

It is the longest-running of the presented protocols. It was created in 1979 by Schneider Automation and quickly became a de facto standard. Modbus is deployed on Ethernet networks (Modbus TCP) and on serial RS 485, 232, and 422.

In the Modbus protocol, data is organized in registers that are accessed by address. The register is the smallest unit on which a write and read operation can be performed. It is universal, open, and easy to use. New industrial products such as PLC, PAC, I/O devices, and instruments may have an Ethernet, serial, or even perhaps wireless interface, but Modbus is still the preferred protocol. The main advantage of Modbus protocol is that it runs on all types of communication mediums including twisted pair wires, wireless, fiber optics and Ethernet. The Modbus devices have memory, where the plant data is stored. This memory is divided into four parts as discrete input, discrete coil, input register, and holding register. The discrete input and coil are 1-bit while the input register and holding register are 16-bit.

- Input register: for read-only operation on numeric registers.
- Holding register: for writing and reading operations on numeric registers.
- Discrete input: for read-only operation on boolean registers.
- Coils: for writing and reading operations on boolean registers.

Even if there are alternative protocols that give better performances, Modbus protocol is widely used because it is open source, has a low development cost, and needs limited hardware. It does not guarantee high speed but it is perfect for monitoring, which requires, in fact, moderate speed.

The master-slave architecture of Modbus TCP can be implemented using relatively simple devices since most of the protocol control and functionality are incorporated in the master device [25]. The situation is reversed in Modbus TCP: the master is a "TCP client" and the slave devices are "TCP servers." As far as networking is concerned, devices that support Modbus TCP must implement all (or

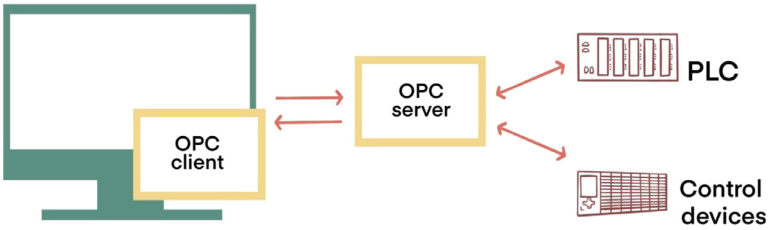

Fig. 2. Client/server communication of OPC Classic.

a significant subset) of the features of a TCP/IP server. The TCP client/server semantics is also more general than the simple master-slave model.The majority of Modbus requests are commands to read or write registers in slave devices that allow communication between the PLC and an interconnected software.

OPC and OPC-UA

Among the pillars at the base of Industry 4.0, we find connectivity and communication within the industrial production process, with the aim of centralizing and interpreting heterogeneous data [16].

OPC is the most important industry standard for the exchange of information between devices and applications in a Windows environment. OPC applications are client/server type and allow the definition of objects, methods, and properties to allow exchanging of information in real time between Server and OPC client (Fig. 2), moreover, the OPC interfaces can provide data from Scada, PLC, or DCS systems to other applications.

OPC Classic consists of three distinct main protocols: OPC HDA (OPC Historical Data Access), OPC DA (OPC Data Access), OPC A&E (OPC Alarms and Events). However, the OPC Classic standard is platform-dependent and relies on Windows-based technologies, its platform-independent evolution is represented by the OPC UA standard [23].

The OPC UA (Open Platform Communications Unified Architecture) released in 2008 by the OPC Foundation (a non-profit organization founded in 1994, with the aim of defining a Plug & Play standard for drivers of industrial devices), is a very flexible Service-Oriented (SOA) architecture, which integrates all the functionalities of the single OPC Classic specifications in a single Platform Independent Framework.

OPC UA is in fact an M2M communication standard that allows exchanging data between PLC, HMI, server, client, or other machines, with a multi-layered approach that allows reaching objectives such as: Functional Equivalence as all the OPC COM specifications Classic are mapped on OPC UA; Platform Independence both Hardware (PC, cloud-based servers, PLCs, CNC, PACs) and Software (Windows, Apple OSX, Android, Linux, etc.); Security (meets multiple standards regarding authentication, authorization, and exchange of encrypted information) [33].

OPC UA can be easily deployed, is compatible with legacy systems and existing infrastructures, and allows for scalability. The characteristic of integrating existing, dated industrial automation systems that would otherwise require important conversions and updates that would also jeopardize the functionality of the same processes, fulfils the requirements of plants and factories (especially in the manufacturing context) that are not necessarily arranged to purchase new equipment and disrupt the current IT infrastructure.

The OPC UA standard was thus adopted in the process control, oil & gas, food and beverage, waste management, and pharmaceutical sectors.

OPC UA is structured in several layers, whose main components are the transport protocols and the data model. Two different protocols are defined in the transport layer: the first is a binary TCP protocol for high-performance intranet communication and the second is a Web Services-based protocol for firewall-friendly internet communication [12,29].

OPC UA Services constitute the interface between the Server (suppliers of information models) and Clients (consumers of such information models). Although a client-server architecture is used (Fig. 3), (taking advantage of the characteristic of physical devices in which the server side is also integrated), in general, an application can play both roles. Within an OPC UA Server, the nodes (contained in the Address Space) [39] represent real objects and can be freely structured in networks, hierarchies, and archives. OPC UA Clients can access data either through a Req/Rsp mechanism or through Subscription (push mode), and thanks to OPC UA a client can access a small portion of data of a complex system, without knowing the complete information model [37].

OPC UA also supports a Publish-Subscribe mechanism that relies on a MOM (Message Oriented Middleware) that receives messages from publishers and makes them available to subscribers. The MOM can be based only on the network structure (e.g., with UDP) or mediated by a broker who can offer additional services (formatting, association, translation, ...) [32].

Implementation of framework for industrial communication

The basis of our framework is the intention to be able to connect the industrial machinery with the software used by the company. Therefore, we chose to implement a web API that can be queried both from the company network and from the outside, offering an interface for any application that needs to access the information offered by the 4.0 machines. What has been realized is a REST API

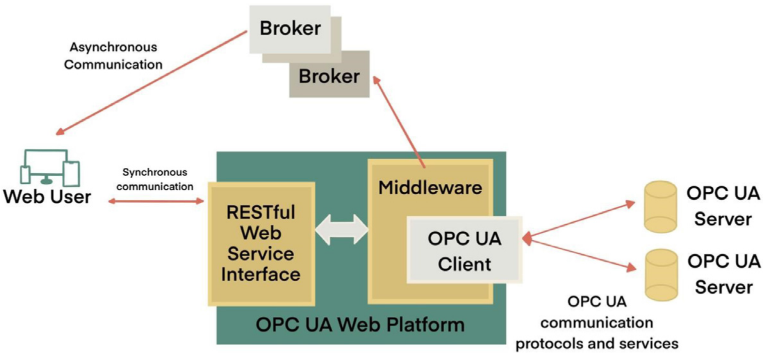

Fig. 3. OPC UA architecture and structure of a request.

that exposes methods for reading and writing data on the 4.0 machines installed in the company network. APIs, Application Programming Interfaces, are mechanisms that allow two software components to communicate with each other using a set of definitions and protocols. API architecture is generally explained in terms of client and server. The application that sends the request is called the client and the application that sends the response is called the server. The client sends requests to the server as data. The server uses this client input to initiate internal functions and returns the output data to the client. Nowadays, it is possible to implement a web API in many ways: SOAP, web socket, REST. In our case, the choice has fallen on REST for its simplicity of implementation and immediacy. REST stands for "Representational State Transfer" and defines a series of functions such as GET, PUT, DELETE, etc., which clients can use to access data from the server. Client and server exchange data via HTTP. The main feature of the REST API is statelessness. Statelessness means that servers do not save client data between requests. Each request is processed individually and the communication channel is interrupted by the response. Unlike a web socket, no further data can be sent to the client after the response. Requests from the client are made to the server by means of URLs similar to those entered into a browser to visit a website, the response from the server is simple data encoded using the JSON format.

After the definition of the communication protocols with the machines and the type of service to be implemented to access this data, it was decided to use Python to implement the server software that has the task of exposing two end-points, one for reading and one for writing, of data and variables on the industrial machines.

Three libraries were used for the implementation of this service, which fulfils the main tasks: the connection to the machines by means of the OPC UA protocol, the connection to the Modbus TCP/IP protocol, and the realization of the REST API.

- **opcua-asyncio**[1]: is an asyncio-based asynchronous OPC UA client and server based on python-opcua;
- **pyModbusTCP**[2]: this library gives access to modbus/TCP server through the ModbusClient object;
- **Flask**[3]: is a popular Python framework for web application development. It comes with built-in functionality and minimum requirements, making it easy to get started and flexible to use.

The network configuration diagram shown in Fig. 4 is an example of a possible configuration of our framework for interconnection. A client who wants to use an MES-type application from his workstation makes a request to a server where the application resides. The MES to obtain the information of the machines necessary to process the request will make calls to two services also exposed on the company network. Each service takes care of the connection with the machines using one of the two protocols seen above. Having obtained the necessary data, the MES will be able to process the content and respond to the client that made the request.

To make the architecture more flexible, the two services, OPC UA and Modbus, are started up separately. In case one of the two is not needed, it may also not be started.

The MES system

Automatic integration can take place after defining the business logic of the production process and after fulfilling the interconnection requirements. As already mentioned in the previous paragraph, it often happens that, inside the same industrial plant, there are more 4.0 machines from different providers or bought in different periods, and that therefore need different connection protocols. In order to meet these needs iInformatica S.r.l developed a custom MES, named ModMes, based on modular web architecture, allowing a quick integration of different communication protocols. The software can be divided into two operational modules: the connection module can be found at a lower level, while at a higher level, we can find the module that integrates the business logic. The connection module, based on the HTTP communication protocol, can offer different servers, depending on the communication protocols required by the company that wants to interconnect their machines, which connect with the installed PLC in the 4.0 machines and

[1] opcua-asyncio project website: https://github.com/FreeOpcUa/opcua-asyncio.
[2] pyModbusTCP project website: https://github.com/sourceperl/pyModbusTCP.
[3] Flask website: https://flask.palletsprojects.com/en/2.2.x/.

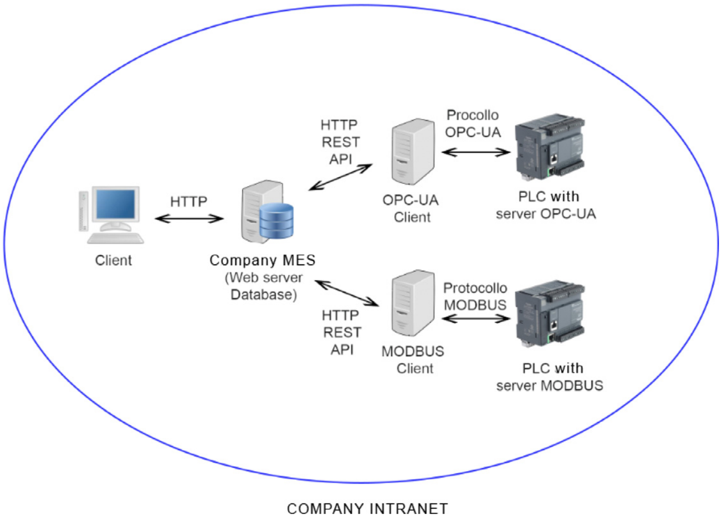

Fig. 4. An example of the network configuration for the framework. Client request data from company MES. MES system get data from machinery using the two API endpoints.

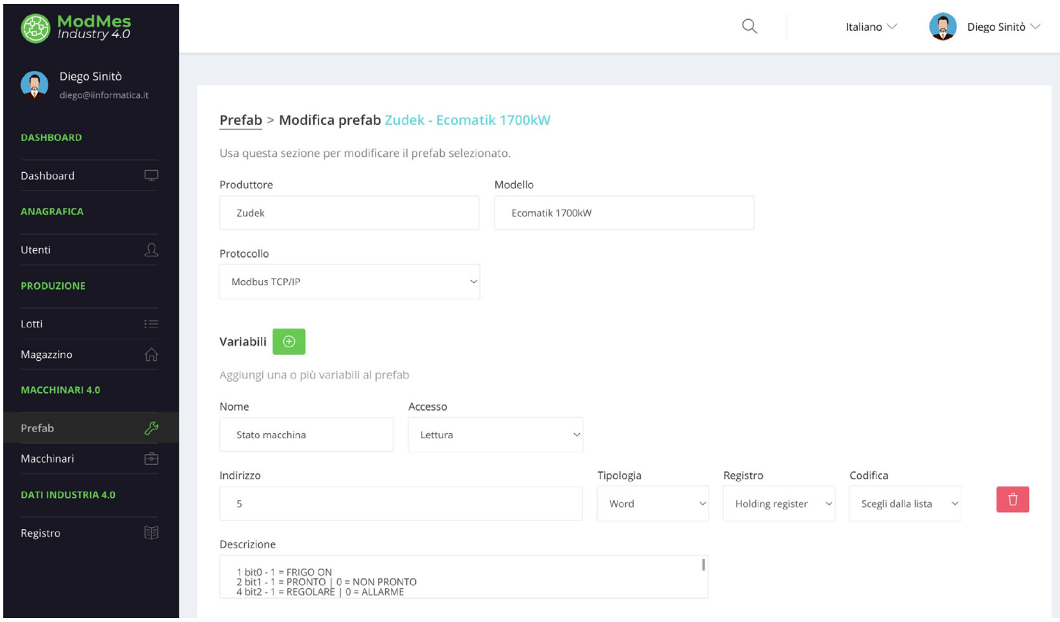

Fig. 5. A screenshot from the configuration section of machinery where the communication protocol and variables are initialized (in the Italian language).

can read and write registers and variables provided by the machinery producer. Every server works independently and exposes to the upper layer, where the MES works, API REST interfaces of the GET, POST type. The MES system will integrate predefined models of each machine in the company in which it operates, specifying all the variables made available by the PLC installed on board. The communication protocol of the 4.0 machine is specified in this configuration so that the MES can automatically recognize the server to forward requests. These predefined models are the basis of the system and allow the connection of an unlimited number of machines in successive instances by specifying only the basic model to instantiate, its IP address, an identification code, and any credentials for access to memory areas (used for example in the OPC-UA protocol that allows the server on board the PLC to be protected by a user name and password). This architecture has the advantage of not requiring specialist intervention every time there will be the need to create a machine already configured within the MES. In fact, configuration by experienced technicians is only needed once, during the creation of the basic model. Subsequently, you can instantiate a new machine and connect it to the system using a simplified HMI that only needs a few pieces of information as shown in the Fig. 5.

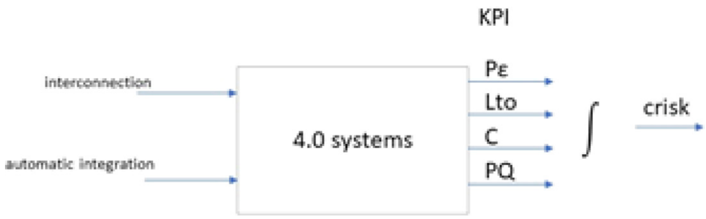

Fig. 6. Definition of KPIs that contribute to finding the company risk.

Business risk and industry 4.0 approach

The interconnection and automatic integration represent a very important way to define possible business KPIs [7,30]. In fact, we can define 4 KPIs:

- Production efficiency ($P\epsilon$). This KPI is obtained considering the monitoring of machine downtime, the employers working times, the output products considering the delivery plan, real-time costs-revenue estimation, and prevision [14].
- Level of technological obsolescence (Lto). This KPI is obtained by comparing datasheet features in relation to fuzzy benchmark, the event about machine maintenance, the entrepreneurial know-how, and the employers' working skill [2].
- Compliance (C). This KPI is obtained considering process mining comparison between the procedure and the real process (log). This is very important to obtain the respect of compliance procedures [4] (e.g. organizational model, ISO model, GDPR, Sarbanes-Oxley Act, Security Act).
- Production quality level (PQ). This KPI considers NPS feedback obtained from customers and also production workers, considering sourcing raw materials and process CSR (corporate social responsibility) impact [28].

Following this approach $P\epsilon$ and Lto can be the right variables related to Financial risk (that summarizes market risk, cost of capital) and to Strategic risk (that summarizes industry changes, competition), C and PQ can be related to ”Operational risk” (construction management, account process, information transfer), “Compliance risk” (regulation, branding, image) and to “Hazard risk” (third-party liability, property loss).

These 4 variables can be represented as mathematical functions over time, and the business risk can be defined as the integral over time of contributions (Fig. 6).

Company risk can be defined as:

$$C_{RISK} = -fs\int_{t_0}^{t_1} P\epsilon(t)dt - fs\int_{t_0}^{t_1} Lto(t)dt - och\int_{t_0}^{t_1} C(t)dt - och\int_{t_0}^{t_1} PQ(t)dt \tag{1}$$

Where f,s,o,c,h are constant to integral tuning based on the semantic of the company, where f is related to Financial risk, s is related to Strategic risk, o is related to Operational risk, c is related to Compliance risk and h is related to Hazard risk.

Case studies

This paragraph provides two examples of Industry 4.0 with two different approaches regarding the automated integration 4.0 carried out in two brilliant realities of Southern Italy. The first case study concerns the benefits of Industry 4.0 applied to the safety and fire prevention sector, of the company L'Antincendio Srl from Matera, which, thanks to an R&D path supported by the innovative SME iInformatica Srl, has acquired numerous innovative tools [15].

The second case study concerns the integration of a concrete mixer washing machine in the supply chain of Matera Inerti Srl, a brilliant company in the aggregates and premixed sector in the city of Matera [17].

“L'Antincendio” case study

L'Antincendio Srl, which has become an innovative SME, is specialized in the fire prevention sector thanks to the installation and subsequent maintenance of highly innovative systems and devices. If this activity is not optimized and managed correctly, it can become very onerous with risks on the related regulatory compliance [9].

To continuously monitor devices, the company has conceived, designed, and patented an IoT system using QR code technology, creating a real network of connected devices [34].

At the heart of the system is a system for smart fire extinguishers that allows you to keep your own safety devices installed by the company under control in a simple and intuitive way and to carry out routine verification operations. Each customer by logging in with his credentials is able to access all the devices installed in his facilities very quickly, he can also check their status and obtain information on the history of the maintenance carried out [3] (Fig. 7).

The app is also available for the company's specialized maintainers, through which they can carry out and record maintenance operations using the blockchain, in order to obtain a temporal certification [6].

Fig. 7. Device login screen and device home page (in the Italian language).

All the data collected during the operational phases are then analyzed by an expert system with the aim of creating a model that allows for improved process efficiency by always estimating more accurately when to carry out maintenance operations and who is the most suitable operator to carry out this operation [10]. Finally, it is possible to obtain logs for a subsequent analysis phase necessary to verify the maintenance of the required operating standards and compliance [8].

With a view to interconnection 4.0, L'Antincendio Srl has equipped itself with a 4.0 interconnected machinery for recharging fire extinguishers. Also, in this case, a tailor-made module has been developed, and modeled according to the company processes of maintenance of the fire extinguishers (Fig. 8).

This module allows a maintenance technician, after logging in with their credentials, to start the maintenance process of a particular device.

First of all, the operator will frame the QR code placed on the device that will allow him to connect to the object of the IoT network. Once connected, it will be possible to obtain some basic information about the device, such as the serial number, the year of production, the maintenance register, etc; or it will be possible to start the charging process using the 4.0 machine.

The 4.0 machinery interconnected to the company network communicates all the results of the operations carried out by means of a PLC, providing a set of very important parameters, such as the number of kg of powder dispensed during the last reloading operation. These parameters are acquired and stored in a database, together with the timestamps associated with every single operation performed by the machine.

Thanks to the interconnection of the machinery and the app it will therefore be possible to certify automatically and in an anti-elusive way that the recharging operation actually took place in that declared time range and that the right quantity of kg of powder has been dispensed the type of fire extinguisher on which maintenance is being carried out.

In fact, after correctly selecting the product by means of the QR code and verifying the connection with the 4.0 machine, the operator can press the "Start maintenance" button to start the charging process. In the event that the 4.0 machinery is offline, the operator will not be shown the start maintenance button and consequently, it is not possible to carry out maintenance operations [31].

After reloading the fire extinguisher using the machine, the operator can return to the application and select one of the buttons:

- Complete maintenance: in the event that the charging process has been completed and no errors have occurred.
- Maintenance error: in the event that a problem has occurred during the charging operation.

Fig. 8. Application login screen and device selection screen by QR code (in the Italian language).

In the event that the operator selects the ”Complete maintenance” button, the software connects to the 4.0 machine and queries the register of operations carried out by crossing the data relating to the timestamps, the type of operation selected on the machine and the amount of powder actually dispensed. Only if all these parameters are compatible with the device on which we started the maintenance, the operation will be completed and saved in the company database. If the parameters are not verified, for example, a fire extinguisher with a capacity of 9kg has been reloaded using only 6kg of powder, an error message is shown to the maintenance technician and it will be impossible to complete the operation, and therefore the subsequent registration in the Company.

The use of the 4.0 machinery has been integrated into the maintenance processes of company safety devices thanks to the use of a QR code that allows you to identify the exact product with its initial state, carry out maintenance operations through the machine, record the ” activity carried out verified in compliance and prepare the delivery plan of the device ready for return to the customer (Fig. 9). The activity information is recorded in the system and is accessible in a simple and transparent way to the user through the application accessible from the same QR code of the device.

“Matera Inerti” case study

A further example of productivity improvement and production quality through industry 4.0 technologies is the case study of the Matera Inerti company, a company that operates in the mining and ready-mixed concrete sectors, particularly suited to innovation, research, development, and training 4.0 [22].

The Matera Inerti 4.0 app allows employees and accredited customers to access in an agile way and by scanning a QR code associated with a 4.0 machinery, relating to the washing of concrete mixers with relative wastewater recovery in a green compliance perspective, to interact in an autonomous and automated way with it [11].

Once the QR code has been scanned on the corporate Wi-Fi intranet, you can safely access an interface that guarantees the control and monitoring of the machinery, view reports on your uses, or plan your business and view your current programs [41] (Fig. 10).

The interconnection of the application with the PLC takes place through the OPC UA protocol [27]. The application allows you to ensure perfect integration of the machinery with the company supply chain. In fact, the system allows you to associate a washing activity of a concrete mixer to a specific customer (the customer can coincide with the supplier in case of use of the plant for their own

Fig. 9. Maintenance screen and registration confirmation message (in the Italian language).

company vehicles), determining in what state their planned washing activities are reading the variables of the machinery, temporally certifying the activities with the automation of the communication to the customer and the supplier of the status of the end of activity through the app and e-mail notification. Of considerable importance is the interconnection section that allows you to read and write the PLC variables with an intuitive HMI interface, allowing the user to see the status of the machinery in real time to analyze the work in progress and intervene if you wish change the state of the machinery [39] (Fig. 11).

In this way, it was possible to finalize a piece of machinery useful for its business process of transporting concrete, with a view to providing a new service, as the machinery has become a new tool of competitive advantage allowing the customers surveyed to be able to benefit from the washing service of the own concrete mixer in compliance with regulatory and green compliance. All this by integrating into the weighing services, supply of aggregates and concrete belonging to the company, and certifying their activities in compliance with the procedures of the corporate 231 organizational model [40].

"Derado" case study

In this section, we will analyze the case study of Derado Srl, a company that operates in the distribution of frozen products. The treatment of food products forces the company to respect high standards of safety and certification of the process phases. Frozen products are subjected to a freezing process to bring the temperature down to -18 °C or, in some cases to even lower temperatures. Once it is frozen, the product must be transported using appropriate means and techniques to preserve its quality. This is where the 'Cold Chain' comes in. The purpose of the cold chain is to preserve the product in the best possible way, to guarantee its integrity, hygiene standards, and food safety. It is in the interest of all operators, i.e. producers, transporters, and distributors, to guarantee the quality of the product and thus respect the cold chain [36]. For this reason, each of them is called upon to follow the current regulations and to use the tools at their disposal to check that the procedures are carried out correctly [26].

One of the most important steps in maintaining the cold chain is certainly the moving of products and pallets from the distributor's cold storage to the end seller's cold storage. During this phase, the products leave the distributor's cold store and are loaded onto appropriately refrigerated vehicles. Product loading operations are therefore the ones exposed to the greatest risk with regard to the integrity of the cold chain [35]. The company has two different areas: the cold rooms, where the products are stored, which are located on the ground floor, and the loading area for outgoing goods, which is located on the -1 floor. The two areas are connected

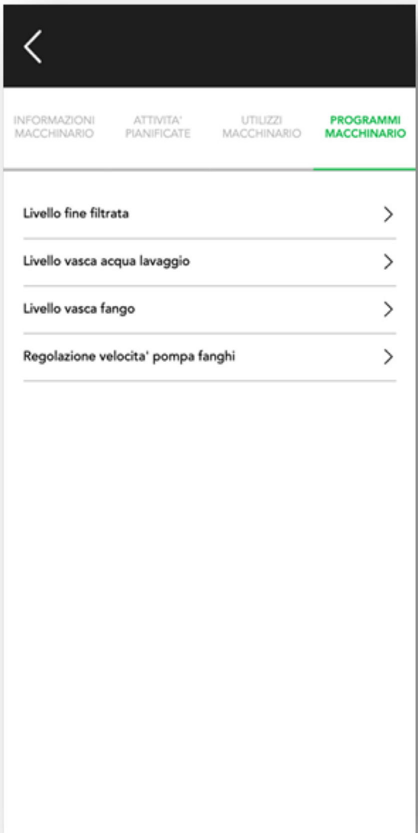

Fig. 10. Machine programming screen (in the Italian language).

by a device (elevator/descender) that allows pallets to be moved from the cold storage area to the goods loading area (Fig. 12). To ensure better control over the loading operations and minimize the time frozen products are exposed to higher temperatures, Derado has interconnected the device to the company's information system, integrating it into the logic of the computer system that manages warehouse operations. Through this connection, it was possible to add a smart functionality that will allow the device to lower the pallet into the loading area only when a series of events controlled by the MES occur.

Every day, the list of pallets is loaded from the warehouse into the MES, with their associated carriers, to be moved from the cold stores to the loading area and finally transported by carriers using a refrigerated truck to the final recipients. Once they arrive at the plant, the carriers use an app to notify the warehouse of their entry into the plant. The entry and exit operations are tracked within the software and verified by acquiring the position via the GPS (global position system) of the device. After logging in, the carrier is shown a waiting screen with a list of the pallets it will have to load on that particular day. When it's time to send a pallet to one of the waiting carriers, the warehousemen physically load the pallet at the entry point of the conveyor belt (PS1) and use the software to assign the downward-facing pallet to the reference carrier. Before the integration of the descender, it would have been possible to send the pallet to the lower level without being sure that the carrier was ready to start loading. Thanks to the communication between the descender and the MES system, the descent operation will only be activated when the carrier indicates through the app that it is ready to receive and load the pallet. Once the pallet has been delivered to the lower level, the carrier can pick it up from the last position on the conveyor belt (PI1) and load it onto the vehicle. At the end of the loading operation, the carrier uses the application to notify that the loading has taken place and returns to the waiting state until a new pallet is assigned. By monitoring the positions on the conveyor belt, it is also possible to inform the waiting carriers about the list and about the correct order of pallets moving on the lower stations (PI4, PI3, PI2) on their way to the final position on the conveyor belt, which coincides with the pick-up point (PI1).

The use of the descender connected to the computer system has in fact made it possible to create a certified log with the times of descent/loading start and loading completion of the pallets in order to accurately assess the maintenance of the cold chain and guarantee to end customers the good quality of the product (Fig. 13).

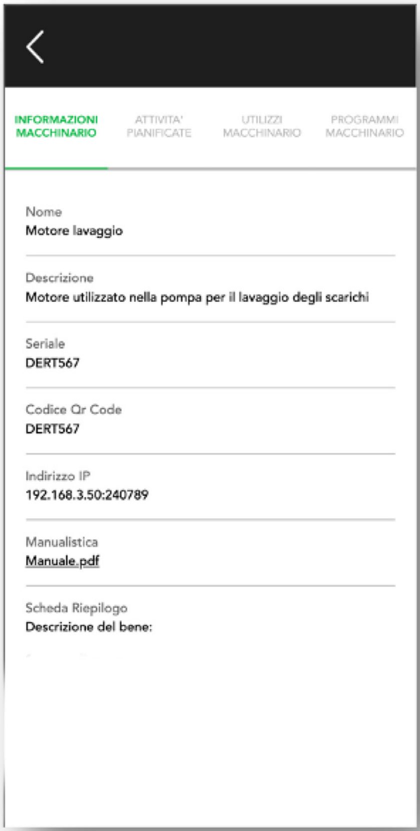

Fig. 11. Interconnection screen (in the Italian language).

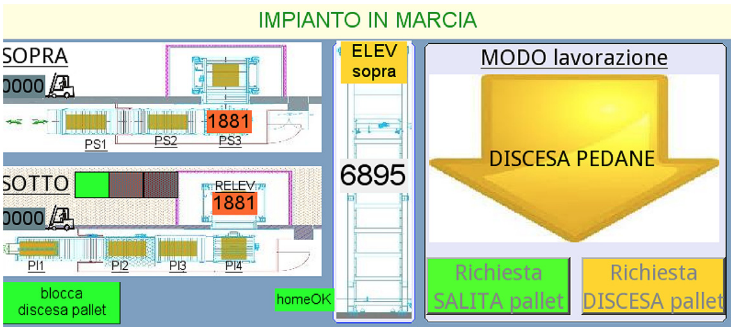

Fig. 12. Scheme of descender positions: PS1 first station upper floor/loading point, PS2 and PS3 upper floor stations, lift, PI4, PI3, PI2 lower floor stations, PI1 last station lower floor/loading point (in the Italian language).

Final remarks

This paper provided a concrete focus on the problems of interconnection and automated integration of 4.0 machinery considering the related solutions through practical case studies. In particular, when it comes to the industrial sector, the current scenario was analyzed in terms of both technological and regulatory aspects. Regulatory aspects are to be considered fundamental in the perspective in which companies investing in digitization want to use the aid and credit instruments put in place by various governments. To meet the requirement of bidirectional interconnection, a framework that makes it possible to dialogue with machines that meet determined requirements has been developed. Thanks to its web API, it allows us to have a layer that is practically compatible with all kinds

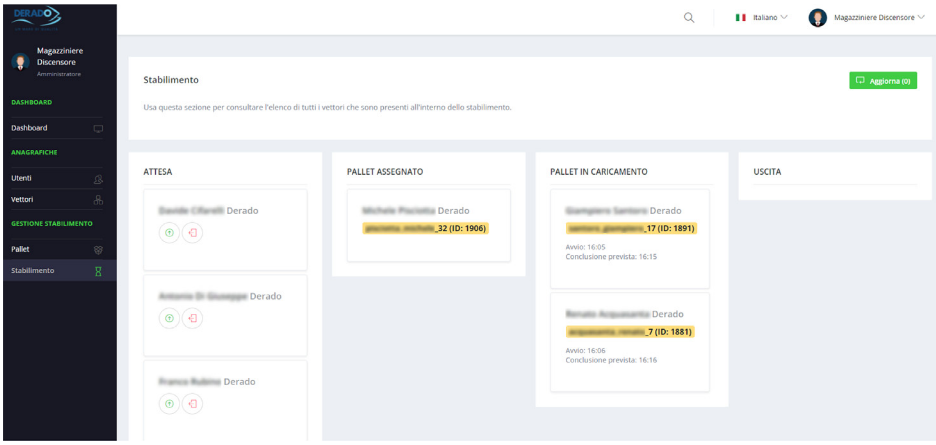

Fig. 13. Dashboard used by warehouse operators for moving the pallets. The first column shows the waiting carriers, the second column the pallets descending towards the loading zone, the third column the pallets being loaded, and the fourth column the outgoing carriers (in the Italian Language).

of applications. Finally, in order to meet the requirement of automated integration, different case studies were presented where the previously elaborated framework was applied and software solutions were developed to meet the needs of the production process of the various companies. All cases presented successfully showed an improvement in the production process and/or in quality standards through the use of digital solutions and 4.0 machinery.

The work neglected the additional features such as remote maintenance and the presence of cyber-physical systems as they are normally satisfied in the real contexts analyzed. We hope that this approach can be helpful to machinery manufacturers and companies in order to benefit from the significant potential of the 4.0 world beyond the mere economic benefit.

Ethics statements

All data used was taken anonymously. The authors abide by MethodsX journal ethics guidelines.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Diego Sinitò: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Software, Validation, Formal analysis, Data curation. **Vito Santarcangelo:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Software, Validation, Formal analysis, Data curation. **Filippo Stanco:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Software, Validation, Formal analysis, Data curation. **Massimiliano Giacalone:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Software, Validation, Formal analysis, Data curation.

Data availability

Data will be made available on request.

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