Process Automation and Monitoring Systems Based on IIoT Using Private LoRaWAN Networks: A Case Study of ArcelorMittal Vega Facilities

Danilo Farias de Carvalho[a] and Charles Christian Miers[b]
Graduate Program in Applied Computing (PPGCAP), Santa Catarina State University (UDESC), Brazil

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Abstract: The Internet of Things (IoT) is increasingly pervasive and ubiquitous in various areas. The industry is incorporating intelligence into its processes through the Industrial IoT (IIoT). However, availability and performance issues may limit IoT usage on the shop floor. Several IoT and IIoT initiatives can be applied on the factory floor to improve processes, also allowing the inclusion of less reliable equipment. Thus, there are several implementation approaches, wireless being the most used one due to its deployment flexibility and centered management. We analyze a real shop floor environment, identifying opportunities for using IIoT systems and equipment such as Long Range Wide Area Network (LoRaWAN) technologies. Our results show the possibility of improving process automation and monitoring using simple IIoT devices in Small and Medium Enterprises (SMEs) still far from Industry 4.0 level.

1 INTRODUCTION

The Operational Technology (OT) is an area known for being conservative (Wollschlaeger et al., 2017), and often dilatory related to more intensive Information Technology (IT) usage on shop floor. Recently, IT and OT have been converging in a way they are often part of the same department, and may share physical resources, including cyber and physical manufacturing spaces (Cheng et al., 2018). The advent of Industry 4.0 allows for a greater technological integration between processes, in which it is possible to have more intelligent sensors and actuators with the support of Industrial Internet of Things (IIoT) (Sauter et al., 2011a). Furthermore, fifth-generation Wireless (5G) technology adoption allows to intensify new possibilities of IIoT usage on shop floor to be evaluated and studied. Based on a list of requirements and a compliance analysis, assessing which technologies can be used to integrate legacy systems is possible. Since performing this type of integration can bring some complexity, depending on how it is realized. Thus, it should consider how the associated legacy system was designed, what technologies were used, whether there is adequate documentation, etc. Furthermore, it is also necessary to identify the problem of OT to integrate simple to complex processes, and there must have a way of communicating to form systems.

There are several possibilities for using process automation and monitoring to bring information from the shop floor to the computational clouds. Therefore, searching for case studies showing the feasibility and benefits of low-cost IIoT equipment with Long Range Wide Area Network (LoRaWAN) is relevant to encourage its wide adoption. We emphasized here that mission-critical equipment that can cause human harm is not the focus of our study and already has an extensive literature.

We analyzed a real shop floor environment, categorized it, and identified opportunities to use IIoT systems and equipment. Moreover, we adopted the LoRaWAN private networks to identify whether these are adherent to the scenario of this study.

This work is organized as follows. Section 2 presents the fundamentals. Section 3 enlists key characteristics of industrial automation and Industry 4.0, IIoT, and LPWAN. Section 4 presents how the industrial systems are divided based on ISA-95 Model. Section 5 briefly lists the main reasons for evolution concerning to automation. Section 6 presents and evaluates the ArcelorMittal Vega environment, expos-

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[a] https://orcid.org/0000-0003-3992-5484
[b] https://orcid.org/0000-0002-1976-0478

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ing our case study details. Section 7 describes our implementation and identified results.

2 FUNDAMENTAL CONCEPTS

Automation is a reality being incorporated more and more, both in homes (also known as domotic automation or *smart house*) (Flores et al., 2018), (Giorgetti et al., 2008), as in industries (Sauter et al., 2011b). In this context Internet of Things (IoT) emerged as a way to enable interaction mainly between devices that until then was essentially between people and devices (Hassan, 2018). The IoT concept was used very broadly, with several residential use cases and cities, but industrial use was slower due to legacy systems (Choi et al., 2018). Thus, industrial automation has occurred for several generations and comprises the types of devices and the networks used to connect the devices.

The evolution has led the industry to the concept of IIoT, which is the use of IoT with industrial requirements, including in spite of the shop floor. Aiming at a parameterization and organization concerning what is performed by OT, IIoT is organized in several levels defining fundamental aspects of operation and their operational requirements.

Both IoT and IIoT have accelerated adoption. While in some cases, there is the only change from older legacy systems, there are several new opportunities for new applications and the need to integrate the new possibilities with the already installed base. According to estimates from International Data Corporation (IDC) (Reinsel et al., 2018), there will be 41.6 billion “connected things” in 2025. At first, IoT integrates a network of physical objects with a series of sensors connected with the possibility of exchanging information with other devices using the Internet as a path. The applicability of this type of solution since domestic applications, through companies in various segments, medical applications, industrial applications, etc. For a device to be considered intelligent, it is not enough to be connected to the Internet. Developing conceptual applications or prototypes on some device (e.g., Arduino, ESP8266, or ESP32), to remotely turn on a light, read sensor data or start a small motor can be considered a good way of learning, but this does not mean you have a smart device and it is a simple device connected using the Internet. When some sensors and software interpret this data and add an ”intelligence” layer to the processing, there will be a real application of IoT.

Industrial IoT or IIoT refers to the application of IoT technology in industrial environments, especially regarding the instrumentation and control of sensors and devices involving cloud technologies. Some branches of industry are currently looking for Machine to Machine (M2M) type communication to achieve wireless automation and control. The emergence of cloud computing (whether public or private) and other technologies (e.g., advanced analytics and Machine Learning (ML)) allow different sectors to reach a new layer of automation, being able to create new revenues and business models. The IIoT also defines the set of technologies and services, allowing devices, computers, and smart objects to be interconnected through the Internet. The IIoT is often associated with Industry 4.0. However, a factory or production process that only has IIoT cannot be considered as belonging to Industry 4.0. Besides technologies such as Big Data, IoT, and cloud computing, it is possible to reduce costs and make production more automated and autonomous (Mohamed, 2018), contributing to the overall result of the company. Another aspect is the industry has specific requirements that must be highlighted, such as performance requirements in IoT / industrial automation services, which can be subdivided into:

1. Motion Control: Category that includes continuous processes as in some steel industries, speed variation of conveyors, painting systems, etc.;
2. Mobile Robots: Robotic control can be static (e.g., assembly line), or autonomous; as well as camera systems and cooperative motion systems;
3. Mobile Control Panels with Safety Functions: Overhead cranes, systems that monitor safety zones (e.g., NR 12 - Safety at Work in Machinery and Equipment - Used in Brazil), robotic arms; and
4. Process Automation / Monitoring: Supervision and control systems of a process in which sensors and actuators can be read.

An industrial plant integrates several automation systems, e.g., measurement systems, welding machines, etc. Thus, heterogeneity is part of this reality. Table 1 lists and categorizes the central industrial automation systems, taking into account important requirements (Brown et al., 2018), covering the main systems in any industrial plant.

Table 1 performance criteria (Brown et al., 2018):

1. Service Availability: It is the percentage of availability of an end-to-end type of communication;
2. Cycle Time and Latency: Refers to the maximum time allowed in communication, in which the time of sending a command to the actuator or requesting a sensor reading until the return of the execution confirmation; and

Table 1: Industrial Automation Performance Requirements / IIoT Requirements.

Use Case (High Level)		Availability	Cycle Time	Typical Payload Size	Number of Devices	Typical Service Area
Motion Control	Printing Machine	>99,9999%	<2ms	20 bytes	>100	100m x 100m x 30m
	Machine Tool	>99,9999%	<0,5ms	50 bytes	~20	15m x 15m x 3m
	Packaging Machine	>99,9999%	<1ms	40 bytes	~50	10m x 5m x 3m
Mobile Robots	Cooperative Motion Control	>99,9999%	1ms	40-250 bytes	100	<1 km^2
	Video-Operated Remote Control	>99,9999%	10-100ms	15-150 bytes	100	<1 km^2
Mobile Control Panels with Safety Functions	Assembly Robots or Milling Machines	>99,9999%	4-8ms	40-250 bytes	4	10m x 10m
	Mobile Cranes	>99,9999%	12ms	40-250 bytes	2	4m x 60m
Process Automation (Process Monitoring)		>99,99%	>50ms	several	10.000 devices per km^2	

3. Service Area and Density: Indicates whether the desired performance has been achieved and the number of devices within a predefined area.

Compliance with the mentioned criteria will directly impact ”how” the automation system will be designed, built, and maintained. The time cycles criterion can determine the level of hardware or redundancy required for the automation system. If the system is monitored only in a process in which there is no risk to human safety, equipment safety, or the environment, the level of redundancy may be lower. The intensification of the use of industrial networks, replacing the old serial communications (e.g., RS232, RS422, RS485, etc.), and the need to transfer data from the lowest levels to the highest levels in convergence to the ISA-95 standard has become even greater (Hood, 2015).

3 INDUSTRIAL AUTOMATION

Process automation, also known as industrial automation, is an area known to be conservative (Wollschlaeger et al., 2017), and sometimes even reactive in using IT resources. However, conservatism impacts finances or the necessity of a complex infrastructure. In this context, there is a need to interconnect devices through communication networks that may be similar, or even the same type, as the networks used in IT. It is an important highlight among the various possibilities of shareable resources: networks (wired, wireless, etc.), data centers, servers, databases, monitoring systems, clusters, storage systems, support teams, etc. The advent of Industry 4.0 promoted a technological integration between processes is proposed, in which it is possible to have improved sensors and actuators supported by IIoT (Sauter et al., 2011a). Therefore, a fundamental issue is the role of communication networks, whether they originate in IT or OT; in the end, these are technologies, and they must contribute to the evolution of society. The purpose of technology is not found in itself but in what it proposes to do with it.

Industry 4.0 has some characteristics and provides some resources. Still, suppose a company has one of them. In that case, this does not indicate that such a company is in this category, as a comprehensive analysis of the technologies and processes involved is necessary. Some authors (Mohamed, 2018) have grouped and highlighted the following characteristics: Autonomous Robots, Simulations, Systems Integration, IoT, Cybersecurity, Cloud Computing, 3D Printing, Augmented Reality, and Big Data. The expected benefits of applying the concept of Industry 4.0 are: Cost Reduction, Energy Savings, Increase in Security, Environmental Conservation, Error Reduction, End of Waste, Business Transparency, Increase in Quality of Life, Unprecedented Customization, and Scale. Even though some essential technologies emerged during the Industry 3.0 phase (e.g., Internet, mobile telephony, and cloud computing), they are still part of the Industry 4.0 basis (Colombo et al., 2021).

Industry 3.0 will continue to be relevant for a long time, not only because it has elements composing the Industry 4.0 basis; but also because there is a whole legacy that cannot be replaced in a short time (Iyer, 2018). The change from Industry 2.0 to Industry 4.0 in a single step is practically unfeasible, being a ”step by step” approach most suitable, investing in equipment from the beginning will bring a gain in scale (e.g., robots, etc.), which will allow the company to enter Industry 3.0, and new or modernized equipment will also serve at the time of migration to Industry 4.0, reducing the technological leap (Iyer, 2018).

3.1 IIoT

IIoT technology is an integral part of Industry 4.0 and can be considered a means for this transition (Pilsan et al., 2019). Thus, defining the set of technologies and services allows interconnecting devices, computers, and smart objects through the internet or industrial network. One of the features inherited from IoT, and which can be very useful in the industry, is the possibility of communication between devices and the collaboration between them M2M (Da Xu et al., 2014). Several companies in Brazil are still in Industry 1.0 and Industry 2.0, and it will take some time to replace these legacy systems; in this way, new approaches arose, and driving characteristics of IIoT can help in the evolution of these systems. As an example, some micro-controlled devices serving as gateways or remotes for Programmable Logic Controller (PLC)s in the field, based on IoT technologies (e.g., ZigBee, LoRaWAN, ESP32, ESP8266, RaspBerry Pi, among others). These can also contribute to raising the level of monitoring of an industrial process. In companies where industrial automation is already in Industry 3.0, the applicability of IIoT can be observed in different contexts, whether in a traditional automation system or in the integration with the cloud, Edge Computing, and Smart Factories, among others. The possibility of having the processing at the end devices (i.e., in the sensors themselves) and that these can be connected in the private enterprise cloud, processes like the evaluation of a stock, or production order, can be initiated or have a certain level of monitoring without human intervention. An area that can also benefit from IoT and IIoT is prescriptive maintenance, which is one in which you can calculate and estimate the ideal time to be performed with a high level of reliability; being a smarter approach, it combines the detection of equipment degradation, with statistical models already consolidated (Choubey et al., 2019), and later with the introduction of Artificial Intelligence (AI) and Machine Learning (ML). Thus, it can also take advantage of IIoT, with the implementation of sensors and wireless networks, using devices with a lower cost than those existing in traditional architecture with PLCs; and in this way, generating historical data which are essential to understand the ”behavior of a production process”, including in terms of maintenance. A model refined with such statistical data, and forecasting techniques can provide users with options regarding corrective measures (MATTIOLI et al., 2020).

3.2 LPWAN

Low Power Wide Area Networks (LPWAN) is a generic term for a group of technologies allowing long distances communications, low cost, and reduced energy consumption (Lin et al., 2017). LPWAN is suitable for IoT applications that need to transmit small amounts of information over a certain distance. The IoT market has expanded rapidly, and technologies based on LPWAN can be used in a wide variety of scenarios. Several technologies LPWAN represented in Figure 1 emerged in licensed and unlicensed markets (e.g., Long Term Evolution (LTE)-M, SigFox, Long Range (LoRa), and Narrowband Internet of Things (NB-IoT), etc.).

LPWAN can cover distances between 10km and 40km in rural areas and between 1km to 5km in urban areas (Mekki et al., 2019). An important characteristic of LPWAN is that they work in the Sub-Ghz bands, directly impacting their ability to overcome obstacles. As a LPWAN technology, it significantly improves the power consumption of IoT and IIoT devices, with a battery life of around ten years. It also has spectrum efficiency, especially in indoor coverage, as it belongs to a *Sub-Ghz* (Mekki et al., 2019) category. Table 2 shows some characteristics of LPWAN technologies in evidence in IoT and IIoT.

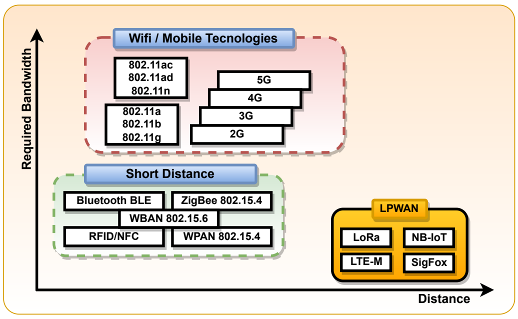

Figure 1: Bandwidth Required vs. Reached Distance.

Table 2: IoT Technologies - Characteristics.

Standard	802.11	Bluetooth Low Energy (BLE)	ZigBee Pro	SigFox	LoRa	LTE-M	NB-IoT	5G
3GPP Adherence?	No	No	No	No	No	Yes (Release 13)	Yes (Release 13)	Yes (Release 15)
Coverage Area	17 - 30 (m)	∼1 - 50 (m)	∼1 a 250 (m)	<12 (km)	<10 (km)	<10 (km)	<15 (km)	<12 (km)
Spectrum / Bandwidth	2.4 Ghz (802.11)	2.4 Ghz (802.15.1)	2.4 Ghz (802.15.4)	900 Mhz	900 Mhz	7 - 900 Mhz	8 - 900 Mhz	5 - 900Mhz (entre outras)
Baud Rate	450 (Mbps) (802.11n)	1 (Mbps)	250 (kbps)	∼100 - 600 (bps)	∼200 - 50 (kbps)	<1 (Mbps)	<144 (kbps)	∼10 (Gbps)
Cost	4.00 USD (2016)	4.00 USD (2016)	3.00 USD (2016)	4.00 USD (2015) 2.64 USD (2020)	4.00 USD (2015) 2.64 USD (2020)	5.00 USD (2015) 3.30 USD (2020)	4.00 USD (2015) 2 - 3 USD (2020)	<2.00 USD
Latency	20 - 40 (ms)	6 (ms)	40 (ms)	1 - 30 (s)	61 - 371 (ms)	50 - 100 (ms)	1.6 - 10 (s)	5 - 50 (ms)
Security	256 bits	128 bits AES	128 bits	16 bits	32 bits AES-128	3GPP 128 - 256 bits	3GPP 128 - 256 bits	3GPP 256 bits

Evaluating the data in the Table 2, when there are long distances for industrial applications, some of these can already be discarded (e.g., IEEE 802.11, BLE and ZigBee) for not fit this requirement.

4 IIoT SCENARIOS, PROBLEMS, CHALLENGES, AND OPPORTUNITIES

A traditional representation or classification regarding systemic levels within an industry is the ”Automation Pyramid”, based on the The International Society for Measurement and Control (ISA) model, the ISA-95 (Hood, 2015). Each specialty (or level) is represented by a layer that composes the pyramid. Figure 2 presents the concept of ISA-95 and some processes exemplifying at which levels they are and how the levels are divided not only in the view of traditional automation but also in the so-called informatics. It is also important to be concerned with issues such as network segmentation, DMZ, firewalls, etc.

This representation starts from the sensor/actuator that is in the base until it reaches the Business Intelligence (BI) systems. At each of these levels, one or more interfaces may perform the role of process integrator. Since each system can compose each level,

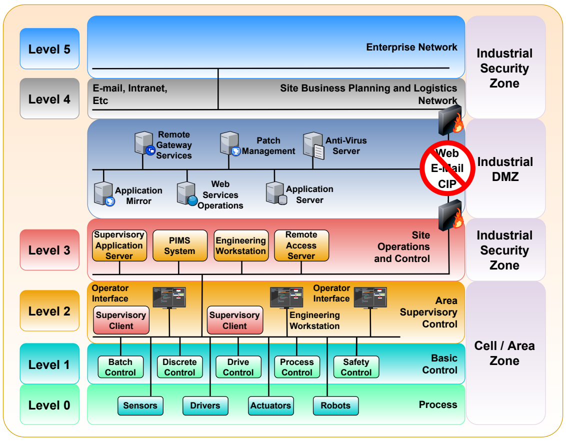

Figure 2: Automation Levels (Hood, 2015).

which can be customized and heterogeneous, different interfaces can be created for this role (Li et al., 2020).

Table 3 lists and categorizes the hierarchical levels present in the ISA-95 Model, which are present in medium and large companies / industrial plants. The difference for smaller companies may be the absence of a BI system or an Enterprise Resource Planning (ERP). ISA-95, is a widely known model and derived from ISA-88. These models are used by manufacturing companies, providing references and standards in automation, integration systems between companies and operations, and Manufacture Operations Management (MOM) (Hood, 2015). International Electrotechnical Commission (IEC) also has a widely used IEC62264 standard, which provides criteria and terminology for batch control systems, sometimes known as batch processes.

Table 3: Automation Levels - ISA-95 Model (Hood, 2015).

ISA Levels	Activities	ISA Name	Type of System	Example
Level 5	Business Intelligence	BI	BI	
Level 4	Business-related activities needed to manage a manufacturing organization	Enterprise	ERP, CRM	ERP, CRM, Logistics
Level 3	Activities of the work flows to produce the desired end products	Site, Area, Work Centre, Work Unit	MES. LIMS, CMM	City X Plant, Cookie Making Area, Cookie Packaging, Line Work Center
Level 2	Activities of monitoring and controlling the physical processes	PLC	HMI, SCADA, Batch Systems	Process Optimization, Mathemathical Model
Level 1	Activities and sensors involved in manipulating the physical process	Device, Control Model	I/O, Devices, Sensors	Cookie Wrapper Paper, Tension Measurer
Level 0	Physical Process	Equipment		Cookie Wrapper

Table 3 not only exemplifies how the systemic levels division but also groups types of systems and some examples. ISA-95 model is the reference to process automation. This division of levels of industrial informatics includes the segregation of processes and functions that the applications in each level need to have, as well as an adequate level of segregation. From the point of view of information security, in some companies, firewalls are installed between the automation network and the corporate network, as seen in Figure 2. For our study, the present work focuses on the controllers and Human Machine Interfaces (HMIs) that makeup Level 1, up to the Supervisory Control And Data Acquisition (SCADA) and process optimization systems, which are part of Level 2. The challenges of data communication and it is integration from the shop floor to the cloud in a production process are already consolidated in a large company or process, or even in a smaller process, part of the same principle; and in this way, even a small process can take advantage of this integration. This study can benefit companies before Industry 3.0, and IoT and IIoT can contribute to this process. Exploring a little more these factors, regarding the problems and challenges, essential features can be grouped into 8 groups ((Technologies, 2019), (NetSuite, 2020), (Artemenko, 2021) and (Jayalaxmi et al., 2021): Interoperability, Reliability, Security, Performance, Management, Storage, Scalability, and Change Mindset.

5 PROBLEM DEFINITION

An industrial plant consists of integrating several automation systems, and heterogeneity is one of its characteristics. Regarding the project, management and technical/economic feasibility are the same regardless of whether a project is automated or not. Thus, if the project is not motivated by legal or safety issues, such a project needs to be ”attractive”. The automation of a production process in a traditional way from scratch, known as (*greenfield*), or even a reform (*brownfield* - also known as *revamp*), can demand engineering, in several specialties, such as: electrical, mechanical, civil, automation, metallic structures, etc. In the case of a *revamp*, there is the additional risk that if the renovation is not carried out within the stipulated deadlines, it may cause damage to a production line that was previously producing (i.e., operational and financial stability problems). When an industry decides to automate it is functions, the motivator is commonly different from types of processes (Autor, 2015):

1. Operation: Improvement of operating conditions, which includes possible technical feasibility;
2. Quality: Product quality, that is, manufacturing in narrower error tolerance bands, using efficient quality control;
3. Safety: Physical integrity of human beings and/or equipment;
4. Flexibility: Easily and quickly allow changes in the parameters of the manufacturing process;
5. Regulatory: When there is a new regulatory standard or the revision of an existing one;

6. Productivity: Efficient use of raw materials, machine time, personal availability, etc.; and
7. Control: Increase the level of process control, generation of statistical data, reports, Key Performance Indicators (KPIs), etc.

However, some questions emerge: (i) What to do when an automation project is necessary but not economically viable? (ii) When does a company of type Small and Medium-sized Enterprises (SME) have budget constraints? (Powell et al., 2013) state SMEs face financial and resource difficulties in acquiring new technologies, one of the reasons why these companies still behave cautiously in this matter. The present work aims at a real case study to analyze how IIoT can contribute to production lines where there is a low level of automation and may not have financially attractive. This case may be what happens in SMEs; in this way, our study can be useful for this industrial segment and those companies or processes before Industry 3.0.

6 PROPOSAL

For the evaluation of a case study and Proof of Concept (PoC), a real production environment was chosen at the company ArcelorMittal (https://brasil.arcelormittal.com/en) Vega located in the city of São Francisco do Sul - Brazil, one of the most modern flat steel transformation units in the world at the time of its startup, but after years it has legacy systems. Standing a total production capacity of 1.6 million tons/year of pickled, cold-rolled and hot-dip coated coils, it mainly serves the automotive, home appliance, pipe production, and civil construction industries. During the analysis phase, the main automation systems in all production lines were evaluated, including the systems considered as ”auxiliaries”. All data were tabulated and classified according to Table 1. Thus, Table 4 was created, which is a sample. Other characteristics were also evaluated (e.g., servers, controllers, remotes, actuators, database, etc.).

The grouping represented in Table 4 evidenced the most predominant characteristic is the ”Automation / Process Monitoring” systems; therefore, this was chosen for the present analysis. In quantitative terms, 23 different types of automation systems were cataloged, and more than one production line can have the same system. Thus, in this case, this was counted as just one. Within this category, approaching the vision of industrial automation, the following characteristics can be highlighted as essential for the types of industrial processes evaluated: (i) Availability in the order of 99.99%; (ii) Cycle time (also called ”scan”), on the order of 50ms; and (iii) High number of devices per km^2. Figure 3 shows the distribution of the categories we observed within the analyzed industrial park.

Table 4: Case Study: Fragment of Study Environment.

System	Description	Factory	Network	Protocol	Category	Sub-Category
CCK	Energy and utilities monitoring system	All	Ethernet	TCP	Process Automation / Process Monitoring	
Eurotherm	Dew point monitoring system	BAF, SPM and RCL 1	Ethernet	Modbus TCP, OPC	Process Automation / Process Monitoring	
Byond	Zinc ingot management system	CGL 1 and CGL 2	802.11	TCP, Zigbee and MQTT	Process Automation / Process Monitoring	
AMPTEM	Cold strip mill bearing monitoring system	TCM	Ethernet	Zigbee	Process Automation / Process Monitoring	
ViWPD	Vision system for online width measurement	CGL 1	Ethernet	TCP, OPC	Process Automation / Process Monitoring	
Thickness Gauge	Online coil thickness measurement system	CPL,TCM, CGL 1, CGL 2 and SPM	Ethernet	TCP (IP and UDP Messages)	Process Automation / Process Monitoring	
Coating Gauge	Online coil coating measurement system	CGL 1 and CGL 2	Ethernet	TCP (IP and UDP Messages)	Process Automation / Process Monitoring	
ASIS	Vision system for online defect detection	CGL 1	Ethernet	TCP (IP and UDP Messages)	Process Automation / Process Monitoring	
Dross Robot	Stationary robot for zinc pot cleaning	CGL 1 and CGL 2	Ethernet	TCP (IP and UDP Messages), OPC	Motion Control	Machine Tool
Coil Marker	Coil marker - alphanumeric texts and barcode	CGL 1 and CGL 2	Ethernet	TCP (IP and UDP Messages)	Motion Control	Printing Machine
Mobile Cranes	Overhead cranes for coil handling	PIMS	802.11	OPC, TCP (IP and UDP Messages), Profibus	Mobile Control Panel with Safety Functions	Mobile Cranes

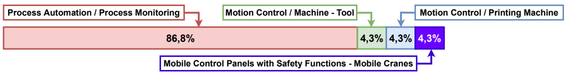

Figure 3: Observed Distribution.

The data stratification presented in Table 4 in it is a complete version and is also presented in Figure 3, describing how automation/process monitoring stands out when compared to the others areas. In addition, the four areas of Table 1 are represented. Based on the analyzed data, some existing systems are adherent to be connected in wireless networks on the shop floor (IEEE 802.11x), a characteristic observed in IIoT approaches. A highlight during the data analysis was that even in a company of this size, there are non-automated processes; and, thus, are not contained in the tabulated data. Based on the analyzed items, coil yards (in their various types) are among the items with no monitoring systems. When analyzing Figure 4, it can also be observed that the yards have large areas and with movement or occupation of coils. Figure 4 shows a coil dispatch yard (aka finished product), which can be found in steel mills, service centers (e.g., coil processing), and even in customers who purchase such reels.

One of the characteristics of the highlighted processes that do not have any level of automation is that they are slow processes and occupy large areas. In this way, the LPWAN technology can contribute to this automation, as it can cover a large area when choosing to use LoRaWAN type networks. A process, as presented in Figure 4, has low systemic integration and high monitoring potential, including communication with existing PLC and with the Manufacturing Execution System (MES) and Warehouse Management System (WMS) system, which are systems of Level 3 systems, according to the ISA-95 model. To carry out our Proof of Concept (PoC), the smallest infras-

Figure 4: ArcelorMittal Vega Coils Warehouse.

tructure for the point-to-point connection in a wireless network may be the most suitable. In addition, there are System on a Chip (SoC) type microcontrollers, which already have the LoRa network built in, along with the antenna and place for installing a rechargeable battery. In terms of infrastructure for automating this process in a traditional model, there is a need for passing cables, assembling metallic structures and/or mechanical structures (e.g., trays), a need to remove interference (e.g., when it is necessary to build something of civil engineering, but cables or pipes are passing through the same place), among others. Figure 5 shows our process proposal for the PoC.

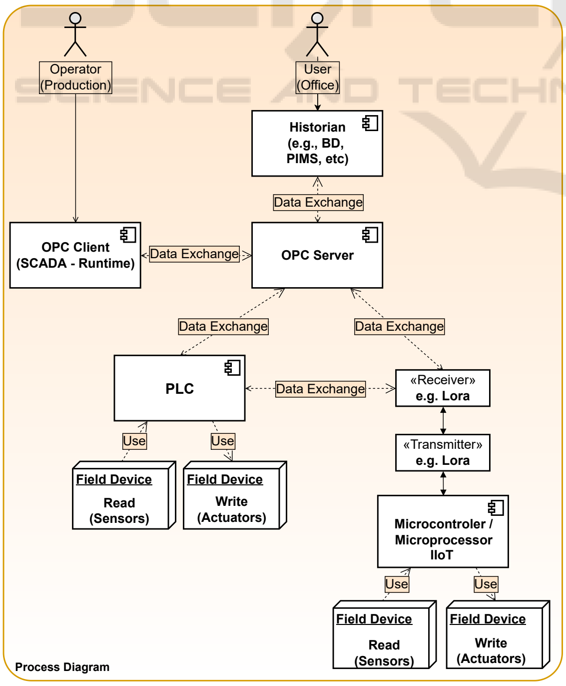

Figure 5: PoC - Process procedures - Static Vision.

Figure 5, shows a PoC using a microcontroller to receive/send data and integration with an automation system. The architecture includes important systems and communication protocols such as OLE for Process Control (OPC) Server, OPC Client, Historians, Database, Fieldbus, etc. The use of OPC communication as middleware also opens up the possibility for data to be sent to any part of the internal or external network (e.g., cloud computing), as well as communication to any other automation system, such as Plant Information Management System (PIMS), Supervisory, SCADA, etc. OPC communication is one of the most used forms of communication in industrial automation, but this is not the only one. For the same proposed scenario for PoC, a *socket* communication (TCP or UDP), IPC, HTTP, REST, XML , among others, could also be used without the need for changes to the architecture. The process proposed in Figure 5 is the representation of the area of interest to be developed in PoC, and which is highlighted in Figure 6. This area of interest (Section 5), in which the focus is on communication and processing at Level 1, Level 2, and communication with Level 3 systems according to the ISA-95 model (Table 3).

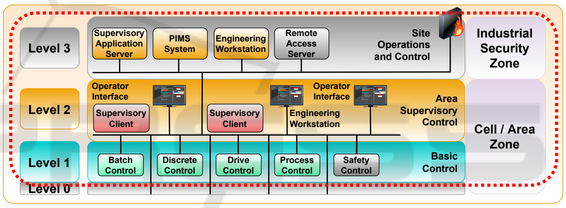

Figure 6: PoC - Process architecture.

Figure 7 graphically exemplifies the sequence of events in a process like this and the behavior of a functionality, considering the interaction between all software components and procedures related to their use. For better visualization, each process macro is represented by the color that each "System Level" received in Figure 2.

It can be seen that both figures (Figure 5 and Figure 7) are adherent to the current automation processes and that it is part of the work of (Koziolek, 2018), notations like Unified Modeling Language (UML) are used in process automation. These representations help to bring software developers closer to professionals in the business areas, with the objective of a clear understanding of the behavior that the software and the process to which it is automated must have.

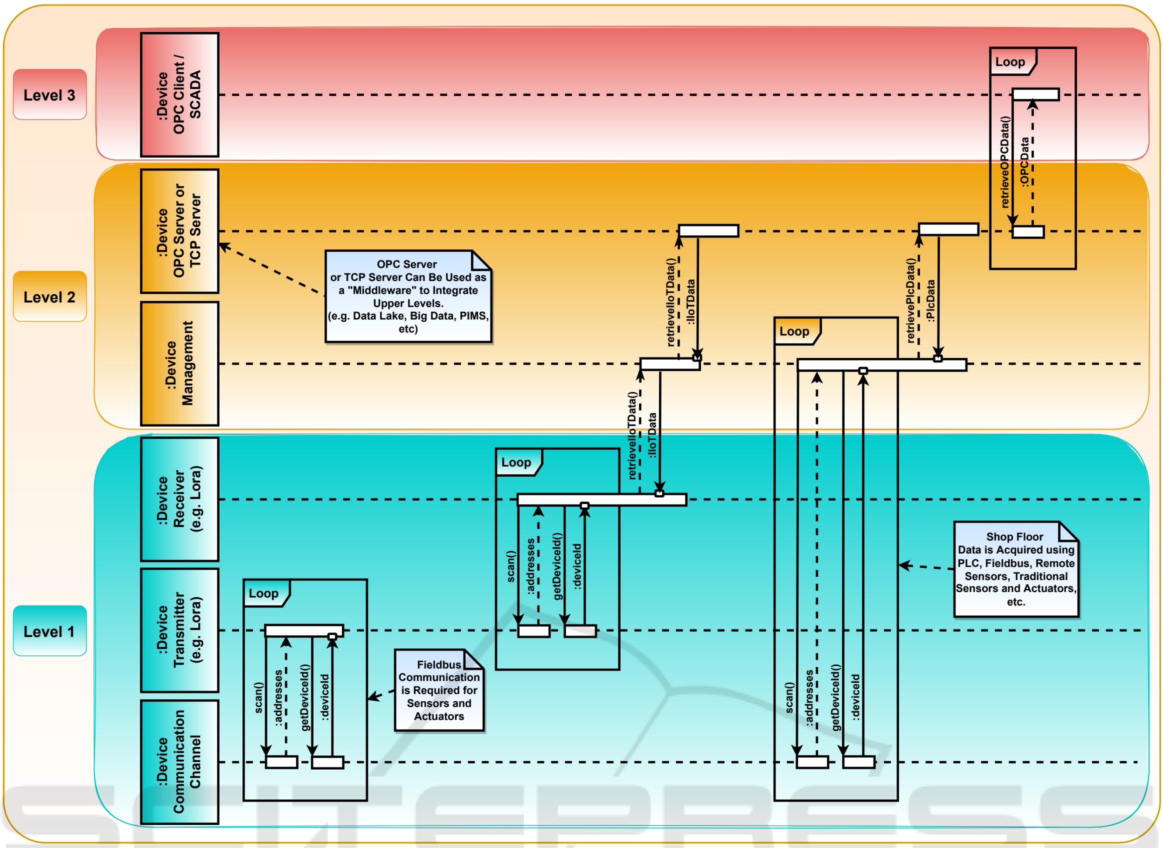

Figure 7: PoC - Process arquitecture - Dinamic Vision.

7 IMPLEMENTATION, RESULTS AND ANALYSIS

7.1 Proof of Concept

To perform the PoC, the LPWAN environment was set up using two approaches. The first concerns the use of commercial gateways and sensors developed by companies that integrate solutions and specialize in IoT; and the second concerns the use of microcontrollers of the type SoC ESP32 models with built-in radio LoRa that the authors of this work developed. This gateway has access to the LoRaWAN network of the KORE Wireless company using the platform called KORA and access to the Microsoft Azure corporate environment. To carry out this PoC ArcelorMittal Vega provided the necessary equipment and resources (e.g., LoRa gateway, network installation services, etc.). The gateway was installed above the line Continuos Galvanizing Line 1 (CGL1) at the height of 65m. The gateway received a final installation since ArcelorMittal Vega is interested in using this technology once in another unit belonging to the same group; this one had excellent results. This model is connected in an automation network using Ethernet (RJ45) cable and integration with internal antennas GPS, LTE/4G, and LoRa Radio. If necessary, the communication LTE/4G is used as redundancy. The gateway is involved in a case with Ingress Protection (IP67) protection. Concerning the technical specification for LoRaWAN communication, this gateway has 8ch RX (125kHz, multi Spreading Factor) + 1ch RX (250KHz or 500kHz, mono Spreading Factor) + 1ch RX (FSK) to get 10ch RX + 1ch TX.

7.2 Site Survey

To determine the coverage area of ArcelorMittal Vega, a coverage site survey procedure was carried out with measuring devices that indicate the quality of data transmission from a device to the gateway. Three ESP32 micro-controllers with LoRa antenna were used, one of which also had a Global Positioning System (GPS) receiver. All micro-controllers transmitted a counter, and the one with GPS also sent the location. The data was received by the gateway and transmitted to Databricks in the Microsoft Azure environment. Once the data is stored, Microsoft PowerBI allows the creation of a map with the entire scope and coverage capacity of the antenna and gateway installed. To carry out this site survey, all factories and offices were visited, including buildings and the underground of some factories. There were locations where the GPS signal was lost depending on the location (e.g., underground), but there was LoRa transmission. The measurement was considered valid in these cases, and the nearest GPS location was considered. The amount of four ESP32 micro-controllers from three different manufacturers was used (e.g., Heltec, TTGO, and Robocore), but all of them had a LoRa radio/shield. In addition to presenting the identification of each device, information related to Received Signal Strength Indicator (RSSI) is also presented, which represents the quality of the received signal (Industries, 2022), which also indicates the level of power received after any possible loss of antenna and cable, and is represented by Decibel Milliwatts (dBm). The higher the RSSI value indicates the signal strength. Information about the Signal-to-Noise Ratio (SNR) is also presented (Industries, 2022), which is an existing relationship between the received signal and the noise that accompanies this signal and which is represented by values in Decibels Relative to Isotropic (dBi). The lower the SNR, the worse the communication. An important indicator that should also be considered is the Spreading Factor (SF). This information determines the amount of data that can be transmitted, the period that information will be "over the air", the distance reached, and others (Pham et al., 2020). The specification of LoRaWAN protocol includes the Adaptive Data Rate (ADR) technology. The main objective is to adjust the SF and Transmission Power (TP) variables to balance each device's consumption and efficiency and include the control of used radio channels. Table 5 shows some characteristics of LoRaWAN technology.

Table 5: Relationship: SF, SNR, RSSI, and Payload.

SF	Required SNR (dB)	RSSI (min)	RSSI (max)	Data Rate (kbps)	Transmission Duration (sec)	User Payload (Bytes)
7	-7	0	-110	5.47	0.036	230
8	-10	-110	-113	3.13	0.064	230
9	-12.5	-113	-116	1.76	0.113	123
10	-15	-116	-119	0.98	0.204	59
11	-17.5	-119	-120	0.54	0.365	59
12	-20	-120	-123	0.29	0.682	59

7.3 Scenario

The area chosen to carry out the PoC was the production line shed called Recoiling Line (RCL)#1, which shares the space with the finished product storage yards, coil packaging, and shipping. We defined six possible scenarios, in which several aspects were taken into account, such as applicability, cost, financial return, security, scope, replicability, and transformation into a product after PoC, among others. The scenario chosen can contribute to ArcelorMittal Vega as they fully meet the company's needs. This scenario concerns the control of the environmental monitoring of the coil yard because it has low automation and because the monitored variables directly contribute to the product's final quality.

7.4 Scenario - Environmental Monitoring

This scenario is for implementing the environmental monitoring project (temperature, humidity, status of gates, and vibration) of the coil yard shed, also called finished product, packaging, and dispatch of coils. The shed environment directly influences the possibility of oxidation in steel coils. Thus, monitoring and calculating the so-called "dew point" is essential for the product's final quality. The coil and packaging yard shed has four dehumidifiers to control the ambient humidity. However, these are turned on manually and are not monitored (only lights on the control panel). Depending on the ambient temperature and climatic conditions of the industrial plant, operators decide whether to turn the dehumidifiers on/off. As there is no online monitoring for these conditions, the equipment can be turned on late or remain turned on even when they need to be in operation. The monitoring of temperature and humidity is done through manual devices. Even if they go through a certification and validation process of the Measurement System Analysis (MSA) type, which is a method that has the objective of evaluating the validity of a measurement system and minimizing external factors to the equipment that can interfere with the quality of a measurement and even the human factors; yet it is a manual process and therefore depends on the measurements being carried out at the appropriate frequencies. Another aspect is that no documentary record indicates whether the measurements were carried out and which values were obtained. The shed gates are another variable that can influence the environment, and in this way, this monitoring is also essential; because with this opening, there is the entrance of temperature and humidity which takes the atmospheric balance of the internal environment. The opening and closing of the gates occur automatically when a vehicle is 1 meter away, both in the entry and exit directions. Eventually, a gate may remain open due to some problem or other need, influencing the balance.

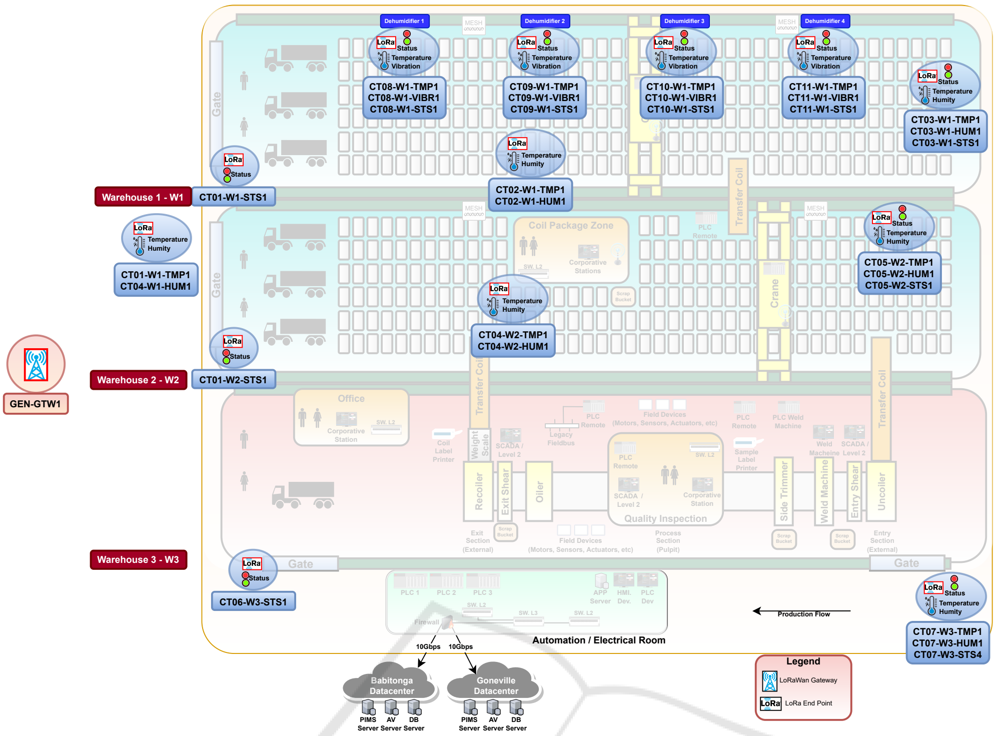

Figure 8: Coil Warehouse, Package Zone, and RCL#1 - ArcelorMittal Vega.

The dew point is the temperature at which the water vapor in the ambient air changes to a liquid state in the form of small drops by condensation, which is called dew (Lawrence, 2005). Integrating all the data mentioned will contribute to better control of this yard and reduce the possibility of generating defect arising from oxidation that brings financial damage and the company's image with customers and the market. In Figure 8, it's possible to observe the distribution of the gateway LoRa of the controllers and of the various sensors that were spread out according to the initial and final distance of the yards where the stock and packing. Figure 8 lists all the necessary hardware for the full automation of this environment using devices like the ones tested in PoC.

The sensors used are for measuring temperature, humidity, the state of the gates, as well as the state of the dehumidifiers. Each device receives an identification (tag), the same as existing in the systems that will use this information. ArcelorMittal Vega also acquired market sensors for monitoring dehumidifier motors. The model chosen is from Advantech, and the sensors are from the WISE-2410 family operating on the LoRaWAN network. The data can be visualized in a supervisory system (AVEVA InTouch) generating animation alarms and alerts to RCL#1 operators through the PIMS tool as well as in a corporate network through tools such as Databricks and PowerBI.

Table 6 relates all devices involved in this PoC are shown and its tagnames.

Table 6: Scenario - Monitoring of Ambiental Enviroment.

Tagname	Type	Location	Controler	Family
GEN-GTW1	General Gateway	Out of Warehouses	Gateway	Kerlink
CT01-W1-TMP1	Temperature	Warehouse 1	CT1	ESP32
CT01-W1-HUM1	Humidity	Warehouse 1	CT1	ESP32
CT01-W1-STS1	Status	Warehouse 1	CT1	ESP32
CT01-W2-STS1	Status	Warehouse 2	CT1	ESP32
CT02-W1-TMP1	Temperature	Warehouse 1	CT2	ESP32
CT02-W1-HUM1	Humidity	Warehouse 1	CT2	ESP32
CT03-W1-TMP1	Temperature	Warehouse 1	CT3	ESP32
CT03-W1-HUM1	Humidity	Warehouse 1	CT3	ESP32
CT03-W1-STS1	Status	Warehouse 1	CT3	ESP32
CT04-W1-TMP1	Temperature	Warehouse 1	CT4	ESP32
CT04-W1-HUM1	Humidity	Warehouse 1	CT4	ESP32
CT05-W2-TMP1	Temperature	Warehouse 2	CT5	ESP32
CT05-W2-HUM1	Humidity	Warehouse 2	CT5	ESP32
CT05-W2-STS1	Status	Warehouse 2	CT5	ESP32
CT06-W3-STS1	Status	Warehouse 3	CT6	ESP32
CT07-W3-TMP1	Temperature	Warehouse 3	CT7	ESP32
CT07-W3-HUM1	Humidity	Warehouse 3	CT7	ESP32
CT07-W3-STS4	Status	Warehouse 3	CT7	ESP32
CT08-W1-TMP1	Temperature	Warehouse 1	CT8	Advantech
CT08-W1-HUM1	Vibration	Warehouse 1	CT8	Advantech
CT08-W1-STS1	Status	Warehouse 1	CT8	Advantech
CT09-W1-TMP1	Temperature	Warehouse 1	CT9	Advantech
CT09-W1-VIBR1	Vibration	Warehouse 1	CT9	Advantech
CT09-W1-STS1	Status	Warehouse 1	CT9	Advantech
CT10-W1-TMP1	Temperature	Warehouse 1	CT10	Advantech
CT10-W1-VIBR1	Vibration	Warehouse 1	CT10	Advantech
CT10-W1-STS1	Status	Warehouse 1	CT10	Advantech
CT11-W1-TMP1	Temperature	Warehouse 1	CT11	Advantech
CT11-W1-VIBR1	Vibration	Warehouse 1	CT11	Advantech
CT11-W1-STS1	Status	Warehouse 1	CT11	Advantech

Table 6 is vital for the areas that maintain the system and the electrical maintenance of the industrial condominium, which will be responsible for replacing components in case of defects, predictive inspection, etc. After the PoC phase, a drawing of the electrical interconnections must be generated and included in this company's archive department. Figure 9 shows the sequence diagram of this scenario and how it relates to all actors, such as sensors, controllers, cloud systems, etc.

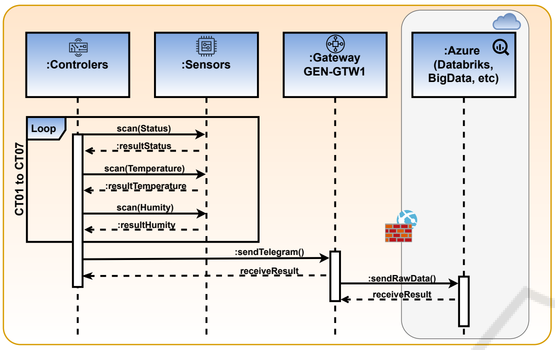

Figure 9: Sequence Diagram - Scenario.

Figure 9 allows us to observe the integration from the shop floor, the interconnection to the general gateway (GEN-GTW1), the interconnection to the corporate firewall, and the connection to Azure Data Bricks, which is hosted in Microsoft's computing cloud.

Table 7: Results per Family Devices.

Device	Case	Sensor to Gateway (ms)	Gateway to Cloud (ms)	Total Latency (ms)	Required Cycle (ms)	Total Bytes
Advantech WISE-2410	Average	8000	3000	11000	3600000	68 + 20 2 msg
	Best	5000	2000	7000	3600000	68 + 20 2 msg
	Worse	22000	13000	24000	3600000	68 + 20 2 msg
ESP32 Devices	Average	2000	2000	4000	600000	20
	Best	1000	2000	3000	600000	20
	Worse	4000	3000	7000	600000	20

Table 7 shows the values obtained in the experiment in which the times were classified as mean, best case, and worst case. For Advantech sensors, two messages are sent, one complementing the other. Thus, the message can only be decoded after receiving the second message. The differences in times between Advantech and ESP32 devices can be explained precisely by the size and need of the complement message. The monitored processes are considered slow; therefore, the total latency is perfectly accepted since the sending frequencies are in the order of 10 minutes (temperature and humidity) and 01 hour (vibration). The status of the gates occurs by eventual opening, and there is no real-time requirement but storage. It can be concluded that all times obtained were satisfactory for the experiment and confirms the data of Table 1 for the category "Process Monitoring" (Brown et al., 2018).

8 CONSIDERATIONS & FUTURE WORK

One of the challenges for implementing systems based on IoT and IIoT on the shop floor is to identify the ideal technology for each organization's requirements. Thus, this implies elaborating a detailed analysis of the cost-benefit ratio compared to the objectives to be achieved. Therefore, a clear specification addresses the life cycle of the data from the generation on the shop floor (e.g., sensors, actuators, etc.) to the level of relevance of the information generated, with the desired degree of reliability. The use of LPWAN technologies, such as LoRaWAN, create new possibilities for an organization to modernize its processes and allowing to ingress under the Industry 4.0 level. Moreover, it can mean lowering the cost of automating processes in companies without a minimally modern or technological park, especially in cases where speed is not a strong technical requirement. Geographically distant areas are also strong candidates for adopting an LPWAN technology. It may also mean greater adoption of Software as a Service (SaaS) technologies, as small IoT and IIoT devices can integrate from the shop floor to a system hosted in some cloud, e.g., Amazon AWS, Microsoft Azure, Google, etc.

Future works, complains a project for the adoption/conversion of the PoC to industrialization using more robust hardware and system entry into production. Despite this, the potential we observed is promising, and a PoC in a real environment such as the one proposed can contribute to a greater adhesion of IoT technologies on the shop floor for the category of "Automation / Monitoring of Processes". Another future work comprises three more scenarios using the same infrastructure, intended to evaluate the operational limits and performances related to the number of sensors, transmission rates, and density per gateway and antenna.

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REFERENCES

Artemenko, A. (2021). Keynote: Advances and challenges of industrial iot. In *2021 IEEE International Conference on Pervasive Computing and Communications Workshops and other Affiliated Events (PerCom Workshops)*, page 526–526.

Autor, D. H. (2015). Why are there still so many jobs? the history and future of workplace automation. *Journal of Economic Perspectives*, 29(3):3–30.

Brown, G. et al. (2018). Ultra-reliable low-latency 5G for industrial automation. *Technol. Rep. Qualcomm*, 2:52065394.

Cheng, J., Chen, W., Tao, F., and Lin, C.-L. (2018). Industrial iot in 5g environment towards smart manufacturing. *Journal of Industrial Information Integration*, 10:10–19.

Choi, H., Song, J., and Yi, K. (2018). Brightics-iot: Towards effective industrial iot platforms for connected smart factories. In *2018 IEEE International Conference on Industrial Internet (ICII)*, page 146–152.

Choubey, S., Benton, R., and Johnsten, T. (2019). Prescriptive equipment maintenance: A framework. In *2019 IEEE International Conference on Big Data (Big Data)*, page 4366–4374.

Colombo, A. W., Karnouskos, S., Yu, X., Kaynak, O., Luo, R. C., Shi, Y., Leitao, P., Ribeiro, L., and Haase, J. (2021). A 70-year industrial electronics society evolution through industrial revolutions: The rise and flourishing of information and communication technologies. *IEEE Industrial Electronics Magazine*, 15(1):115–126.

Da Xu, L., He, W., and Li, S. (2014). Internet of things in industries: A survey. *IEEE Transactions on industrial informatics*, 10(4):2233–2243.

Flores, P., Moscoso-Martinez, M., Minchala, L. I., Vazquez-Rodas, A., and Astudillo-Salinas, D. (2018). A simple reliable wireless bus design for home automation systems. In *2018 IEEE XXV International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, page 1–4.

Giorgetti, G., Gambi, E., Spinsante, S., Baldi, M., Morichetti, S., and Magnifico, I. (2008). An integrated solution for home automation. In *2008 IEEE International Symposium on Consumer Electronics*, page 1–4.

Hassan, Q. F. (2018). *Environment, People, and Time as Factors in the Internet of Things Technical Revolution*, page 51–76. IEEE.

Hood, G. W. (2015). Industry standard models for design/discussion of manufacturing systems. In *2015 5th Australian Control Conference (AUCC)*, page 12–15.

Industries, T. T. (2022). Rssi and snr.

Iyer, A. (2018). Moving from industry 2.0 to industry 4.0: A case study from india on leapfrogging in smart manufacturing. *Procedia Manufacturing*, 21:663–670.

Jayalaxmi, P., Saha, R., Kumar, G., Kumar, N., and Kim, T.-H. (2021). A taxonomy of security issues in industrial internet-of-things: Scoping review for existing solutions, future implications, and research challenges. *IEEE Access*, 9:25344–25359.

Koziolek, H. (2018). Software architecture in process automation: Uml & the "smart factory".

Lawrence, M. G. (2005). The relationship between relative humidity and the dewpoint temperature in moist air: A simple conversion and applications. *Bulletin of the American Meteorological Society*, 86(2):225–234.

Li, C., Mantravadi, S., and Møller, C. (2020). Aau open source mes architecture for smart factories – exploiting isa 95. In *2020 IEEE 18th International Conference on Industrial Informatics (INDIN)*, volume 1, page 369–373.

Lin, J., Shen, Z., and Miao, C. (2017). Using blockchain technology to build trust in sharing LoRaWAN IoT. In *Proceedings of the 2nd International Conference on Crowd Science and Engineering*, pages 38–43.

MATTIOLI, J., PERICO, P., and ROBIC, P.-O. (2020). Improve total production maintenance with artificial intelligence. In *2020 Third International Conference on Artificial Intelligence for Industries (AI4I)*, page 56–59.

Mekki, K., Bajic, E., Chaxel, F., and Meyer, F. (2019). A comparative study of LPWAN technologies for large-scale iot deployment. *ICT express*, 5(1):1–7.

Mohamed, M. (2018). Challenges and benefits of industry 4.0: An overview. *International Journal of Supply and Operations Management*, 5(3):256–265.

NetSuite (2020). Iiot & manufacturing.

Pham, C., Bounceur, A., Clavier, L., Noreen, U., and Ehsan, M. (2020). Radio channel access challenges in lora low-power wide-area networks. In *LPWAN Technologies for IoT and M2M Applications*, pages 65–102. Elsevier.

Pilsan, H. O., Amann, R., and Gerstenberg, M. (2019). Realization of a small iiot node: A greenfield approach. In *2019 20th International Conference on Research and Education in Mechatronics (REM)*, page 1–5.

Powell, D., Riezebos, J., and Strandhagen, J. O. (2013). Lean production and erp systems in small- and medium-sized enterprises: Erp support for pull production. *International Journal of Production Research*, 51(2):395–409.

Reinsel, D., Gantz, J., and Rydning, J. (2018). The digitization of the world from edge to core.

Sauter, T., Soucek, S., Kastner, W., and Dietrich, D. (2011a). The evolution of factory and building automation. *IEEE Industrial Electronics Magazine*, 5(3):35–48.

Sauter, T., Soucek, S., Kastner, W., and Dietrich, D. (2011b). The evolution of factory and building automation. *IEEE Industrial Electronics Magazine*, 5(3):35–48.

Technologies, M. (2019). 6 challenges for industrial iot.

Wollschlaeger, M., Sauter, T., and Jasperneite, J. (2017). The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0. *IEEE industrial electronics magazine*, 11(1):17–27.