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DANILO FARIAS DE CARVALHO

ANALYSIS OF LORAWAN USAGE IN PRIVATE IIOT NETWORKS APPLIED TO PROCESS AUTOMATION AND MONITORING

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Master thesis presented to the Graduate Program in Applied Computing of the College of Technological Science from the Santa Catarina State University, as a partial requisite for receiving the Master's degree in Applied Computing.
Supervisor: PhD Charles Christian Miers

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I dedicate this work to everyone who believes that education paves the way for a better society and that it's always possible to start over and never too late to learn.

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RESUMO

A Internet of Things (IoT) está cada vez mais pervasiva e ubíqua, nas mais variadas áreas. Diversas indústrias também estão incorporando esta inteligência aos seus processos através de Industrial Internet of Things (IIoT). Contudo, há diversas abordagens em termos da escolha de tecnologia, bem como em termos de implementação, sendo que as abordagens sem fios são as mais empregadas pela dinamicidade de implantação e gerenciamento. A Tecnologia Operacional (OT) é uma área conhecida por ser conservadora, e por muitas vezes reativa quanto a utilização tecnologias que fazem parte da Tecnologia da Informação (IT). Com uma lista de requisitos bem elaborada, e com o auxílio de uma análise de aderência, é possível avaliar quais tecnologias podem ser utilizadas na integração de sistemas legados, pois alcançar este tipo de integração pode trazer algum nível de complexidade, em função de como foi desenhado este sistema legado, quais tecnologias foram utilizadas, se existe documentação adequada, dentre outros motivos. Assim, identificar a problemática da (OT) para integrar processos simples a complexos, e que todos estes devem possuir de alguma forma, um modo de comunicarem-se para formar sistemas. O presente trabalho tem como objetivo analisar um ambiente real de chão de fábrica, categorizá-lo, e identificar oportunidades de utilização de sistemas e equipamentos da IIoT, observando a tecnologia Long Range Wide Area Network (LoRaWAN) em redes privadas, e avaliando se esta é aderente ao ambiente objeto deste estudo. A implementação de vários cenário reais dentro nas intalações da ArcelorMittal Vega mostrou a possibilidade de obter diversas informações relevantes, bem como aprimorar os processos produtivos da empresa.

Palavras chave: IoT, IIoT, Automação de Processos, Indústria 4.0, LoRaWAN e Sistemas Legados.

ABSTRACT

The Internet of Things (IoT) is increasingly pervasive and ubiquitous in the most varied areas. Several industries also incorporate this intelligence into their processes through Industrial Internet of Things (IIoT). However, there are several approaches in terms of technology choice and implementation, with wireless networks being the most used due to the dynamics of deployment and management. The Operational Technology (OT) is an area known for being conservative and often reactive in terms of using Information Technology (IT) technologies. With a well-designed list of requirements and with the help of an adherence analysis, it is possible to evaluate which technologies can be used in the integration of legacy systems, as achieving this type of integration can bring some level of complexity depending on how this legacy system was designed, what technologies were used, if there is adequate documentation, and others reasons. Thus, identify the problem of OT to integrate simple to complex processes, and that all these must have, in some way, a way of communicating to form systems. The present work aims to analyze a real shop floor environment, categorize it, and identify opportunities to use IIoT systems and equipment, observing Long Range Wide Area Network (LoRaWAN) technology in private networks and evaluating whether is adherent to the environment object of this study. The implementation of several real scenarios within the ArcelorMittal Vega facilities showed the possibility of obtaining relevant information and improving the company's production processes.

Keywords: IoT, IIoT, Process Automation, Industry 4.0, LoRaWAN, and Legacy Systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

3G Third-generation Wireless
3GPP Third-generation Partnership Project
4G Fourth-generation Wireless
5G Fifth-generation Wireless
ACL Access Control List
ADO ActiveX Data Objects
ADR Adaptive Data Rate
AI Artificial Intelligence
API Application Programming Interface
BI Business Intelligence
BLE Bluetooth Low Energy
CCTV Closed-Circuit Television
CGL1 Continuos Galvanizing Line 1
CNI *Confederação Nacional da Indústria*
CRT Cathodic Ray Tube
dBi Decibels Relative to Isotropic
dBm Decibel Milliwatts
DDC Direct Digital Control
DCS Distributed Control System
DMZ Demilitarized Zone
ERP Enterprise Resource Planning
FIESP *Federação das Indústrias do Estado de São Paulo*
GPS Global Positioning System
FR Functional Requirements
HMI Human Machine Interface
HTML HyperText Markup Language
HTTP Hypertext Transfer Protocol
IDC International Data Corporation
IEC International Electrotechnical Commission
IEEE Institute of Electrical and Electronic Engineers
IIC Industrial Internet Consortium
IIoT Industrial Internet of Things
IP67 Ingress Protection

IP Internet Protocol

IPC Inter-Process Communication

IoT Internet of Things

IRR Internal Rate of Return

ISA The International Society for Measurement and Control

IT Information Technology

KPI Key Performance Indicator

LoRa Long Range

LoRaWAN Long Range Wide Area Network

LPWAN Low Power Wide Area Networks

LTE Long Term Evolution

M2M Machine to Machine

MES Manufacturing Execution System

ML Machine Learning

MOM Manufacture Operations Management

MQTT Message Queuing Telemetry Transport

MSA Measurement System Analysis

MTBF Mean Time Between Failures

NB-IoT Narrowband Internet of Things

NR *Norma Regulamentadora*

NFR Non-Functional Requirements

ODBC Open Database Connectivity

OPC OLE for Process Control

OT Operational Technology

PC Personal Computer

PIMS Plant Information Management System

PRE Prerequisites

PoC Proof of Concept

PPC Production Planning and Control

PLC Programmable Logic Controller

RCL Recoiling Line

REST Representational State Transfer

ROI Return on Investment

RSSI Received Signal Strength Indicator

RTC Real-Time Clock

SaaS Software as a Service

SCADA Supervisory Control And Data Acquisition

SF Spreading Factor

SME Small and Medium-sized Enterprises

SNR Signal-to-Noise Ratio

SoC System on a Chip

TCM Tandem Cold Mill

TCP Transmission Control Protocol

TP Transmission Power

UML Unified Modeling Language

UDP User Datagram Protocol

VLAN Virtual Local Area Network

WAN Wide Area Network

WMS Warehouse Management System

XML eXtensible Markup Language

CONTENTS

1 INTRODUCTION

Industrial automation or Operational Technology (OT) as we know it is based on the third industrial revolution or Industry 3.0. Even with the advancements of Information Technology (IT), that has provided new research and possibilities in automation, mainly on the shop floor. In Brazil, there is still a considerable proportion of companies in Industry 1.0 and Industry 2.0, mainly in Small and Medium-sized Enterprisess (SMEs) (INDúSTRIA. . . , 2020). With Industry 4.0 growing and gaining relevance daily, companies need to know the benefits and gains these new technologies can provide from the shop floor to cloud-based systems and thus generate value for the entire production chain.

This master thesis addresses how automation is being incorporated from smart homes or smart houses (FLORES et al., 2018), (GIORGETTI et al., 2008), to industries (SAUTER et al., 2011a). Then, the foundations of Internet of Things (IoT) are also presented, such as the differences between the "Internet of Things" and "Things simply connected". The types of Machine to Machine (M2M) communication and intelligent systems are also covered. Continuing with the vision of industrial systems, Brown et al. (2018) contributes with categorization and grouping of industrial systems that support the idea of how systems based on Industrial Internet of Things (IIoT) which is a derivation of IoT can contribute to the shop floor systems and especially with the integration with legacy systems.

Industrial automation, in general, is presented and also demonstrates the items that compose it from the shop floor with dedicated I/O passing through the first dedicated acquisition boards that were installed in Personal Computer (PC) and that used protocols based on serial communication such as RS232 connected directly to PC, or with converters for RS422 and RS485 protocols (COUTO, 2010). Industrial networks and industrial protocols are also discussed, and convergence with the systems and protocols used in IT is observed. Wollschlaeger, Sauter e Jasperneite (2017) presents the evolution of these protocols through mobile protocols and reaching the present day. Some scenarios involving Programmable Logic Controllers (PLCs), Supervisory Control And Data Acquisition (SCADA) systems, and market systems such as Database, Plant Information Management System (PIMS), and modern programming languages are also covered. As a natural evolution, IoT and Industry 4.0 are also explored. Finally, it is explored how these technologies based on IIoT can relate to the shop floor based on the The International Society for Measurement and Control (ISA)-95 model (HOOD, 2015), which is a concept widely used in industrial automation as a whole, and how it can be applied in a real environment in a factory already in operation and with legacy systems.

Regarding the objectives to be achieved with this present work, the main goal is a case study to analyze how IIoT can contribute to production lines in which there is a low level of automation and which may not have a financial attractiveness. This point is explored in Section 2.6. This same case may be usual in SMEs. In this way, this present study intends to be helpful for this industrial segment and those companies or processes before Industry 3.0 that is the foundation of Industry 4.0.

This work is organized as follows. Chapter 2 introduces the theoretical foundation, approaching how the concept of IoT and IIoT provides a favorable environment for the industrial scenarios as well as its challenges and opportunities. Based on the theoretical foundation, the basis for identifying the proposed research problem and its motivations is established. Chapter 3 presents and details the Functional Requirements (FR) and Non-Functional Requirements (NFR) that guide the development of the work. The research method adopted is also presented, as the search, inclusion, and exclusion criteria, academic search mechanisms used, and how the identified related works meet or do not meet the established FR. Then, the proposed solution for the identified research question is detailed, addressing individually how the FR will be attended. With the definition of the proposed solution, the chapter also details the ArcelorMittal Vega scenario in which the solution will be evaluated.

Finally, Chapter 4 describes the implementation, collection, and analysis of the results of all specified scenarios. Additionally, an extra scenario was included to allow exploring other applications of the proposal.

The method used in this work consists of referenced research carried out to develop the theoretical foundation, followed by applied research to verify the feasibility and functionality of the proposed solution. This work's main contribution is the development of a IIoT monitoring solution and a technical evaluation of IIoT related protocols and solutions based on recognized industrial standards.

2 FUNDAMENTAL CONCEPTS

Automation is a reality that is 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., 2011a). 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). Thus, understanding the basics of IoT (Section 2.1) is necessary to understand it is origins and most basic characteristics.

The IoT concept was used broadly with several residential use cases and cities, but its industrial use was slower due to legacy systems (CHOI; SONG; YI, 2018). Thus, industrial automation (Section 2.2) has been occurring for several generations and comprises not only the types of devices but also the networks that are used to connect the devices.

The evolution has led the industry to the concept of Industrial Internet of Things (IIoT) (Section 2.3), which is the use of IoT with industrial requirements, including despite the shop floor. Aiming at a parameterization and organization concerning what is performed by Operational Technology (OT), theIIoT is organized in several levels defining basic aspects of operation and their operational requirements.

Both IoT and IIoT have an accelerating pace of adoption. Although there is only change from older legacy systems in some cases, there are several new opportunities for new applications and the need to integrate the new possibilities with the already installed base. Therefore, it is essential to identify and understand the main scenarios, challenges, problems, and opportunities in IIoT (Section 2.5). Identifying problems and opportunities allows for defining a clear scope of action and developing a clear proposal for a solution based on well-defined requirements (Chapter 3).

2.1 IOT BASICS

The emergence of Wide Area Network (WAN), and the integration between this type of network and the execution of commands/requests, and later with the advances in microelectronics, leads to a natural path for researchers to study and perform remote activations. With the advent of the Internet, the challenge took on new proportions, bringing a technological leap. This idea made it possible to create smart devices like those in cartoons and movies of the late 60s and 70s.

The term IoT was coined in 1999 by Kevin Ashton, a computer scientist working at Procter & Gamble. He was looking to use radio-frequency identification tags and other sensors. As he was looking for a strong title for his idea, and that is when the term was coined. Years before, in 1990, at a conference called INTEROP, John Romkey created the first Internet of Things (IoT) device, a toaster capable of turning on over the Internet. Through this realization, it was possible the emergence of new technologies and new forms of communication.

According to estimates from International Data Corporation (IDC), a leader in market intelligence, consulting, and conference services for the Information and Communications Technology industries, there will be 41.6 billion “connected things” in 2025. At first, IoT integrates a network of physical objects that can have 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 such as 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 lamp, read a sensor or start a small motor can be considered a good way of learning. However, this does not mean that you have a smart device, but there is a simple device connected using the Internet. When some sensors and software interpret this data and add a layer of "intelligence" to the processing, then there will be a real application of IoT. When different types of sensors are spread across a city, and these data are obtained and available so that people and systems can interact with each other, then it will be the vision of smart cities. These interaction flows are considered intelligent because they strategically use infrastructure, services, information, and communication with urban planning and management to respond to society’s social and economic needs.

Industrial IoT or IIoT refers to the application of IoT technology in industrial environments, especially concerning the instrumentation and control of sensors and devices that involve cloud technologies. Some branches of industry are currently looking for Machine to Machine (M2M) type communication to achieve wireless automation and control. However, with the emergence of the cloud (whether public or private) and allied technologies such as advanced analytics and Machine Learning (ML), different sectors can reach a new layer of automation and thus 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 term was created by General Electric (GE), one of the founders of Industrial Internet Consortium (IIC). 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 (COELHO, 2016a). Another aspect that should be noted is the industry has specific requirements that must be highlighted, such as performance requirements in IoT / industrial automation services and 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 (*Norma Regulamentadora* (NR) 12), 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, ovens, etc. Thus, heterogeneity is part of this reality. Table 1 lists and categorizes the main industrial automation systems considering important requirements covering the main systems in any industrial plant (BROWN et al., 2018).

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	

Source: Adapted from (BROWN et al., 2018).

According to Brown et al. (2018) the data in Table 1 performance criteria can be divided into:

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 and/or requesting a sensor reading, until the return of the execution confirmation; and

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 where there is no risk to human safety, equipment safety, or the environment, the level of redundancy may be lower. In Section 2.2, industrial automation is presented, and the convergence between Information Technology (IT) and Operational Technology (OT) on the shop floor is explored; and with the help of IoT and IIoT and with the intensification of the use of industrial networks, replacing the old serial communications (e.g., RS232, RS422, RS485, etc.) the need to transfer of data from the lowest levels to the highest levels in convergence with the ISA95 standard has become even greater (HOOD, 2015).

2.2 **INDUSTRIAL AUTOMATION**

Process automation, also known as industrial automation, is an area known to be conservative (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017) and sometimes even reactive in the use of IT resources. However, conservatism impacts financial or complex infrastructure. In recent years IT and OT have converged in such a way that they are often part of the same organizational structure sharing different resources (MARTINS, 2015; STREY et al., 2017). In this context, there is a need to interconnect devices through communication networks that may be similar or even the same type of the networks used in IT (Subsection 2.2.1). Among the various resources that can be shared, it is important to highlight: networks (wired, wireless, etc.), data centers, servers, databases, monitoring systems, clusters, storage, support teams, etc. With the advent of Industry 4.0 (Subsection 2.2.3), greater technological integration between processes is proposed, in which it is possible to have improved sensors and actuators with the support of IIoT (SAUTER et al., 2011b). Furthermore, this tends to intensify with Fifth-generation Wireless (5G) technology, and new possibilities must be evaluated and studied (BROWN et al., 2018). Therefore, a fundamental issue is the role of communication networks, whether they originate in IT or OT, because, in the end, these are technologies and should contribute to the evolution of society. The end of technology is not found in itself but in what it proposes to do with it.

2.2.1 Industrial Networks

The beginning of industrial networks as we know them started with the advent of Industry 3.0 and microelectronics when 8-bit microprocessors began to be used (e.g., Zilog Z80, Intel 8080, etc.), and these devices were connected to monitors of the Cathodic Ray Tube (CRT) type, the idea of the first supervisory systems was born. These then displayed information only in "text mode." Years later, the convergence and union of areas such as IT and OT are unprecedented, reflected in many ways. For example, it is already acceptable in some companies to use the same network for office equipment, process data, Closed-Circuit Television (CCTV), etc., in which Gigabit speed equipment is used with network segmentation through Virtual Local Area Network (VLAN). However, when Ethernet networks were consolidating as one of the leading automation networks, then it was not likely to be used in all situations (SILVA; OLIVEIRA, 2003). Some of these situations were:

- Absence of interoperability due to the lack of an application layer (by itself, it presents definitions only for Layers 1 and 2 of the ISO model);
- Lack of determinism and insufficient response time for some applications;
- Synchronization difficulties at milliseconds level;
- Lack of solution for intrinsic safety; and
- Others...

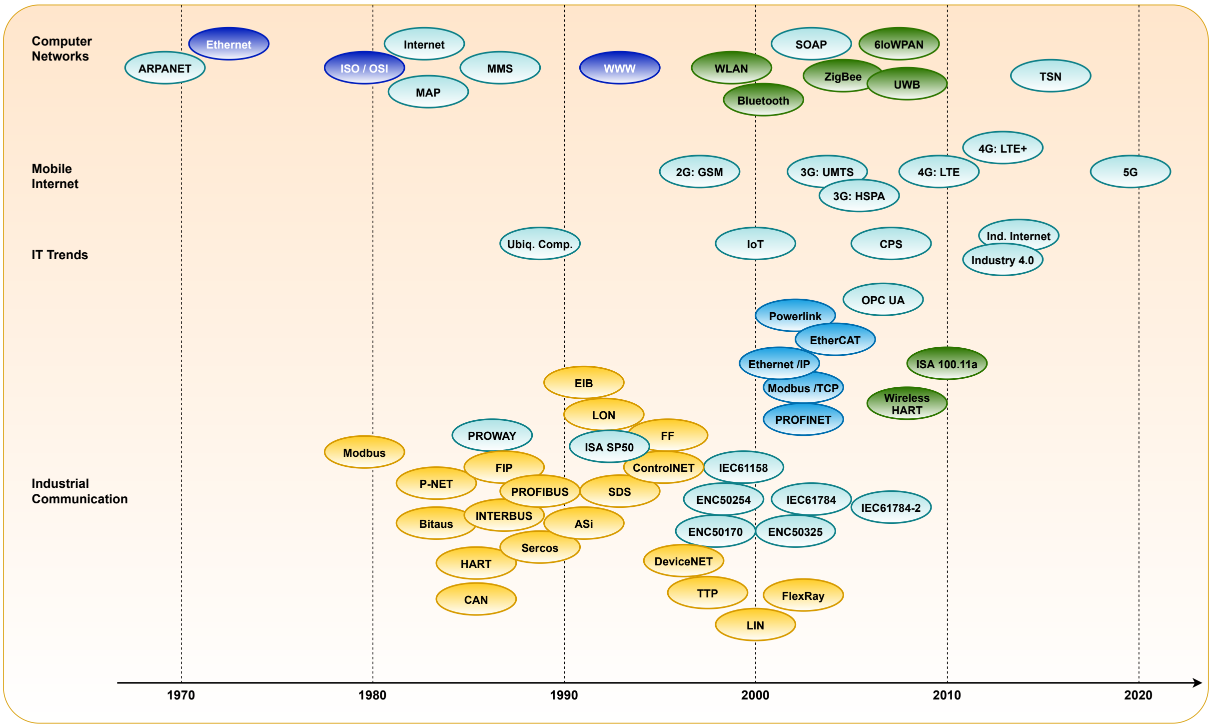
On the other hand the advantages were very promising (SILVA; OLIVEIRA, 2003), such as:

- Ability to carry a high flow of information between the industrial process and the corporation;
- High number of qualified technical personnel;
- Ability to provide diagnosis and actuation remotely; and
- Others...

One of the reasons that influenced these changes was the adoption of smarter sensors and actuators, the use of market databases (leaving the proprietary models), wireless networks on the shop floor (e.g., IEEE 802.11x), the adoption of data analysis and modeling, Big Data, IoT, Internet, cloud computing, and smart products and services (LASI et al., 2014), (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017). At the beginning of industrial automation, communication networks were dedicated and proprietary, developed "from scratch" without compatibility with existing ones. In some cases (e.g., Allen-Bradley, Rockwell Automation, Siemens, etc.), dedicated acquisition boards were used; or systems based on serial communication, such as RS232, RS422, and RS485 (COUTO, 2010) protocols. At that time, sensors and actuators were connected directly to the Programmable Logic Controller (PLC) panels through fieldbus cables; at this time, the open proprietary networks, known as CAN, Profibus, and Interbus, appeared. These protocols were for serial communication and could interconnect products from different manufacturers. Such networks were developed due to the limitation of traditional serial and parallel communication between field instruments (sensors and actuators) (COUTO, 2010). It is also important to note that the architecture of automation systems and their networks evolved from local to centralized architecture, distributed in controllers, and distributed interconnected through the communication network.

The next step was the evolution to be distributed in sensors and actuators, as well as the adoption of IoT and IIoT (BOYES et al., 2018) technologies. An important "character" at the beginning of industrial automation networks and systems is the so-called Distributed Control System (DCS), in which all the hardware and software were from the same manufacturer. The DCS predates the use of PLC, but even with the advancement of both technologies depending on the type of process, the first one is recommended (e.g., gas, oil, blast furnaces, etc.). They are not necessarily competitors in all scenarios of industrial automation. This was the evolution of the first industrial computers called Direct Digital Control (DDC) with some I/O. Thus, like PLC itself, this platform has been modernized over the years, and networks such as Ethernet and computer-based operating stations have become popular (SEGOVIA; THEORIN, 2012). Soon, new dedicated solutions emerged without interoperability guarantees between them. Due to the advent of Ethernet (IEEE 802.3x) for IT networks, several groups started to develop tests in an industrial environment. Still, this technology didn't satisfy real-time and low latency requirements (SILVA; OLIVEIRA, 2011) and (SILVA; OLIVEIRA, 2003). The different existing protocols, variety of devices, and different standards make communication between the different levels of industrial automation complex and heterogeneous. Figure 1 shows these characteristics when the number of existing protocols is observed. The variety of protocols used in Industrial Automation, while helping to integrate different products, also poses the challenge of integrating different systems.

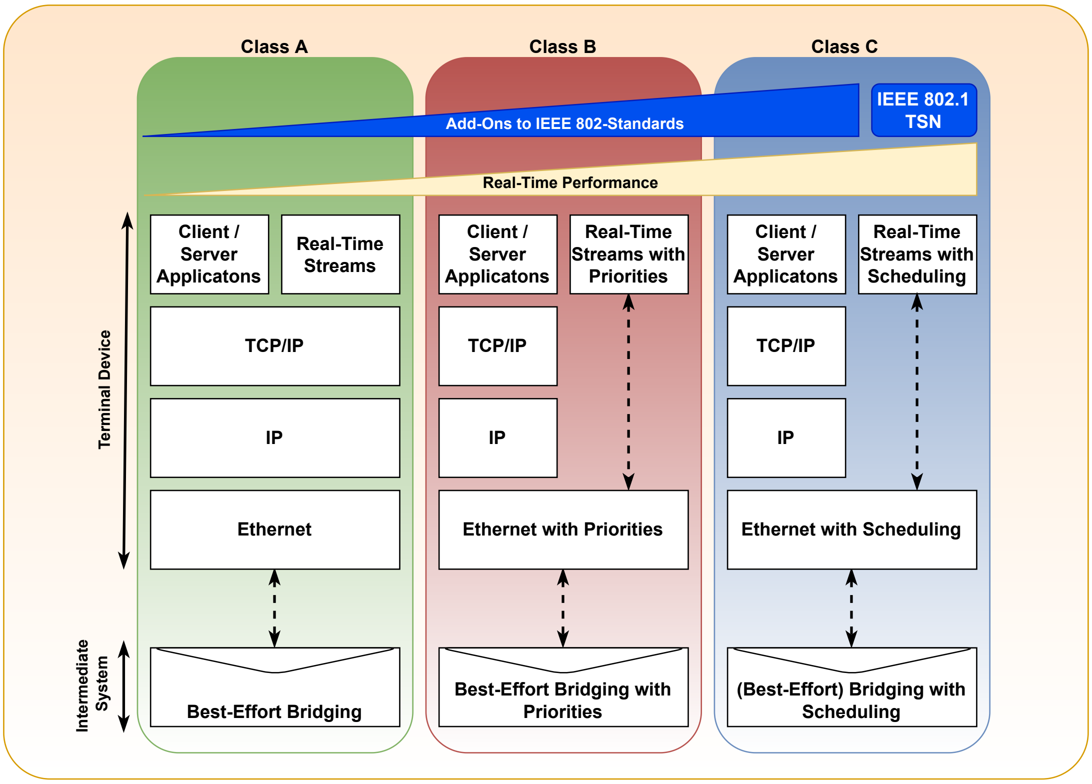
Figure 1 – Protocols Evolution - Based on IT and OT Protocols.



Source: Adapted from (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017).

Figure 1 presents the evolution of some protocols (e.g., Modbus), which have evolved their physical environment (e.g., serial to Ethernet, and even IEEE 802.15). Other well-known examples on the market worth mentioning are Profibus, which is widely used by Siemens and KTX boards, which were used to communicate with the PLC of the Allen-Bradley SLC family. In both cases, these technologies evolved into the Ethernet physical environment. It can be noted in Figure 2 how the Ethernet classes are divided and how each change in each of the classes adds a new characteristic that can affect performance in terms of communication prioritization or execution time of each scheduled task.

Figure 2 – Ethernet Class.



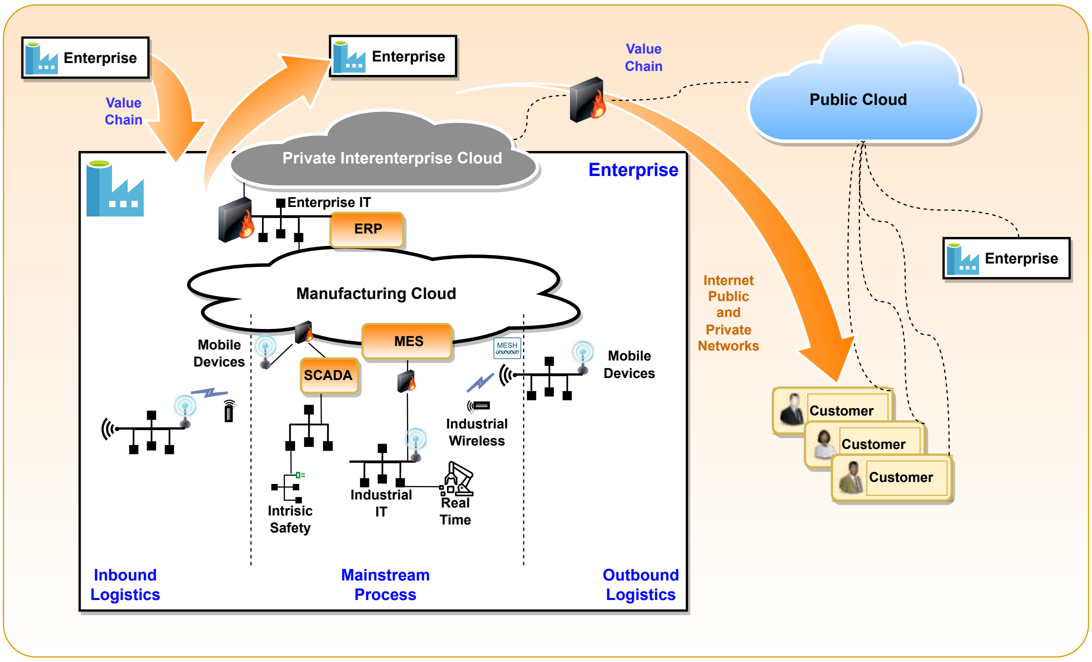
Source: Adapted from (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017).

Ethernet has evolved and become a standard in industrial automation and on the shop floor, beyond the office or corporate network. Most real-time solutions are Fast Ethernet types and can be divided into three classes, which differ in performance within IEEE 802:

- Class A: Real-time services are performed above the transport layer, with transfer rates at intervals of 100 ms, e.g., old Modbus serial protocol, gained the physical environment of Ethernet for communication between devices, such as frequency inverters and low-power drivers;
- Class B: Real-time services are performed directly over the media access control (MAC) layer, using approaches such as prioritization and the use of virtual networks (VLAN) to separate real-time data from the rest of the data. network traffic. The transfer rate can occur in 10 ms cycles, e.g., Profinet Real Time; and
- Class C: This is the class in which real-time communication capabilities are achieved by modifying the Ethernet MAC layer. The transfer rate can occur in cycles of less than 1 ms; e.g., EtherCAT remotes fall into this category.

Industrial networks operate an important role in integrating the entire network of industry, as it connects data from the Enterprise Resource Planning (ERP) to the shop floor. As can be seen in Figure 2, the Ethernet network can handle all the necessary communication; because while Class A meets the main requirements of "corporate systems", classes A, B, and C meet industrial automation. A great variety of industrial technologies uses Ethernet in massive ways, such as PLC, Data Networks in the most diverse protocols, Supervisory Systems or Supervisory Control And Data Acquisition (SCADA), databases, programming languages, and systems categorized as "automation data historians", which are called of Plant Information Management System (PIMS), etc. Figure 3 shows how integrating systemic levels is a challenge in any production process, especially with adopting cloud systems, and the technologies based on Ethernet are part of this scenario. However, this also exemplifies how much in-depth analysis is necessary to evaluate all the details from a process and system point of view.

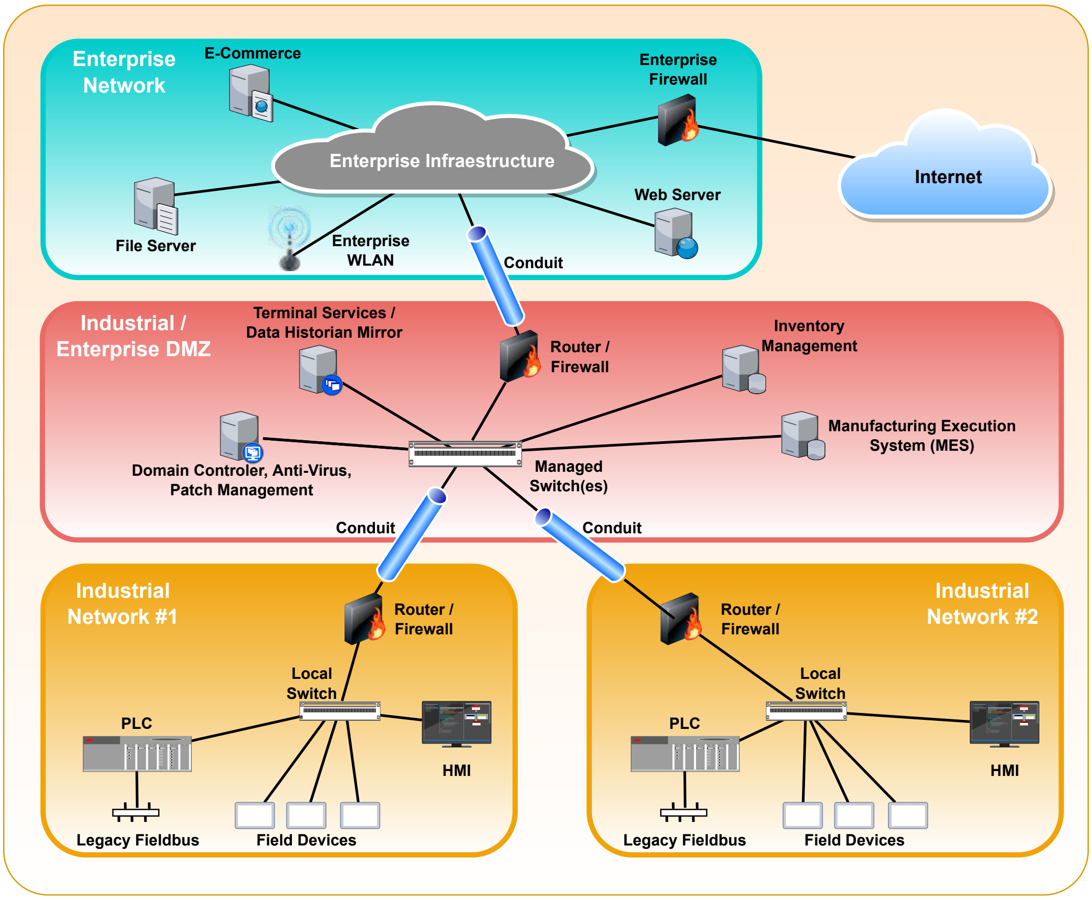
Figure 3 – Complexity of integration among automation levels.



Source: Adapted from (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017).

Figure 3 exemplifies several opportunities for integrating systems and processes. Also, how distributed systems can play an important role in this type of integration, and an example of this type of approach is shown in Figure 4, which presents a view of a physical network that can be seen from the sensor or actuator on the shop floor to a connection to a cloud using the Internet.

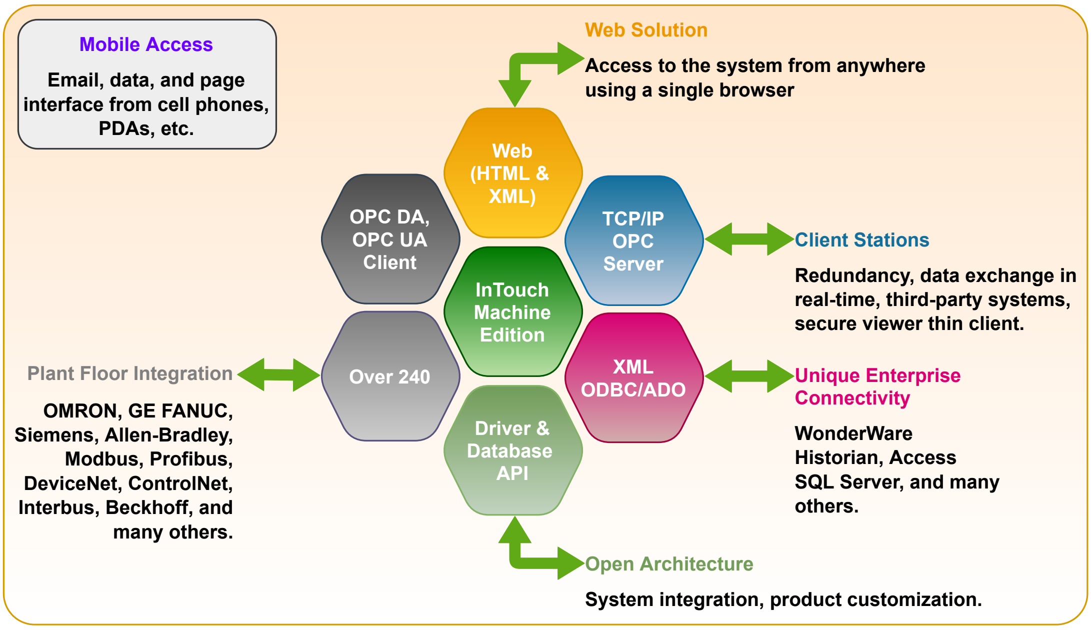
Figure 4 – Automation network based on IEC62443.



Source: Adapted from (BLOGS.CISCO.COM, 2021).

Depending on the criticality of a process, a greater concern with correct integration between all connection points concerning the hardware or software of the environment. In this representation (Figure 4), there is the Ethernet network, proprietary sensor networks, redundant systems, wireless networks, etc. In a SCADA system, in addition to the possibility of communicating with different models of controllers from different PLCs, through proprietary drivers, there are also open standards such as OLE for Process Control (OPC) which is maintained by OPC Foundation. In some modern SCADA systems (e.g., Aveva InTouch), features such as the possibility of communication through technologies such as: Application Programming Interface (API), HyperText Markup Language (HTML), eXtensible Markup Language (XML), ActiveX Data Objects (ADO), Open Database Connectivity (ODBC), etc., being possible to observe this on Figure 5.

Figure 5 – Typical SCADA system - Example of The communications types.



Source: Adapted from (WONDERWARE.COM, 2015).

Figure 5 exemplifies how this software can be modular and cover a set of features (e.g., integration with the shop floor, possibility of mobile communication, web solutions, cloud solutions, security, redundancy, etc.). These examples of technologies can contribute to integration in different situations, industrial processes, etc. Subsection 2.2.2, describes a traditional automation system's standard or even minimal architecture and how this type of system evolved up to the actual day. This model can be used in any production process that needs to be automated.

2.2.2 Traditional Automation Architecture

A traditional automation system comprises controllers and Human Machine Interfaces (HMIs) that compose Level 1, up to the SCADA and process optimization systems, which are part of Level 2. Thus, a commonly used architecture for this type of system is represented in Figure 6, and is composed of:

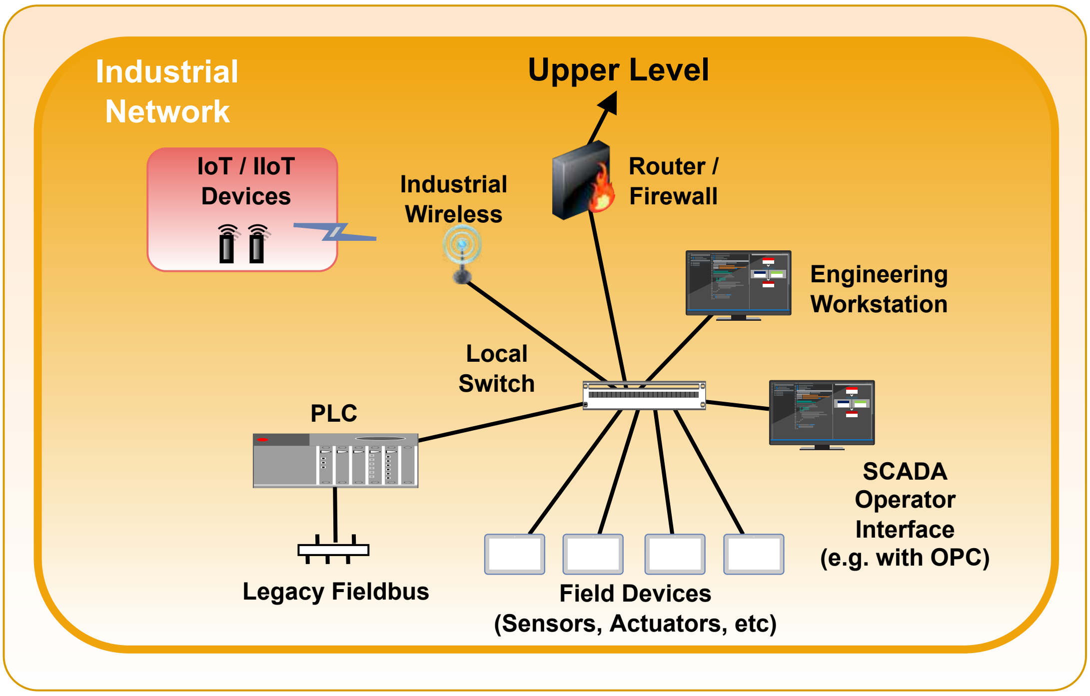
1. Switch: For interconnecting devices with Ethernet communication;
2. PLC: Industrial controller in which a programming logic is executed in a time interval defined by the process characteristic;
3. Sensors: Receives incentive of electrical quantities, which are converted into standardized scales (e.g., level, temperature, position, speed, etc.);
4. Actuators: These are devices that produce movement, converting pneumatic, hydraulic, or electrical energy into mechanical energy (e.g., relay, etc.);

5. SCADA: Supervision and control system, which can monitor and execute activations through software that normally runs from a computer;

6. Engineering Station: It is a computer connected to the automation network, where specific programs are installed for the development of automation applications, SCADA, PLC programming, etc.; and

7. Operation Station: It is a computer connected to the automation network, where a SCADA application is executed. It may or may not rely on a communication driver (e.g., OPC) or other communication technology (e.g., TCP/IP, UDP, Serial, etc.).

Figure 6 – Representation of a standard automation system.

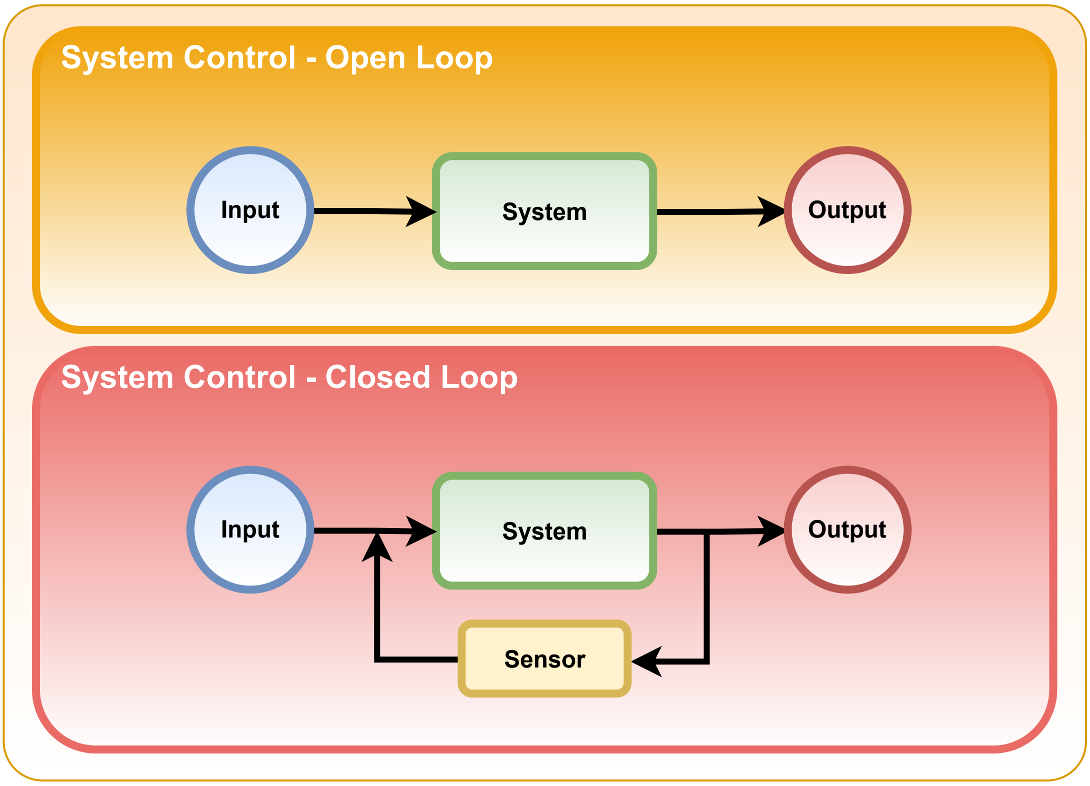


Source: Adapted from (BLOGS.CISCO.COM, 2021) - Simplification.

In addition to the items listed above, it is also possible to have communication with a higher level (e.g., Level 2 or Level 3 systems), firewall to protect the industrial network, wireless networks on the shop floor (IEEE 802.11x), IoT or IIoT networks, etc.

In terms of automation process, a control system can be classified as "Open Loop", where an actuator directly controls a process (an output) without feedback, or "Closed Loop", in which a preset value is compared to the measured value generating feedback to the system, which in turn can more precisely control the desired output value. Figure 7 represents these types of controls.

Figure 7 – Representation of Open / Closed Control System.



Source: Adapted from (JIANHONG; RAMIREZ-MENDOZA, 2021).

Examples:

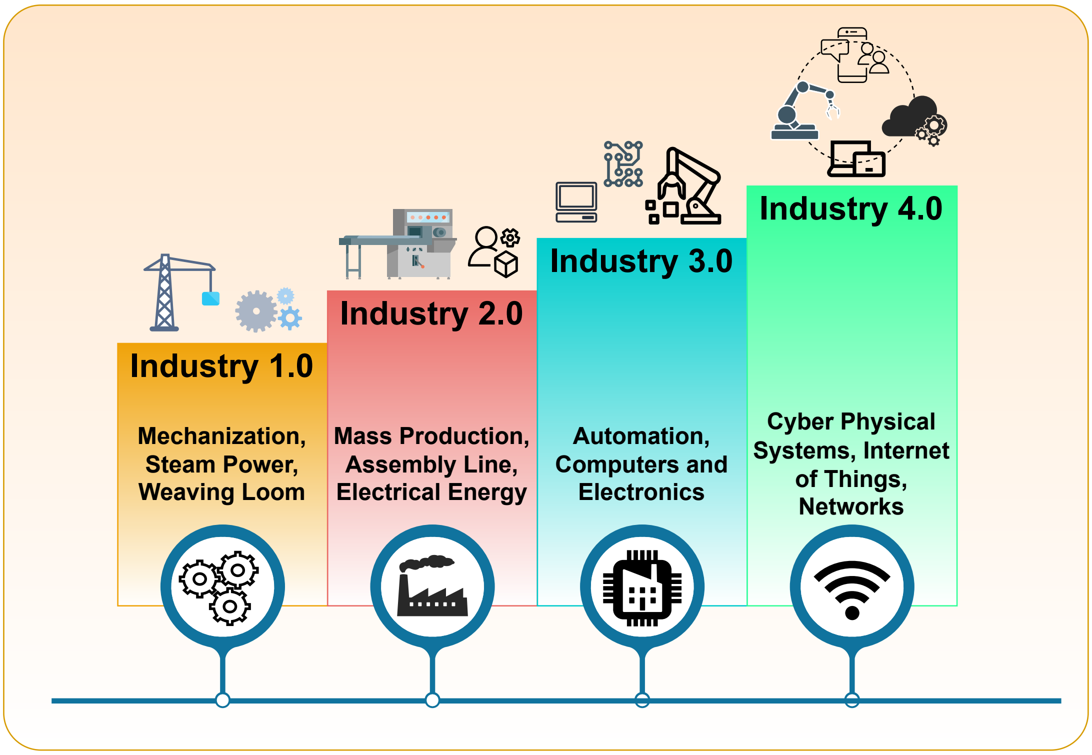
1. Open Loop: In a traditional washing machine, all processes (e.g., wash, rinse, spin, etc.) are controlled by the duration of each task; and
2. Closed Loop: Plastic extruders, blast furnaces, rolling mills, etc.

The starting point to define how the automation system will be developed is how precise the process will be and how the system will be integrated with the new technologies. Concerning integration, the subsection 2.2.3, starts the characteristics of Industry 4.0 and the discussion as the definition of the industrial revolution. The role of industrial networks is especially enhanced and amplified, and IoT, and technologies based on the IEEE 802.11x standard, contribute especially to this.

2.2.3 Industry 4.0

The term Industry 4.0; smart factory; intelligent factory; factory of the future are terms that describe a vision of what a factory will look like in the future. In this vision, factories will be much more intelligent, flexible, dynamic, and agile. Another definition for Smart Factory is a factory that makes smart products, smart equipment, in smart supply chains (COELHO, 2016b). An industrial revolution is characterized by a disruptive scope for the time in which it took place. Figure 8 illustrates the fourth industrial revolution and some of its characteristics.

Figure 8 – Industrial revolutions.



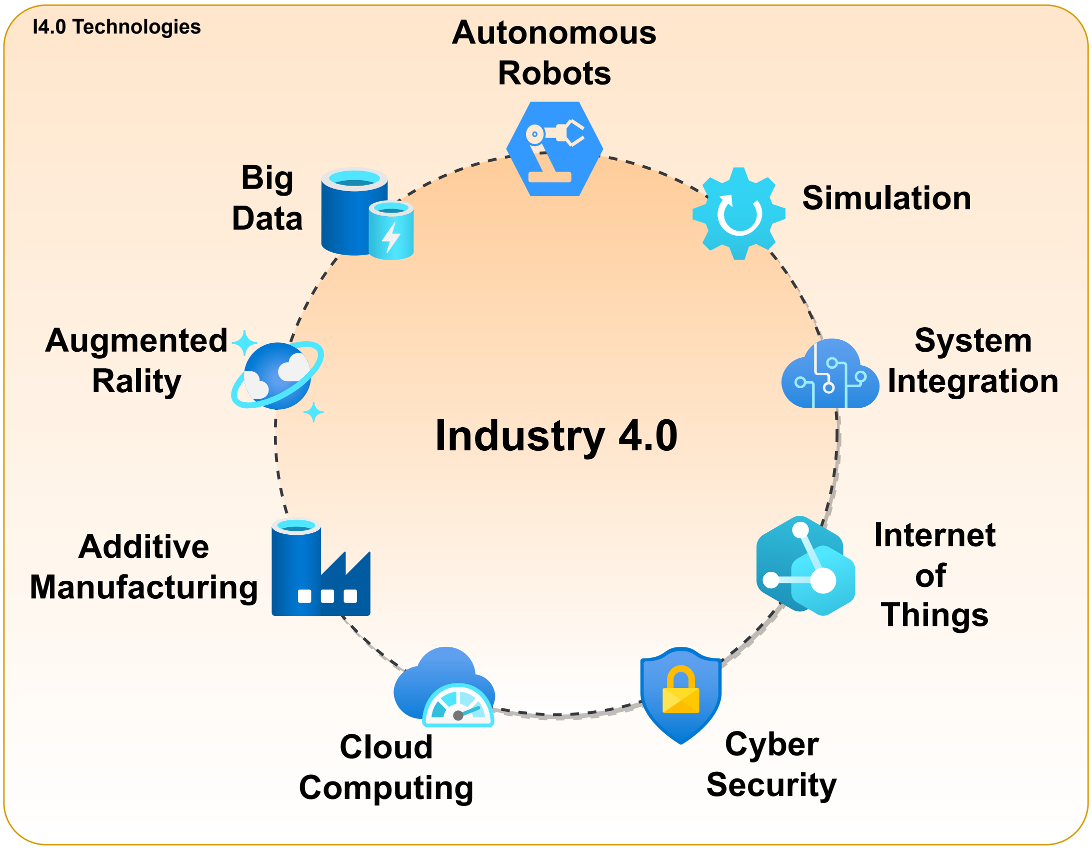
Source: Adapted from (CONSULTING, 2019).

Industry 4.0 terminology was first used in Germany in 2011, and in 2013 a report was presented to the German government with a set of recommendations for it is an implementation based on six principles:

1. Interoperability: Ability of people and systems to connect through Cloud Computing and the Internet of Things;
2. Virtualization: Interconnected sensors that monitor physical processes and enable simulation models;
3. Decentralization: Decision-making by the systems without human intervention, based on rules and parameters;
4. Real-Time Capability: Collect and analyze data, delivering knowledge immediately;
5. Service Orientation: Services through cloud computing; and
6. Modularity: Adaptation of smart factories through the replacement or expansion of individual modules.

The characteristics listed in Figure 9 are the ones that are in evidence, and a factory or process that has only one of them, for example, does not belong in this category. Using technologies such as Big Data, IoT, and cloud computing, it is possible to reduce costs and make production more automated and autonomous (COELHO, 2016a).

Figure 9 – Industry 4.0 characteristics.



Source: Adapted from (LERMENSYS, 2019).

Therefore, some of the technologies observed in Figure 9, gained emphasis, and were grouped as follows (MOHAMED, 2018), (LERMENSYS, 2019):

1. Autonomous Robots: Technologies such as 5G will contribute to advances in this area;
2. Simulations: Machine Learning (ML), computing power, and data science will play an important role, reducing analysis and testing time;
3. Systems Integration: Allow communication between the most varied types of systems and/or necessary devices, from the shop floor to the cloud. In particular in geographically distributed locations;
4. Internet of Things: Connectivity and device simplification;

5. Cybersecurity: New challenges have emerged, and security as a whole will present itself as a challenge to be overcome;
6. Cloud Computing: Increasing use of the "as a service" concept, with the cloud being an important asset for any company;
7. 3D Printing: Additive manufacturing and the possibility of printing parts will contribute to the reduction of several costs and development time;
8. Augmented Reality: Important ally of learning and field maintenance; and
9. *Big Data*: Data transforming into information and generating value.

For (MOHAMED, 2018) and (LERMENSYS, 2019), the expected benefits of applying the concept of Industry 4.0 are:

- Cost Reduction: More qualified workforce, increased automation, standardization, etc.;
- Energy Savings: Flexibility of production, increase in asset monitoring, increase in the use of renewable energies (e.g., solar energy absorption), etc.;
- Increase in Security: Cybersecurity and constant monitoring of assets;
- Environmental Conservation: Reduction of waste, reduction of CO emissions, etc.;
- Error Reduction: Use of artificial intelligence from Production Planning and Control (PPC) to process optimization on the shop floor;
- End of Waste: Intensification of the use of mathematical models from the acquisition of raw materials through the entire production chain;
- Business Transparency: Technologies such as blockchain can provide more reliable operations, more democratic transactions, process optimization, easier coordination between companies, etc.;
- Increase in Quality of Life: Reduction of manual activities, the possibility of remote work, and decentralization are some characteristics that can be obtained with this model; and
- Unprecedented Customization and Scale: Automatism, artificial intelligence, and mathematical modeling working together produce more adherent to customers' needs.

Even though some important technologies like the Internet, mobile telephony, cloud computing, etc., emerged during the period of Industry 3.0, they are still part of the foundation of Industry 4.0 (BOETTCHER, 2015). It can be seen, then, that Industry 3.0 will continue to be relevant for a long time, not only because it has elements that are part of the foundation of Industry 4.0; but also because there is a whole legacy that cannot be replaced in a short time (TIBURI, 2019).

In terms of Brazil, according to a study carried out by *Confederação Nacional da Indústria* (CNI) at the request of the Euvaldo Lodi Institute, it points out that many small and medium-sized companies are still in Industry 2.0 (INDúSTRIA. . . , 2020). In another 2019 study carried out by *Federação das Indústrias do Estado de São Paulo* (FIESP) in 417 companies in the state of São Paulo, it shows that there is a stagnation in investment and research when it comes to Industry 4.0, with 97% of these not considering themselves prepared to it is adoption (BERNARDES, 2020). On the other hand, it is expected that the adoption of Industry 4.0 by medium and large companies will reach an approximate value of 21.8% by the year 2027 (BRASIL, 2020); This fact also highlights the distance between small companies and those that are in the first steps of medium size, and those that are already well established as medium-sized, to large ones. According to (TIBURI, 2019), as moving from Industry 2.0 to Industry 4.0 in a single step is practically unfeasible, a "step by step" approach is the most suitable, investing in equipment that 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, thus reducing the technological leap. In summary: Industry 3.0 will be relevant for a long time to come, while it will be important to aim for Industry 4.0 without overlooking Industry 3.0. One of the technologies that can help is IIoT.

2.3 IIOT

IIoT is an integral part of Industry 4.0 and can be considered as a means for this transition (COPADATA, 2019), being IIoT included as part of IoT framework. This defines the set of technologies and services that allow 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 (XU; HE; LI, 2014). Several companies in Brazil are still in Industry 1.0 and Industry 2.0, and it will take some time for these legacy systems to be replaced; in this way, new approaches can be proposed so that some characteristics of IIoT can help in the evolution of these systems. As an example, some micro-controlled devices serving as gateways or remotes for PLCs in the field, based on IoT technologies (e.g., ZigBee, Long Range Wide

Area Network (LoRaWAN), ESP32, ESP8266, Raspberry Pi, among others). These can also contribute to raising the monitoring level of an industrial process.

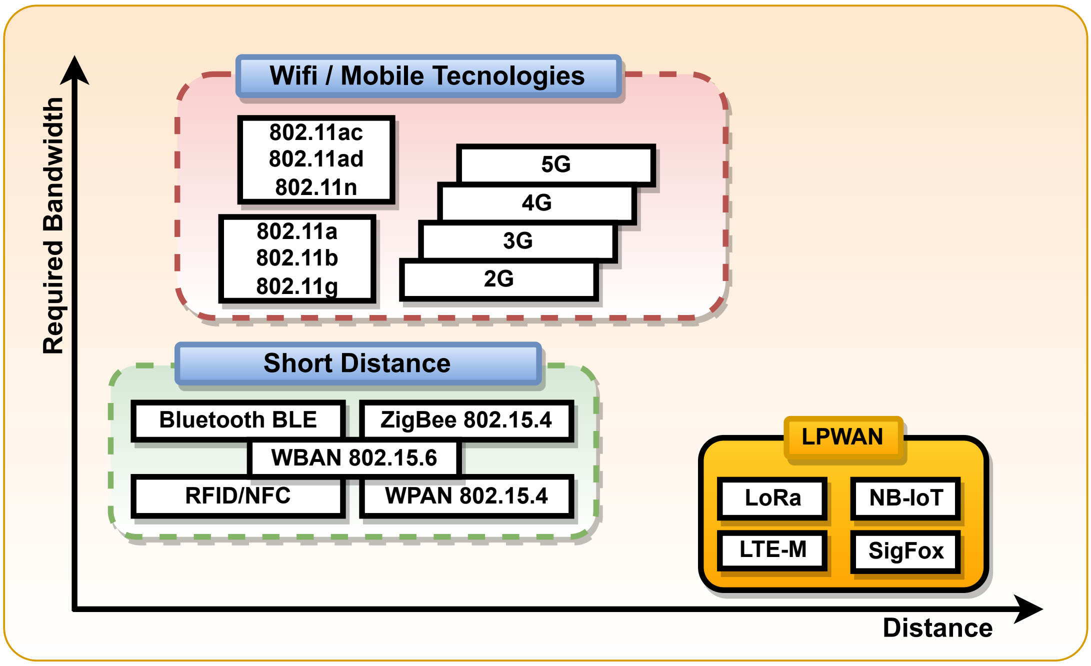
In companies where industrial automation is already in Industry 3.0, the applicability of IIoT can be observed in different contexts, whether in a traditional automation system or in the integration with the cloud, Edge Computing, and Smart Factories, among others. With the possibility of having the processing at the end; that is, 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; BENTON; JOHNSTEN, 2019), and later with the introduction of Artificial Intelligence (AI) and Machine Learning (ML). This 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 that are important 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 that can be taken (MATTIOLI; PERICO; ROBIC, 2020). Section 2.4 presents the hierarchical levels of industrial automation, the integration between such levels, and the opportunities that exist when using IIoT to integrate automation systems on the shop floor.

2.4 **Low Power Wide Area Networks (LPWAN)**

LPWAN is a generic term for a group of technologies that allow communications over long distances, with low cost and reduced energy consumption (LIN; SHEN; MIAO, 2017). Such technology is suitable for IoT applications that only 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 various scenarios. Many of the technologies LPWAN represented in Figure 10 emerged in licensed and unlicensed markets, such as Long Term Evolution (LTE)-M, SigFox, Long Range (LoRa), and Narrowband Internet of Things (NB-IoT), among others.

Figure 10 – Relationship between Required Bandwidth and Distance.



Source: Based on (SINHA; WEI; HWANG, 2017).

According to (MEKKI et al., 2019), LPWAN can cover distances between 10km and 40km in rural areas and between 1km to 5km in urban areas, and as already mentioned, at a low cost and low energy consumption. An important characteristic of the technologies that compose LPWAN is that they work in the Sub-Ghz bands, directly impacting their ability to overcome obstacles. Among these, LoRaWAN and NB-IoT are the two leading emerging technologies, which on the one hand, have technical differences, on the other hand, and in some cases, can be used in the same type of application.

2.4.1 Long Range Wide Area Network (LoRaWAN) and Narrowband Internet of Things (NB-IoT)

NB-IoT is generally used in environments where cellular connectivity Third-generation Wireless (3G) / Fourth-generation Wireless (4G) or Institute of Electrical and Electronic Engineers (IEEE) 802.11 may not work satisfactorily, such as spaces with physical interference, metal structures, or in rural areas. NB-IoT standardizes three operations when deployed on other networks (RATASUK et al., 2016). These operations are:

1. *In-band*: When using blocks of physical resources from a service provider 4G/LTE;
2. *Band Guard*: When regulating unused spectrum in a guard band service provider 4G/LTE; and

3. Standalone: When deployed on a dedicated spectrum.

The NB-IoT is indicated when it is not needed to transfer considerable amounts of data and does not require low latency. As it makes use of the LTE structure and has adherence to future 5G networks, according to Third-generation Partnership Project (3GPP), this is a feature that may attract it is adoption.

As a LPWAN technology, it significantly improves the power consumption of IoT and IIoT devices, with a battery life of around 10 years. It also has spectrum efficiency, especially in indoor coverage, as it belongs to a *Sub-Ghz* (MEKKI et al., 2019) category. LoRa is part of the LoRa Alliance, and also belongs to the *Sub-Ghz* category, and can be used in a point-to-point or star configuration, or even in connections with gateways through the LoRaWAN network. LoRaWAN is the name given to the protocol that defines the system's architecture and the communication parameters using the LoRa technology. The LoRaWAN protocol implements the details of the operation, security, quality of service, and power settings to maximize module battery life and application types on both the module and server sides. Thus, it can be considered that LoRa is the network's physical layer, and LoRaWAN is the logical layer of the network. In Table 2, you can see the technologies LoRaWAN, NB-IoT and others that are in evidence in IoT, and IIoT.

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

Source: The Author.

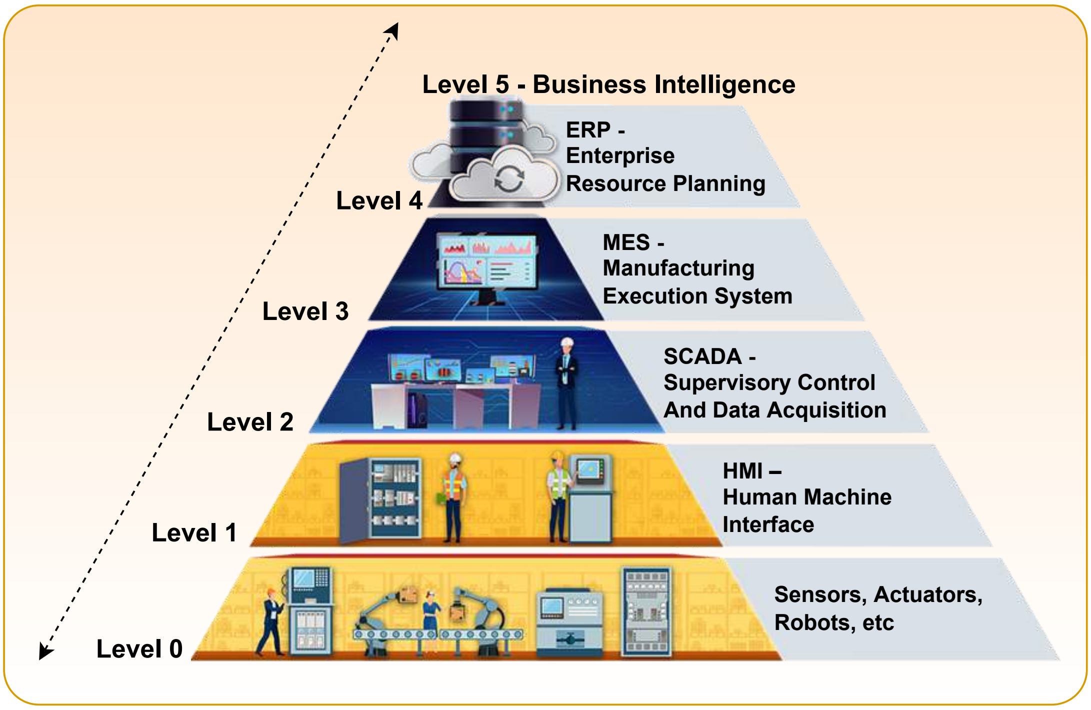
Evaluating the data in the Table 2, among the various technologies, when there are long distances for industrial applications, some of these can already be discarded (e.g., IEEE 802.11, Bluetooth Low Energy (BLE) and ZigBee) for not fit this requirement. The Sigfox network can also be excluded, depending on the infrastructure to set up such a network, the low transmission capacity in the order of a few bytes, high latency, and low security. The LTE-M network has a higher cost to deploy and a higher cost to maintain. However, it has a good communication rate (see these facts in Table 2). The 5G network was auctioned in November 2021, and in this way, it will still take some time before it becomes a fully available for Brazil.

In Section 2.5, some industrial automation scenarios are discussed, which with the support of IoT and IIoT, can be evolved, how industrial automation is divided, as well as some problems and opportunities.

2.5 IOT SCENARIOS, CHALLENGES, PROBLEMS, AND OPPORTUNITIES

A traditional representation or classification regarding systemic levels within an industry is the "Automation Pyramid," which is based on the The International Society for Measurement and Control (ISA) model, the ISA-95 (HOOD, 2015). As can be seen in Figure 11, each specialty (or level) is represented by a layer that composes the pyramid.

Figure 11 – Automation levels - Pyramid Model.



Source: Based on ISA-95 Model (HOOD, 2015).

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 or a group of systems can compose each level, and these can be customized and heterogeneous, different interfaces can be created for this role (LI; MANTRAVADI; MøLLER, 2020).

Table 3 lists and categorizes the hierarchical levels present in the ISA-95 Model, which is present in medium and large companies / industrial plants. The difference for smaller companies may be the absence of a BI system or an 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 the field of automation, integration systems between companies and operations, and Manufacture Operations Management (MOM) (HOOD, 2015). International Electrotechnical Commission (IEC) also has a widely used standard, the IEC62264 standard, which provides standards and terminology for batch control systems, also sometimes known as batch processes.

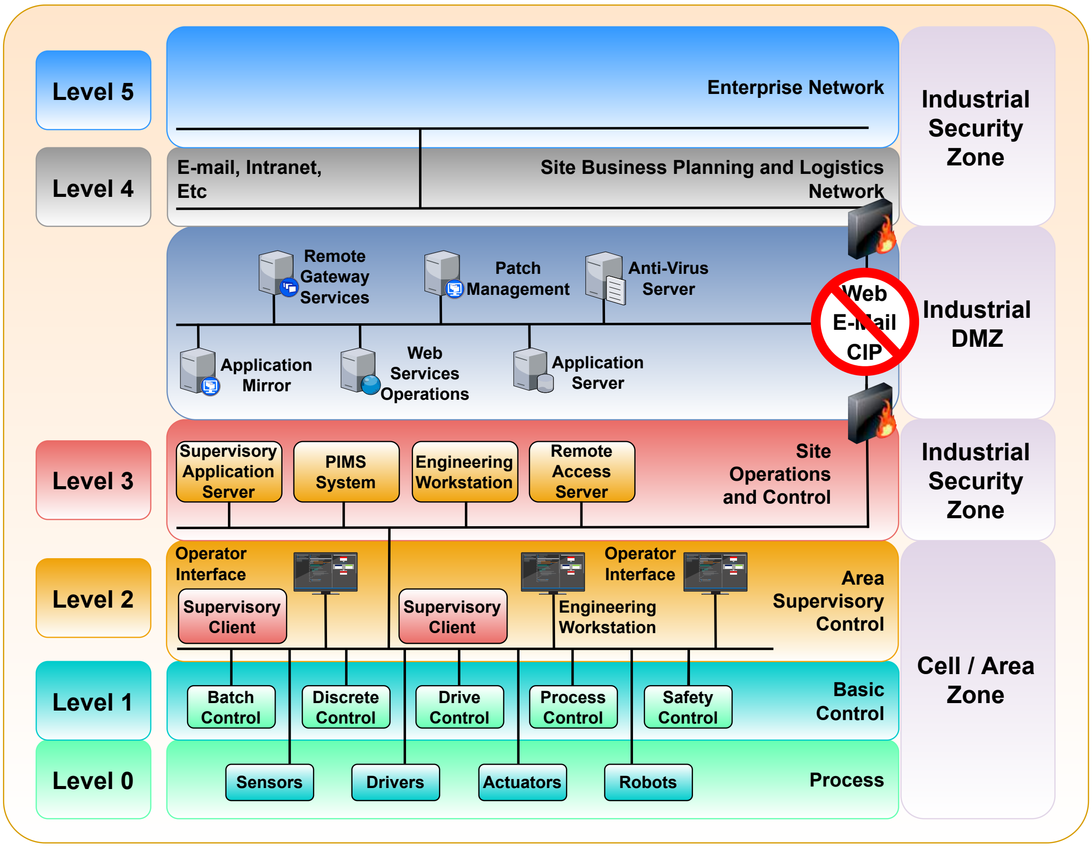
Table 3 – Automation levels - ISA-95 Model

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, Mathematical 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

Source: Adapted from (HOOD, 2015).

Table 3 exemplifies how the systemic levels are divided and groups types of systems and some examples. This model is a reference when it comes to process automation. Figure 12 illustrates how the levels are divided not only in the view of traditional automation but also of the so-called industrial informatics, being also important to be concerned with some issues, such as network segmentation, use of Demilitarized Zones (DMZs), firewalls, etc. Thus, Figure 12 presents some processes, exemplifying in which levels they are.

Figure 12 – Automation levels.

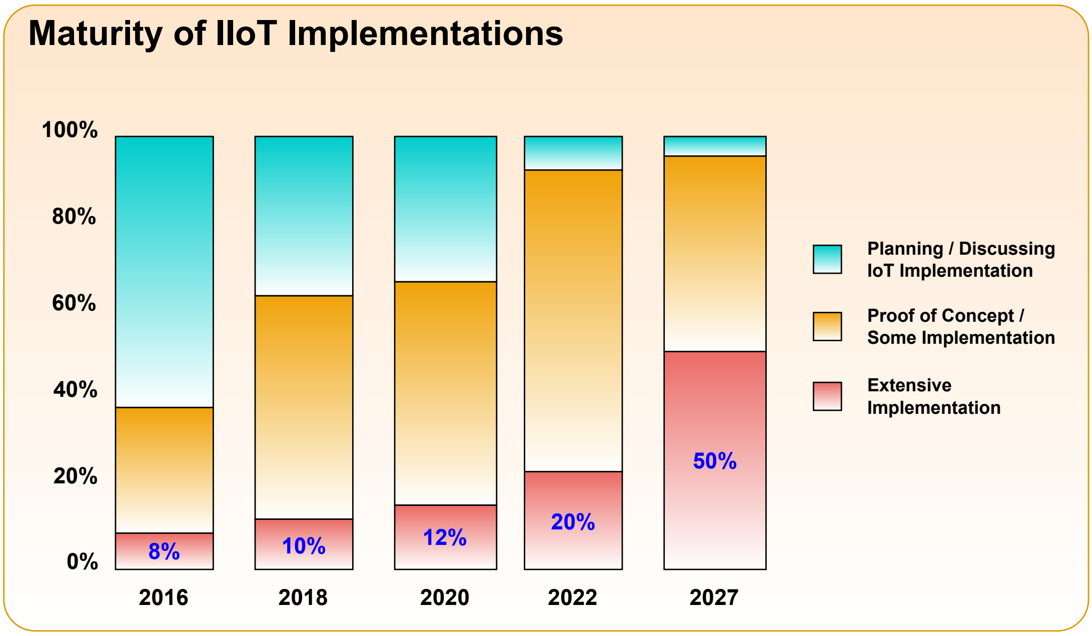


Source: Adapted from ISA-95 Model (HOOD, 2015).

It is observed in this division of levels of industrial informatics a 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 can be seen in Figure 12. For the purpose of study, the present work focuses on the controllers and HMIs that compose Level 1, up to the SCADA and process optimization systems, which are part of Level 2. Data communication challenges are integration from the shop floor to the cloud, in a production process already consolidated in a large company or process, or even in a smaller process, part of the same principle. In this way, even a small process can take advantage of this integration. As mentioned (Subsection 2.2.3), this type of study can benefit companies that are still before Industry 3.0, and IoT and IIoT can contribute to this process.

According to (NETSUITE, 2020), the adoption of systems based on IIoT has been slow, noting that many initiatives do not go beyond the Proof of Concept (PoC) stage. A survey conducted by Bain & Company (NETSUITE, 2020) concluded that many executives are concerned about the possibility of high implementation costs, structural changes, and the diversity of technologies without necessarily having one technology interact with another. Half of the group of respondents are from the industrial sector. Figure 13 allows to observe the evolution of discussions regarding the implementation of systems in IIoT, also in PoCs, when comparing the first survey carried out in 2016 with the survey conducted in 2020. However, what is considered "extensive use"; i.e., adopting important functions on the shop floor didn't follow the same growth rate.

Figure 13 – Maturity of IIoT Implementations.



Source: Based on Bain IoT Customer Survey (NETSUITE, 2020).

It is also possible to observe in Figure 13 that until 2027 this situation tends to change, indicating a 12% increase in the maturity level to 50% in 2027. Exploring a little more these factors regarding the problems and challenges, important features can be grouped into 8 groups, according to studies by (TECHNOLOGIES, 2019), (NETSUITE, 2020), (ARTEMENKO, 2021) and (JAYALAXMI et al., 2021):

1. Interoperability: A characteristic that brings IIoT and OT together is the fact that they are heterogeneous. However, IIoT has a challenge beyond interoperability issues. According to a survey by the company Nexus, 77% of respondents believe that is the main challenge for the industrial IoT vision. For systems integration, industrial automation systems seek platforms such as Ethernet and OPC. This means that when they are designed, they already follow a premise like this. However, the possibility of integrating devices as different as those of IIoT, different protocols, different application possibilities, and the number of smart devices connected to the Internet brings a greater challenge than what is observed in traditional automation, also in due to the lack of common interfaces. According to (GLOBAL, 2020), this integration can bring some pitfalls, such as increasing complexity in critical systems, depending on how an IIoT system is implemented.

It is also important to note that to achieve this interoperability, legacy systems must be considered throughout the lifecycle of the adopted solution. According to the same research, middleware compatible with the OPC protocol and gateways for systems based on Internet Protocol (IP) may be a way to be observed.

2. Reliability: Reliability is a fundamental requirement in process automation. In Table 1, it can be seen that in all categories, the expected reliability is above 99%. This is because issues involve safety, not only of physical equipment but mainly of human safety. IIoT devices need to have such physical reliability (robustness) to be able to tolerate climatic differences, physical differences, temperature variations, etc.; thus providing a high Mean Time Between Failures (MTBF). Redundancy can be a key factor contributing to reliability.

3. Security: IoT brought as a challenge the possibility of connecting many devices in terms of security. With the advent of COVID-19, remote access to companies, including the shop floor, also had a significant increase according to (GLOBAL, 2020) and (KAYALY; HAZEM; FAHIM, 2021). Besides cloud-based services, these two factors have brought new possibilities for cyber attacks. The authentication of people and devices must be observed at all points of integration between the levels of the automation layers, observing the cybersecurity standards based on the IEC-62443 standard, which deals with this topic. (JAYALAXMI et al., 2021), proposes the use of a framework with different types of authentication services (e.g., M2M), three-layer authentication, biometrics, context identification, digital certificates, etc.

4. Performance: Massive data transmission is part of the demands for Industry 4.0 and is one of the pillars of 5G technology. It is expected that with the amount of connected equipment, the increase in the need for authentication, and the increase in systems based on video transmission, such as streaming, in which the performance of networks can represent the success or failure of any initiative for IIoT. Especially in industrial networks that are still based on old protocols and IPv4. (ARTEMENKO, 2021) points out latency as one of the needs and challenges to be overcome. A Gigabit-based *backbone* can be considered the minimum in any implementation, which can also bring difficulties for Small and Medium-sized Enterprises (SME) and companies still based on Industry 2.0.

5. Management: Some management challenges can be observed in:

   a) Network: An integrated set of tools that take into account installation, operation, maintenance, and diagnostics;

   b) Productivity: Ability to configure and deploy devices quickly;

c) Maintenance: Predictive systems that involve sensing for continuously monitoring assets on the shop floor (e.g., motors, drivers, sensors, meters, etc.). Prescriptive maintenance will also be important a key role;

d) Resilience: Systems that are monitored and adaptable to any change in the environment, such as a node crash or a server crash; and that can automatically recover in a failure scenario;

e) Mobility: Systems that can be accessed and monitored wherever the support team is. Systems that make use of real-time notifications will be paramount; and

f) Integration: The APIs are great tools for simplifying application development and integration between systems.

6. Storage: According to (GLOBAL, 2020), IoT devices can generate significant data. IDC (IDC, 2020) estimates that by 2025, 175 ZB of data will be generated globally, and the adoption of industrial-grade IoT devices is touted as one of the driving factors for this. In a scenario of increasing data volume, as pointed out by the research, the storage and consultation of this data will be crucial for the success of projects to adopt this type of automation system.

7. Scalability: The need to have an agile way of being scalable, whether in several servers, processors, memory, or storage space, will be paramount. The adoption of cloud-based technologies has "elasticity" as one of the most striking features of this business model.

8. Change in Mindset: Second (NETSUITE, 2020) realizing the benefits of IoT may first require investments. Especially in the industrial environment, the scope of an automation project tends to be broad. Furthermore, it requires a change "in how" something is produced in processes that have been consolidated for decades.

Section 2.6 addresses real problems in an industrial environment and how IoT and IIoT can contribute in areas, e.g., process monitoring, digitalization, automation of geographically distant areas, etc.

2.6 PROBLEM DEFINITION

An industrial plant consists of integrating several automation systems, and heterogeneity is one of its characteristics. In terms of design, management and technical/economic viability are the same, regardless of whether the project is for industrial automation or not. Thus, if the project is not motivated by legal or safety issues, such a project needs to be "attractive". Therefore, Internal Rate of Return (IRR) and Return on

Investment (ROI) must adhere to the objectives set by the company (KASSAI, 1996) and (MONDIN, 2014). 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. That is operational and financial stability problems. When an industry decides to automate it is functions, it can be seen that the motivator for this is common to different types of processes, among which, according to (COSTA; LISBOA; SANTOS, 2002), there are:

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 process control level, statistical data generation, reports, Key Performance Indicators (KPIs), etc.

Thus, some questions emerge: (i) What to do when an automation project is necessary but not economically viable? (ii) When does a company of type SME have budget constraints?

SMEs face financial and resource difficulties concerning acquiring new technologies, one of the reasons why these companies still behave cautiously in this matter (MENDES; FILHO, 2007),. 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 that may not be financially attractive. This same case may be what happens in SMEs; in this way, this present study can be useful for this industrial segment and those companies or processes prior to Industry 3.0. For the evaluation of a case study, a real production environment was chosen at the company ArcelorMittal Vega, located in São Francisco do Sul/SC, one of the most modern flat steel transformation units in the world at the time of its implementation, but after the years 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 "auxiliaries". All data were tabulated and classified according to Table 1. Thus, Table 4 was created as a sample. Other characteristics were also evaluated (e.g., servers, controllers, remotes, actuators, database, etc).

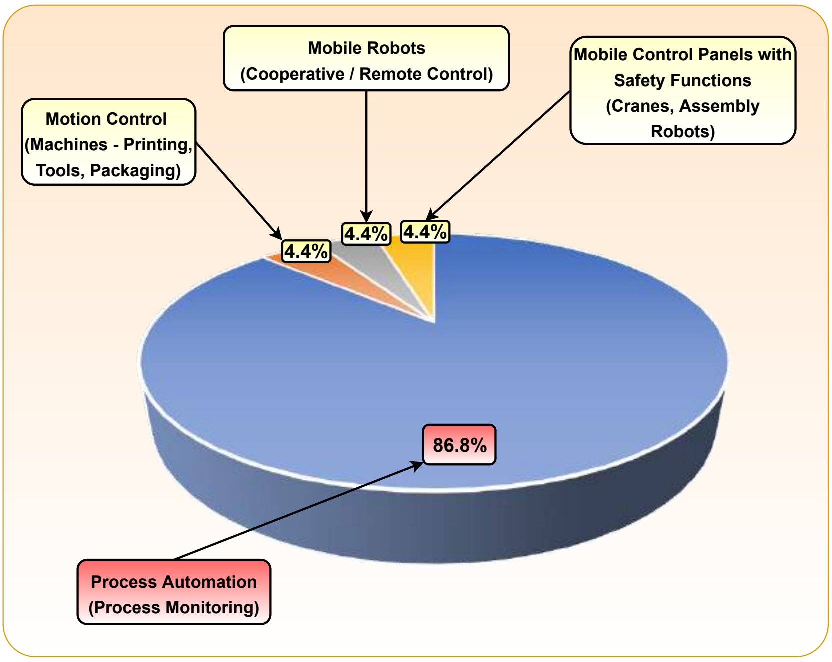
Table 4 – Case study: section/part of the environment (ArcelorMittal Vega.

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

Source: The Author.

With the grouping represented in Table 4, it was evidenced that 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. 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 14 allow to observe the distribution of the categories observed within the analyzed industrial park.

Figure 14 – Observed distribution.



Source: The Author.

The data stratification presented in Table 4 in it is a complete version and is also presented in Figure 14, describing how automation/process monitoring stands out when compared to the other areas. In addition, the four areas of Table 1 are represented. Evaluating the tabulated data, some existing systems are adherent to be connected in wireless networks on the shop floor (IEEE 802.11x), a characteristic observed in approaches about IIoT. A highlight was that during the data analysis, it was noticed that even in a company of this size, there are non-automated processes; and, thus are not contained in the tabulated data. Among these can be mentioned:

1. Receipt: Yard where the raw material is stored before the start of processing. Also known as "Yard of Hot Coils";
2. Intermediate: Cold rolling mill outlet yard, which stores coils that will be processed in three other production lines (Batch Annealing, Galvanization Line 1, and Galvanization Line 2);
3. Dispatch: Four large yards where the "Finished Product" waits to be packed and dispatched to customers or to external storage yards;
4. Warehouse: Although there is a computerized system, all materials are still stored on shelves, and there is no quick way to carry out an inventory or the robotic removal of an item;

5. Scrap Yard: Yard where process scraps (in the form of plates of different sizes) are temporarily stored in the open yard, awaiting placement in buckets and subsequent dispatch; and

6. Zinc Dross: Bath slag taken from zinc pots, which are shaped, labeled, and later sold. They are "bricks" weighing around 600 kg, which are moved by forklifts and stacked until they are sold.

Based on the items listed, coil yards (in their various types) are among the items with no monitoring systems. When analyzing Figure 15, it can also be observed that the yards have large areas with movement or occupation of coils. This figure is illustrated a coil dispatch yard (also called finished product), which can be found in steel mills, service centers (e.g., coil processing), and even in customers who purchase such reels.

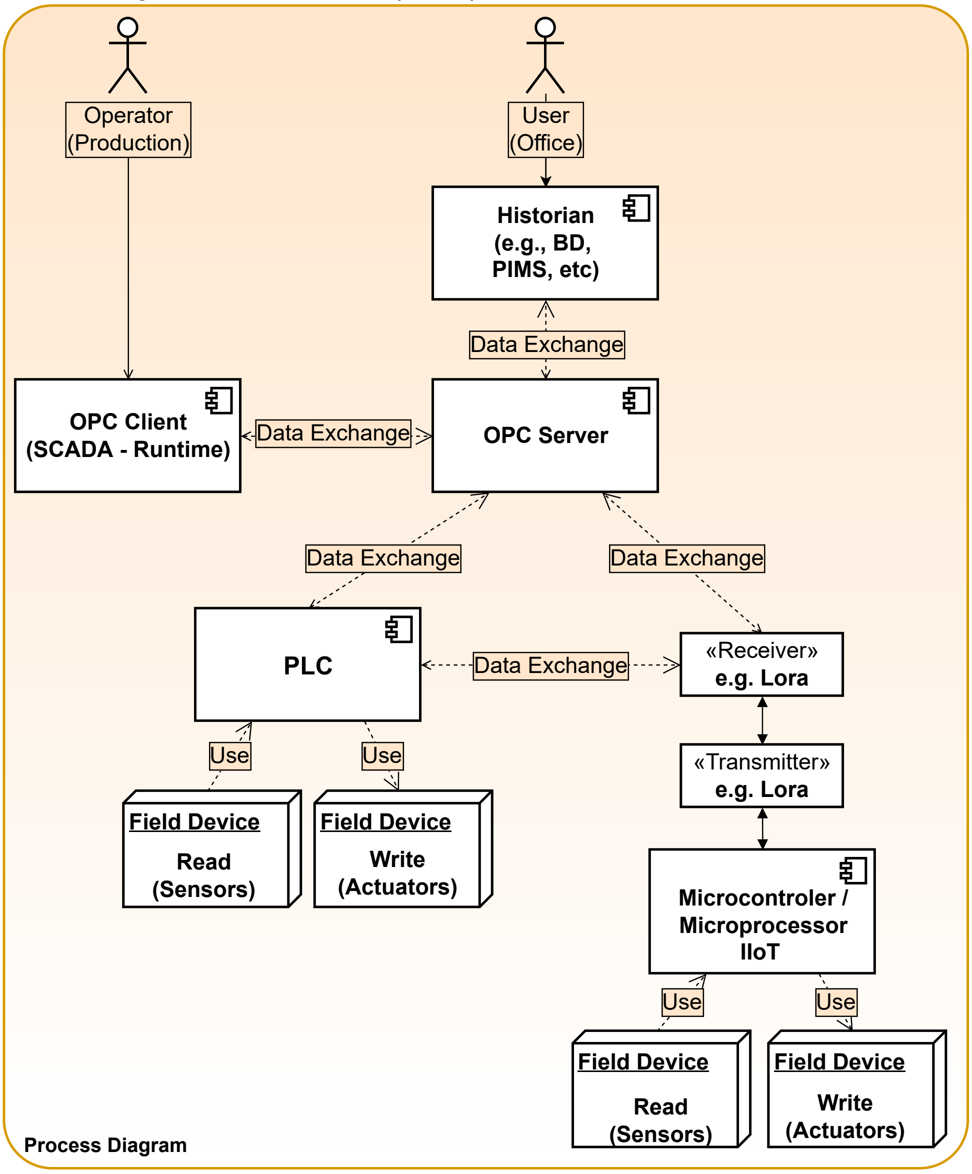
Figure 15 – The Representation of Coils Warehouse.

Source: ArcelorMittal Vega - Intermediate Coil Warehouse.

One of the characteristics of the highlighted processes that do not have any level of automation is that they are slow processes and they occupy large areas. In this way, the LPWAN technology can contribute to this automation, as it can cover a large area when you choose to use NB-IoT or LoRaWAN type networks. A process like the one in Figure 15, 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 that are part of Level 3 systems, according to the ISA-95 model. To carry out a Proof of Concept (PoC), the smallest infrastructure 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 needed to build something of civil engineering at a point, but that cables or pipes are passing through that same place), among others.

Figure 16 exemplifies an architecture or process proposal for PoC, in which a microcontroller is used to receive/send data and integrate it with an automation system. The architecture includes important systems and communication protocols such as OPC Server, OPC Client, Historians, Database, Fieldbus, etc.

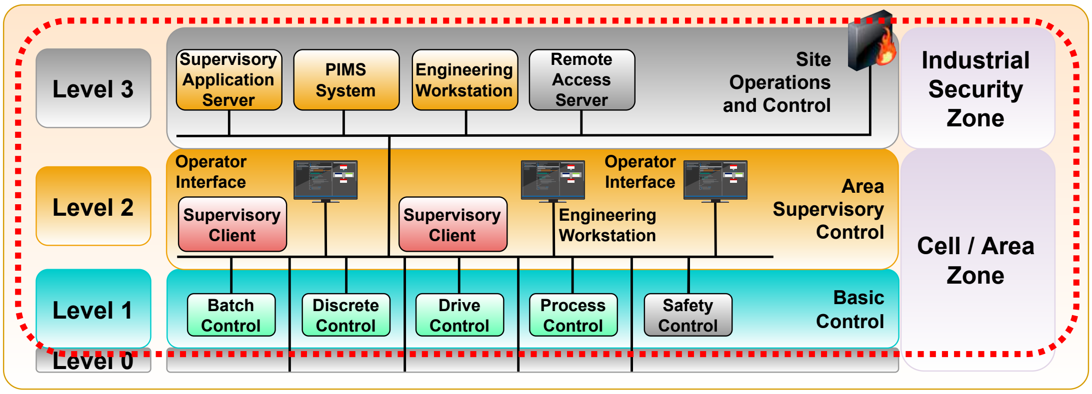
Figure 16 – PoC - Example of process architecture - static view.



Source: The Author.

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 with any other automation system, such as: 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 (Transmission Control Protocol (TCP) or User Datagram Protocol (UDP)), Inter-Process Communication (IPC), Hypertext Transfer Protocol (HTTP), Representational State Transfer (REST), XML, among others, could also be used without the need for changes to the architecture. The process proposed in Figure 16 is the representation of the area of interest to be developed in PoC, and which is highlighted in Figure 17. This area of interest is mentioned in Section 2.6, 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).

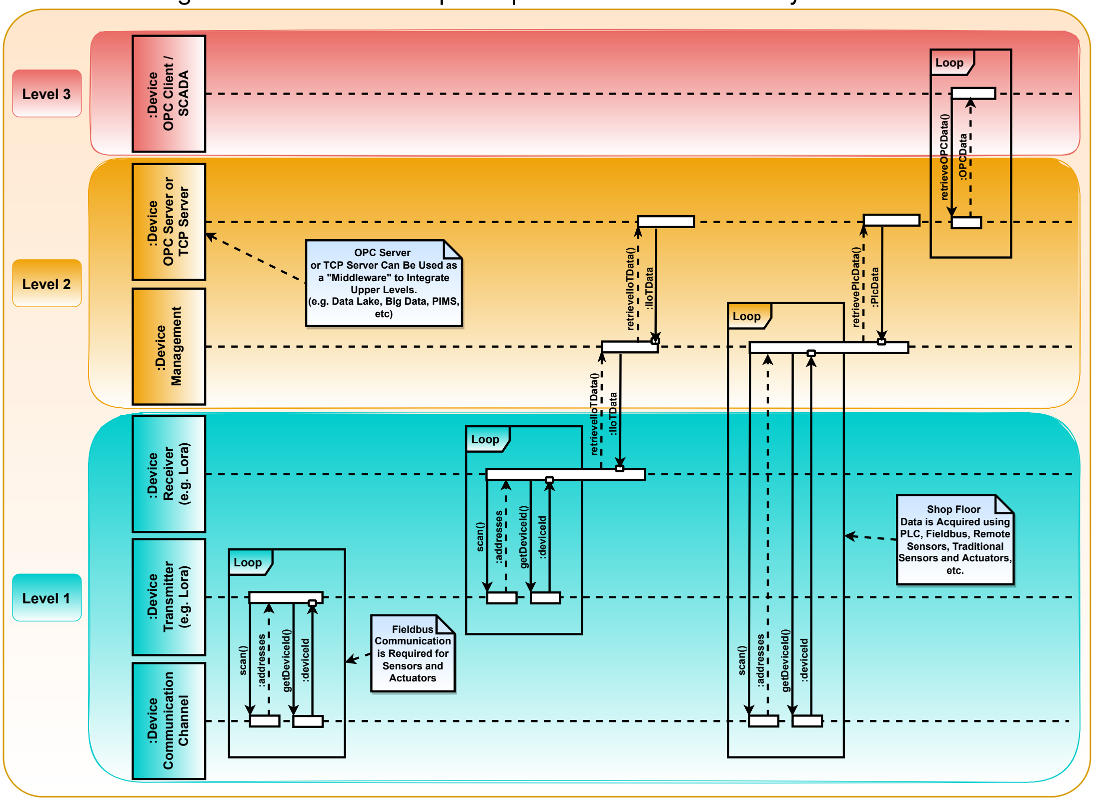
Figure 17 – PoC - Example of process achitecture.



Source: Based on ISA-95 Model (HOOD, 2015).

Figure 18 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 processes related to their use. For better visualization, each process macro is represented by the color that each "System Level" received in Figure 12.

Figure 18 – PoC - Example of process architecture - dynamic view.



Source: The Author.

It can be noted that both figures (Figure 16 and Figure 18) 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 forms of representation 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.

Section 2.5 presents 8 points of attention and challenges for adopting IIoT technologies in an industrial plant. These items can be addressed in a broader way, in which an IoT device is part of the IT or OT ecosystem, or with such a specific adoption, in which the other components of this so-called "ecosystem" are not even aware of the existence of such a device. Criteria like security or performance might be the first that comes to mind, but others like "interoperability" if legacy systems exist must also be considered.

For this present work, the PoC to be developed will address the following items:

1. Interoperability: This is one of the most desirable characteristics in the objectives to be achieved since the PoC will be integrated into an existing system and already considered legacy. The architecture designed allows this type of integration and is "open" enough to be integrated into any traditional automation system, even when you have a heterogeneous environment;

2. Reliability and Change in *Mindset*: These two items are correlated. Reliability can be interpreted by the quality of the equipment and the developed solution (logic). However, IoT and IIoT on the shop floor is still a big change in the *mindset* of automation professionals;

3. Security: The development will use the internal automation network, which does not have direct access to the corporate network. There are routers with filters for protocols, ports, and addresses, supported by Access Control Lists (ACLs). There is also an ongoing project where firewalls will be installed on the shop floor. Wireless communication will be point-to-point, linking data from a PLC to its remote. Another concern in terms of safety is that a deep analysis of the existing radio bands in the factory halls is necessary. An example of this is that radio bands can interfere with radio-controlled overhead cranes;

4. Performance: As it is a PoC in which one of the main objectives is integrating systems, information considered "slow" will be monitored. In this way, high performance is not a requirement to be achieved;

5. Storage: As the integration tends to send data to existing systems, such as Level 2, PIMS and SCADA, these are already dimensioned to support the increased storage demand of the new variables; and

6. Management and Scalability: The solution will be developed to be scalable, easy to maintain, monitorable, and integrated with existing systems.

2.7 CHAPTER CONSIDERATIONS

One of the challenges for implementing systems based on IoT and IIoT on the shop floor is to identify the ideal technology for each need. This implies elaborating a detailed analysis of the cost-benefit ratio compared to the objectives to be achieved. Therefore, a clear specification which 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.

Desired features:

1. Flexibility: When using a wireless device (e.g., sensors, controllers, etc.), such a system can be expanded as needs arise;
2. Optimization: Optimization of physical spaces and reduction of materials;
3. Installation: With the optimization achieved, it is also easy to install equipment in a more practical and faster way, without the need for cabling or changes in physical structures for them to work;
4. Range: You can reach places cables cannot reach (e.g., cost reasons, technical infeasibility, etc.). Some technology can be used for signal extension (e.g., repeaters). In some cases, *mesh* technologies may be used;
5. Costs: In addition to the above items that can generate cost savings, maintaining a wireless system may not require a high recurring cost. Carrying out feasibility tests may require a lower cost, greater agility; and
6. Security: If properly configured, a wireless system can have the same level of information security as a wired system.

Attention points:

1. Interference: The signal quality may be lower than in wired systems. The main reasons for this are the small bandwidth due to radio transmission limitations and the high error rate due to interference (if it exists);
2. Security: If misconfigured, a wireless system can have the same level of information security as a wired system. Wireless channels are more susceptible to unwanted interceptors. The use of radio waves in data transmission can also

interfere with other high-tech equipment, such as equipment used in hospitals. In addition, electrical equipment is capable of interfering with the transmission, resulting in data loss and a high rate of transmission errors; and

3. Low Data Transfer Rate: Although the transmission rate of Wireless Networks is growing rapidly, it is still very low compared to guided networks.

Despite this, the potential observed is promising. 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," according to Table 1.

3 REQUIREMENTS AND PROPOSAL

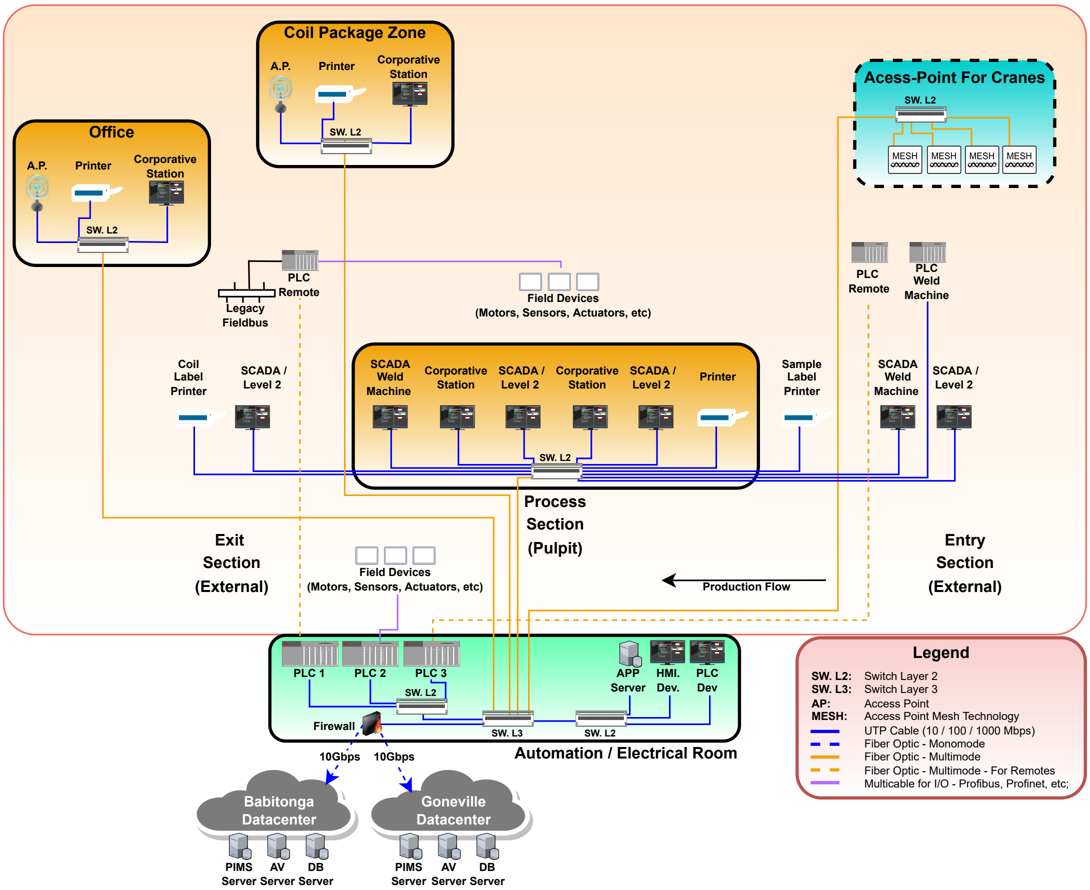
Technologies based on IoT and IIoT can contribute positively and even be revolutionary to supporting shop floor automation as we know it. Versatility is also a feature when using this type of technology, especially when associated with LPWAN technologies. In a traditional industrial automation project model that uses technologies such as PLC, SCADA, and cable communication, the technical/economic feasibility analysis of the project sometimes becomes theoretical and relies on the experience of those who are developing this project. Although empirical knowledge is the result of experience, experimentation, and observation in a given area of knowledge, this acquired knowledge does not cover all possible applicability of a given technology; in these cases, there is an “extrapolation” of the previously mentioned acquired knowledge in which there is a risk of assuming an expected result without due experimentation. Based on clear and objective prerequisites, it is possible to use a series of technologies based on IoT, such as: LoRa, NB-IoT, ZigBee, IEEE 802.11, among others, and thus, promote technological acceleration in shop floor environments. The table developed by (BROWN et al., 2018) suggests that in industrial automation systems where response time is not a fundamental requirement, technologies such as IoT and IIoT can be used in the concept of "Process Monitoring". This category of automation systems allows the monitoring/visualization of a production process, contributing to the increase of data generated on the shop floor, which will positively contribute to the management of such a process.

Based on the requirements specification (Section 3.2), it is possible to identify related works, evaluating the approaches adopted in similar situations or environments in accordance to Sections 2.5 and 2.6, and thus contribute to the dissemination and adoption of such technologies in shop floor environments with a potential reduction of investments when compared with traditional technologies of traditional automation.

3.1 SCENARIO SPECIFICATION

Figure 19 illustrates a traditional shop floor environment on a real production line called Recoiling Line (RCL)#1 at ArcelorMittal Vega where PoC will be developed. This line was built parallel to the packaging and coil dispatch yards (also known as package zone), where the wired and IEEE 802.11 network connections are interconnected in the same electrical room with a link to the company’s two data centers.

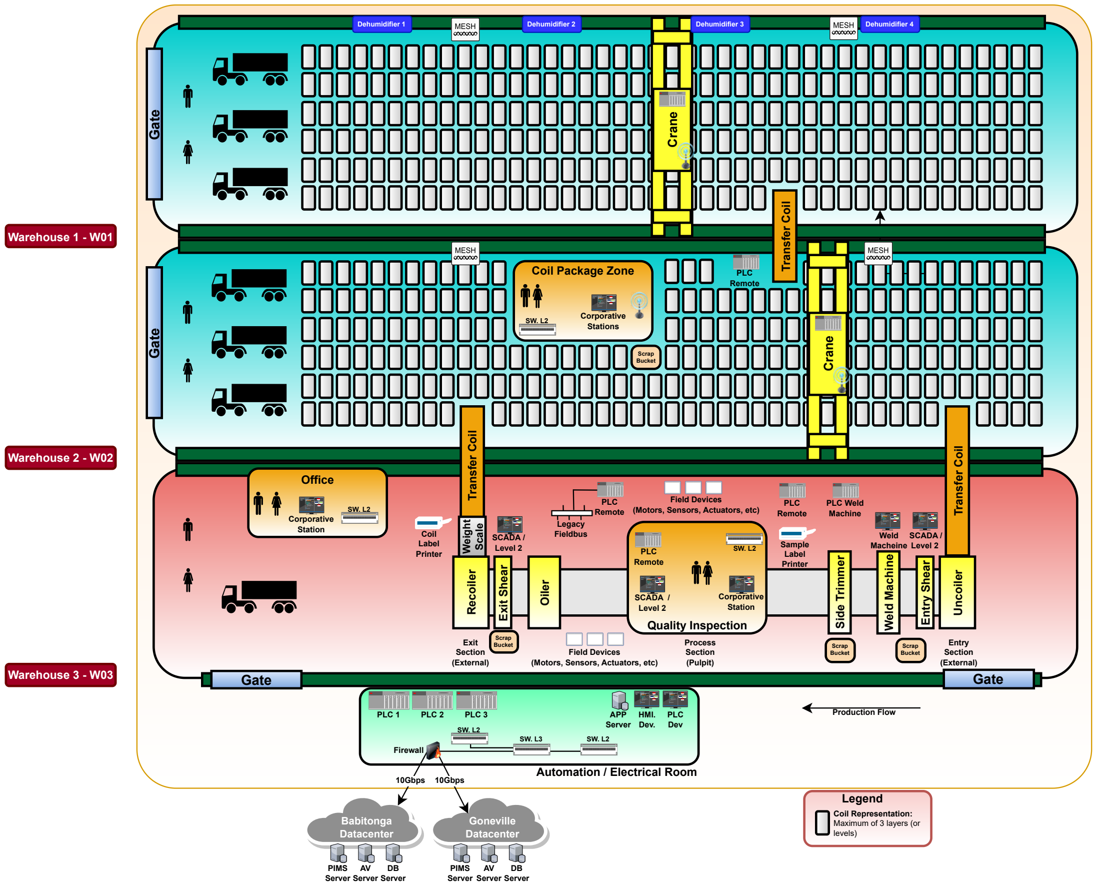
Figure 19 – Network diagram - Based on RCL#1 - ArcelorMittal Vega.



Source: The Author.

The "orange" frame has a network at the production line; the green frame represents the master network connection in the electric room, and the "cloud" represents the interconnection between the electric room with both data centers. Even if physically this is a small production line, conceptually, it is a suitable environment for the development of a PoC, as it has easy access, low process speed when compared to the others, and several Level 1 / Level 2 equipment and connectivity to all data centers. Physically, this line is also close to the administrative buildings. Figure 20 shows the floor plans of the RCL#1 in red frame, the warehouse and package zone in blue frame (small gray frames represent the coils). The electric room and the connection with data centers are represented too. Based on this type of visualization, it is possible to observe some equipment and devices that may be candidates for the automation of some processes. It is also possible to observe that the automation implemented is based on a traditional model using PLC, wired network, SCADA systems, remote I/O, etc.

Figure 20 – Based on warehouse, package zone, and RCL#1 - ArcelorMittal Vega.



Source: The Author.

The observed environment (Figure 20) has some non-automated activities, such as packaging coils, requesting the exchange of scrap buckets, monitoring the temperature and humidity of the electrical rooms, etc.

ArcelorMittal Vega intends to promote digital acceleration in non-automated or manual processes. It understands that a traditional automation framework can be time-consuming, with some level of complexity, and with a considerable investment compared to IoT. For example, to monitor temperature and humidity in an area considering traditional automation, the sensors must be connected to a PLC. After that will be necessary to develop the reception of data in the SCADA or Level 2 system and then create an interface with the company's ERP and later create a dashboard with Microsoft PowerBI or another tool for the development of dashboards. For example, with the technologies LoRa and LoRaWAN, it is possible to use standard sensors and send the data directly to a data lake and share this information with all levels of the company with reduced cost and time.

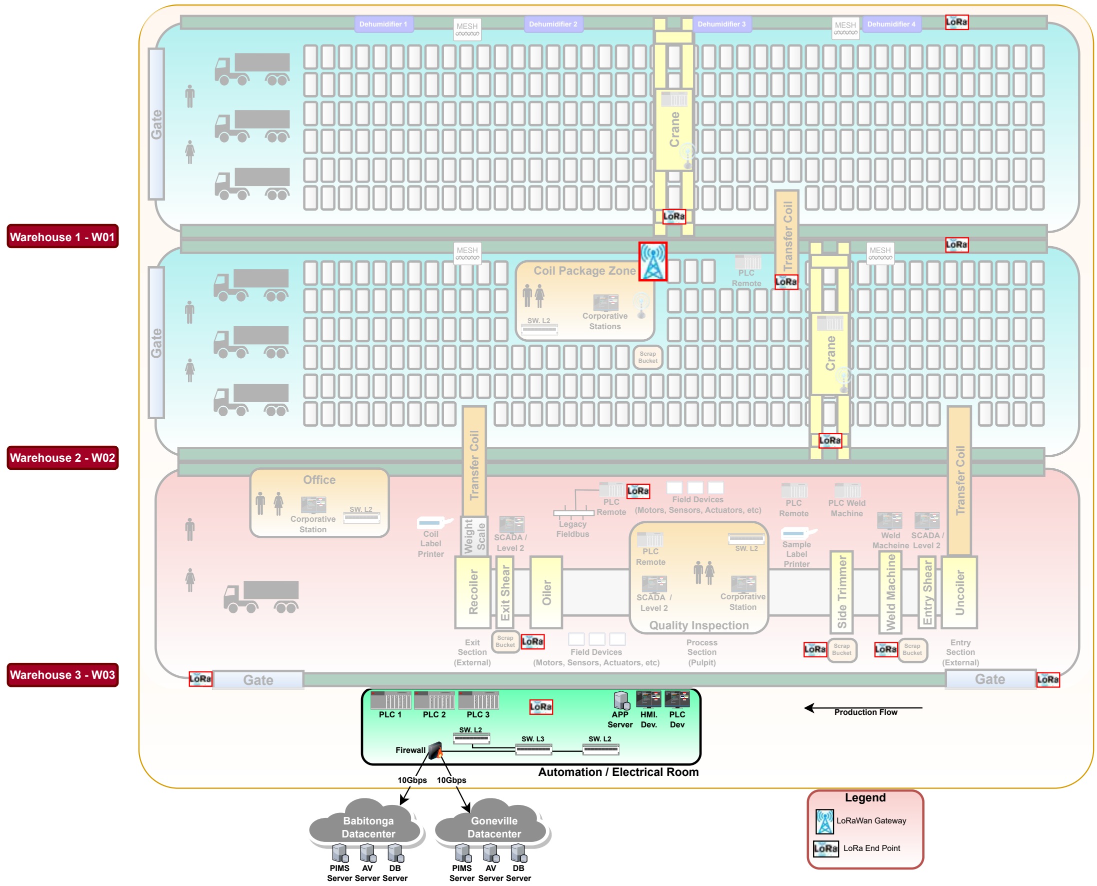
In the area of interest in carrying out the PoC, the following problems will be studied:

- Coil Yard: Monitoring the temperature and humidity of the coil yards as it can influence the oxidation of coils and in package process;
- Scrap Bucket: Monitoring the location of process scraps. These scraps can be head scraps, tail scraps, welding machine scraps, and side-trimmer. The bucket position location also indicates the type of scrap and if the bucket is in use or standby position. Knowing this information, it is possible to automate the process of changing buckets with automatic scheduling of trucks;
- Overhead Cranes: Monitoring the positioning of overhead cranes where their location can be used to identify the approach to the packaging zone; and
- Electric Room: Monitoring the temperature and humidity for equipment security.

Figure 21 indicates using the floor plans the possible points that can be modified to promote the initiatives based on IoT and IIoT, the connection points of the devices, and LoRaWAN gateway. These candidates' points for monitoring are highlighted in red boxes (endpoints and gateway). The wired and WiFi infrastructure can interconnect with other shop floor or corporate networks. This type of connection, in addition to meeting the needs of the shop floor, also makes it possible to send data to "higher levels"[1] and even to a cloud platform.

[1] ISA-95 Model - The proposal is developed considering Level 1 and Level 2 systems. In this case, the higher levels mean Level 3, Level 4, or Level 5 systems.

Figure 21 – Proposal for IIoT based on LPWAN technology at ArcelorMittal Vega.



Source: The Author.

Figure 21 indicates that in compliance with the PRE4 prerequisite and the FR5 functional requirement, the solution will be integrated into the industrial automation network, and in this way, the data can be accessed by Level 1, Level 2, PIMS, SCADA, and others. These systems will be modified to support the new variables, including the status of the sensors and the gateway themselves. The monitoring criteria include presence sensors, temperature, and humidity sensors, Global Positioning System (GPS), battery signal level, signal quality level, amount of errors, and others. Actuators using light and sound activation are also expected for the system. This monitoring can send alerts by email or messages using Microsoft Teams, and the monitoring can feed a dashboard using Microsoft PowerBI. Concerning the baud rate, the supervisory systems support transmission rates below 1 second. However, the definition of speed must be thought of according to the type and function of the data acquired. For example, in a blast furnace where the temperature is on the order of 1500ºC, a significant temperature variation would take a few minutes to be noticed; thus, an acquisition rate of the order of a few seconds would not be necessary. This type of analysis must be performed for each process variable.

3.2 REQUIREMENTS SPECIFICATION

Concerning the traditional automation, Figure 20 demonstrates part of two large coil yards and a production line. Even though the figure indicates an automated environment, there are known limitations, such as: PLC and remotes that do not cover all the necessary distances, high use of inputs/outputs (I/O) of PLC and remotes, need changes in civil and mechanical infrastructure, and others. The problem presented occurs in industrial environments in the discipline of industrial automation. Therefore, developing a prototype in such an environment is necessary, considering the baud rate, accessibility, integration, security, and simple maintenance to promote the best possible MTBF. To achieve the necessary objectives in the proposed scenario, it is essential to guarantee the conditions required for the stages of development and implementation of PoC. Thus, it's essential to identify the necessary Prerequisites (PRE) and, through this result, specify the functional and non-functional requirements for developing the proposed solution.

The following Prerequisites (PRE) are identified:

- **PRE1:** Based on technologies as LPWAN for communication and integration;
- **PRE2:** Collect data I/O from Level 0 based on the shop floor or add a new sensor/actuator;
- **PRE3:** Communication and integration with existing legacy systems; and
- **PRE4:** Collect metrics such as processing, memory, network traffic (TCP and UDP), and transaction latency.

To achieve the prerequisites established in the proposed scenario, it is mandatory to guarantee the necessary conditions for the stages of development and implementation of PoC. Moreover, it is necessary to specify the set of Functional Requirements (FR) and Non-Functional Requirements (NFR) to develop the proposed solution.

The FR specified are:

- **FR1:** Use a real shop floor environment (factory) where the prototype is linked to the production process and automation system;
- **FR2:** Directly access to the sensors/actuators to be automated and communicate to other devices of the same type or typical devices used in industrial automation;
- **FR3:** The baud rate and communication must be compatible with the category of industrial automation system and with the production process in which the communication will occur;

- **FR4:** Ensure the security of communication between the solution processes and other actors; and
- **FR5:** Provide shop floor data as a gateway for integration with other automation systems (e.g., OPC Server, OPC Client, PIMS, TCP or UDP, and others).

The NFR identified:

- **NFR1:** The solution must be as parameterizable as possible, allowing it to be adapted to the characteristics of PoC;
- **NFR2:** The operation of the solution as well as the techniques adopted to capture metrics and transactions, shouldn't affect the overall performance of the solution and do not permit it to cause disturbances in shop floor systems with which it will be used to communicate;
- **NFR3:** Use in a clear way one of the levels of the industrial automation pyramid - adherence to ISA95;
- **NFR4:** Possibility of adding new devices or field signals with low effort; and
- **NFR5:** Possibility of communication with higher level systems, e.g., MES, ERP, and others.

The definition of requirements makes it possible to identify the aspects that need to be addressed and provide subsidies to identify related works. Therefore, the requirements defined here are used to compare related works against the problem to be solved.

3.3 RELATED WORK

To conduct comparative analyzes between IoT and IIoT technologies on the shop floor in private networks, searches are carried out in search tools for scientific articles to identify works that have a similar scope to the objective of this research. To conduct a systematic review of the literature (DETROZ; HINZ; HOUNSELL, 2015), the review is applied, and from there, a review protocol is established containing inclusion and exclusion criteria, the definition of the research bases, keywords, and reading sequence of abstracts and articles.

3.3.1 Related work selection

The search for related works begins with the established objectives and requirements for developing the research. At this point, it's necessary to define the keywords to be used in scientific search tools to delimit the scope of the research.

The protocol developed establishes the following criteria:

- Language: Portuguese and English;
- Bases used in the research: IEEE, ACM, Springer, and Elsevier;
- Samples: conferences, periodicals, white papers, dissertations, thesis, and monographs;
- Keyword: ("LoRaWAN" OR "NB-IoT") AND ("PLC" OR "SCADA");
- Research period: 2015 to 2022;
- Inclusion criteria: Articles and reviews that contain the terms used in the search string in your abstract and that development has taken place on the shop floor; and
- Exclusion criteria: Articles and reviews that do not contain the terms used in the search string in their abstract, where the focus is infrastructure, or that only present technology comparisons regarding data transmission without the application on the shop floor.

Google Scholar can perform a broad search, and in some cases, it is unclear whether an article has been published. This mechanism was only used to assist in developing the search string. The searches using the settings established from the criteria presented in the protocol returned a total of 30 works that were published between 2015 and 2022. The search string used was the third version developed. The first versions were tested in the IEEE Xplore search engine and returned 64 articles. They were variations using "IIoT", "AUTOMATION", and "LPWAN". However, after reading the titles and introduction, it was discovered that most of the articles weren't related to the shop floor as the focus. Thus, the search string focused on terms related to Level 1 systems, such as: "SCADA" or "PLC". In this way, 30 articles on the four platforms surveyed were obtained, and the evaluation process was started for inclusion and exclusion criteria. The process of reading the titles and the introduction were not enough to reduce the number of selected articles. From reading the abstracts of the 30 studies that returned from the first phase of exclusion and insertion criteria, 16 studies were selected in the systematic review.

3.3.2 Inclusion and exclusion criteria

Firstly, works written in English or Portuguese were defined as inclusion criteria. The second indicates that the bases used in the research: IEEE, ACM, Springer, and Elsevier The third inclusion criterion establishes that the selected works must be articles, extended abstracts, book chapters, or technical reports. Finally, the papers should address the topic of automation in the shop floor environment. In the case of the identification of duplicated works, only the most recent result should be considered. Exclusion criteria were ”gray” literature works (*i.e.*, publications in blogs and journals without scientific rigor) and productions in a language that is not among the predefined ones. Another exclusion criterion defined was concerning the publication date. As the present work presents a proposal aimed at the container virtualization environment, only the results with a publication date since 2015, the year in which the Docker technology was developed, and reference of the model, were considered.

3.3.3 Search Results

After the reading process using the introduction and abstract of the selected articles, there was a need to do a first complete reading of the article to determine whether they would be related or not. After reading it, it was found that even if some of them were not directly related, they could be good support material, and that's why they were included. Thus, the following list presents the related works and the identified tools:

1. **A Simulation of an IoT-based Solution Using LoRaWAN for Remote Stations of Peruvian Navy** (AGUILAR; MERINO, 2019): This paper presents a simulation of an IoT-based Solution Using LoRaWAN for Remote Stations of Peruvian Navy;

2. **Edge analytics for anomaly detection in water networks by an Arduino101-LoRa based WSN** (BABAZADEH, 2019): This paper presents a novel distributed data analytic architecture and corresponding algorithms that apply to infrastructure anomaly detection;

3. **Control Communication Co-Design for Wide Area Cyber-Physical Systems** (BHATIA et al., 2021): This paper presents the Wide Area Cyber-Physical Systems (WA-CPSs) are a class of control systems that integrate low-powered sensors, heterogeneous actuators, and computer controllers into large infrastructure that span multi-kilometer distances;

4. **A Performance Study of an IoT System Using LoRa Access Network Technology** (ELSELINI et al., 2020): This paper presents the growing interest in the

"Internet of Things" different types of techniques for linking and communicating between things has emerged, such technologies LoRa-LoRaWAN technology;

5. **Turning old into new: adding LoRaWAN connectivity to PLC in brownfield installations** (FERRARI et al., 2021): This paper presents the design and the experimental validation in a real-world use case of a low-cost solution aiming at providing LoRaWAN Class A connectivity to a Programmable Logic Controller (PLC);

6. **A Survey of IIoT Protocols: A Measure of Vulnerability Risk Analysis Based on CVSS** (FIGUEROA-LORENZO; AñORGA; ARRIZABALAGA, 2020): This paper presents the security process in IT environments and the efforts to develop a model that suits industrial environments;

7. **Applications of LoRaWAN in SCADA Systems** (HASANOV; PARSAYAN, 2020): This paper explores possible applications of LoRaWAN in the oil & gas industry (SCADA Systems);

8. **LoRaWAN-based Smart Sewerage Monitoring System** (JEFFERY et al., 2021): In this paper introduces a smart sewerage system based on LoRaWAN and Cloud computing technologies;

9. **An IoT LoRaWAN Network for Environmental Radiation Monitoring** (MANZANO et al., 2021): This paper explains about a reliable and highly scalable Internet of Things (IoT) end-to-end data infrastructure has been developed for environmental radiation monitoring at the European Organization for Nuclear Research (CERN) based on a low-power wide-area network (LPWAN);

10. **Multilevel IoT Model for Smart Cities Resilience** (MODARRESI; STERBENZ, 2017): In this paper proposes a new multilevel IoT network-centric model and discusses it is applicability to the application of resilience and survivability;

11. **IoT Retrofitting Approach for the Food Industry** (PANDA et al., 2019): In this paper, an advanced quality check method has been proposed by identifying influencing process parameters and proposes a retrofitting architecture for existing machines by implementing a hardware device capable of collecting a vast amount of process data and integrating them with a cloud platform for further analysis;

12. **Industry 4.0 in the port and maritime industry: A literature review** (ZARZUELO; SOEANE; BERMúDEZ, 2020): This article reviews state-of-the-art on these new emerging technologies, summarizing how ports and terminals are deploying specific projects in the new era of smart ports and Ports 4.0;

13. **On-line Monitoring System with LoRaWAN** (PENKOV; TANEVA; PETROV, 2019): This article presents the practical experiment with LoRa specification shifted to LoRaWAN and implemented in industrial monitoring system;

14. **IoT platform for failure management in water transmission systems** (PéREZ-PADILLO et al., 2022): This paper describes the development and implementation of a web tool for the management of breakdowns in water transmission networks;

15. **Smart Device for Multi-band Industrial IoT Communications** (RHOLAM; TABAA; DANDACHE, 2019): This paper explains Industry 4.0 and the interaction between products, machines, and even between machines (M2M). This article presents a communication model based on Modbus and multiband communication using NB-IOT and the exchange between different industrial equipment (PLCs, SCADA systems, etc.) via MODBUS RTU and ASCII, via RS485, or via analog and digital inputs for sensors and actuators; and

16. **Hybrid PLC and LoRaWAN Smart Metering Networks: Modeling and Optimization** (STIRI et al., 2022): This paper explains the evolution toward the so-called smart grid (SG) needs to be supported by robust and cost-efficient advanced metering infrastructure.

3.3.4 Related work analysis

After analyzing the systematic review and applying the criteria of Subsection 3.3.1, 16 works were raised. Table 5 compares related works and functional requirements from Section 3.2.

Table 5 – Related works: Functional Requirements Attendance.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
FR1 - Use on the shop floor (factory)	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes
FR2 - Access to the sensors / actuators	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
FR3 - Sufficient baud rate	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FR4 - Security of communication	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	No
FR5 - Integration with others automation systems	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

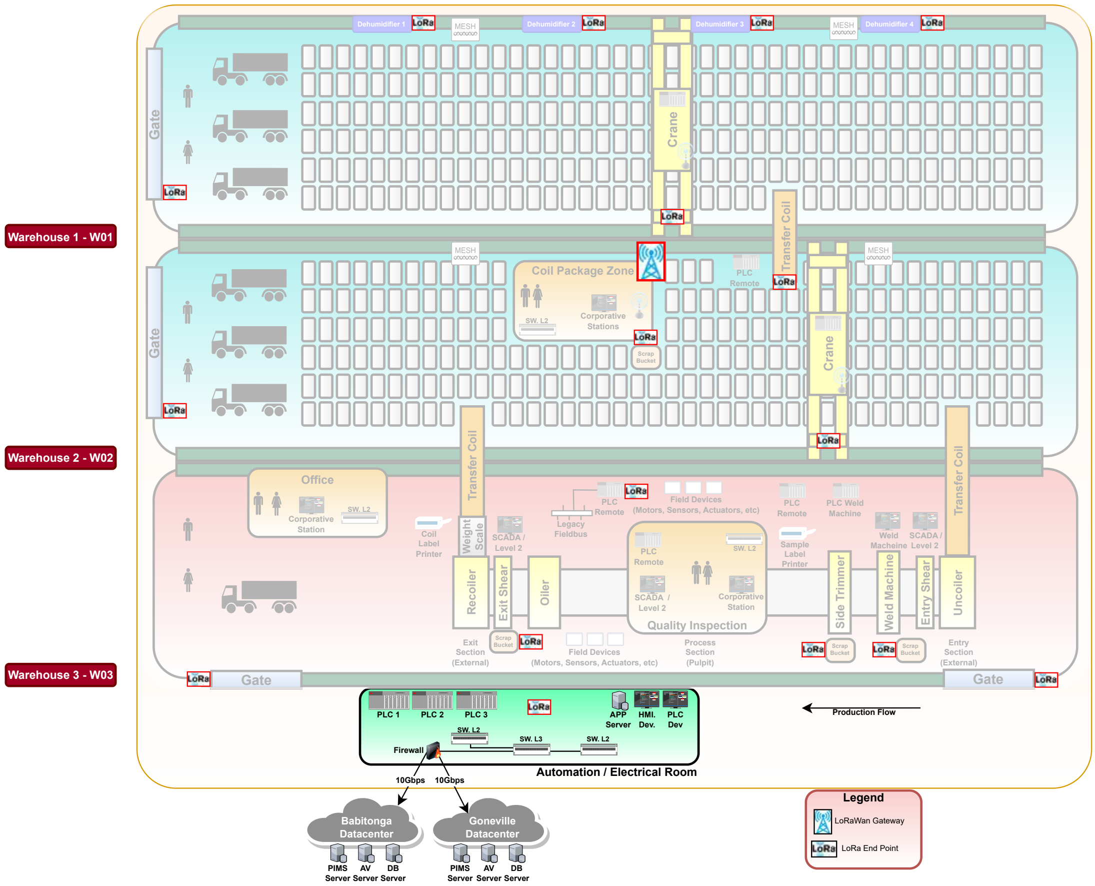
Source: The Author.

Table 5 shows not all selected works are a direct connection to the proposal of this present work, but all of them contribute directly to it. Thus, not all of the selected papers handle automation on the shop floor, but by analogy, it will be used. The choice of this work is due to the intention of obtaining a greater scope for selecting criteria for carrying out the performance and safety analysis of this work. The paper produced by (FERRARI et al., 2021) is the one that has the greatest adherence to the specific objectives of this work, as it deals directly with the integration and development of projects with legacy systems. The paper produced by (JEFFERY et al., 2021) explains the advantage of reduction investments on IoT compared to a traditional automation system. Finally, the other works also contribute to addressing topics such as SCADA, PLC, and how LPWAN technologies and others can be integrated into traditional automation systems. The few articles relating the integration between IIoT and legacy automation systems on the shop floor demonstrate the need for further studies in these areas, as the digital transformation and advancement from Industry 3.0 to Industry 4.0 will still take time, and gateways or middleware to carry out this integration will be necessary for the operational stability of the factories during the next years. Section 3.4 presents the technologies LoRaWAN that can be used in a real environment on the shop floor, generating the desirable integration with legacy systems.

3.4 PROPOSAL

Figure 22 is based on Figure 21 being a small part of these coil yards. The amount of equipment will be enough for the environmental monitoring of two different points. The temperature and humidity strongly influence these points of interest (coil yard and electrical room). The other point of interest is monitoring two of the four scrap buckets. This is a manual process that will be evaluated for automation. In the Figure, these monitoring points are highlighted in red boxes (endpoints and gateway). Each endpoint can represent a LoRaWAN sensor or traditional sensors connected in a microcontroller with LoRaWAN.

Figure 22 – Final Version of Proposal for PoC - Gateway and Endpoints to be installed.



Source: The Author.

The new points to be monitored in Figure 22 will be integrated into the shop floor automation system, being able to interact and contribute with the points observed in Section 2.5. In our proposal, this model could be met in all highlighted points, i.e., interoperability, reliability, security, performance, management, storage, scalability, and change in mindset.

For the development of this proposed solution, the technologies LPWAN will be seen as an industrial automation solution or a new technology but will always be seen as an automation solution because, in this way, the standards currently used, such as ISA-95 (HOOD, 2015), ISA-88, IEC62264, UML and others will still be valid. Moreover, technologies developed for industrial automation, such as supervisory systems (SCADA), OPC communication, TCP, and others, will still be valid. To create the proposed environment, a series of hardware and software will be necessary, as well as modifications in others. Among the needs mentioned, the following were identified:

- Hardware: ESP32 modules will be installed with the built-in LoRa system. Raspberry Pi Model 3b and Model 4b will also be used;
- Operating System: For the Raspberry Pi, the GNU/Linux-based distribution known

as RaspOS will be used, which was developed by the Raspberry Pi board manufacturer;

- Software: The software that will be developed for client modules using the Arduino IDE and for servers in Python;
- Server OPC: The existing OPCs servers will be configured to receive the data collected by the ESP and Raspberry Pi modules. This data will be available for the other automation systems using this hardware for collections. Once the data has been received on the OPC server, it can also be sent to the Level 1 system (e.g., PLC);
- SCADA: The SCADA system based on Wonderware InTouch in the production line will be modified to receive the information that was made available via OPC;
- PIMS: The PIMS system based on InfoPlus will be modified to accommodate the new devices and thus allow the history of this information; and
- DataBricks: The new information generated will be able to feed ArcelorMittal's DataLake, which is Azure DataBricks. Through them, data scientists can develop models based on ML.

Concerning the transmission technologies in the Table 2 it is possible to observe other technologies adherent to this proposal, such as LoRaWAN, LTE, NB-IoT, and 5G. The last technology still needs to be available to be evaluated in the scenario of interest. The LTE technology will be replaced by 5G and will therefore enter an end-of-life period. Thus, LoRaWAN will be adopted as the main technology, requiring a smaller infrastructure and can be installed in a point-to-point format.

The expected gains with this solution are: monitoring the possible effect of humidity and temperature in the packaging area to avoid oxidation. Another expected gain is the possibility of automating scrap bucket changes because it is a manual process. This study also aims to promote digital acceleration on the shop floor and to break a paradigm in shop floor automation that is not using traditional automation devices.

3.5 CHAPTER CONSIDERATIONS

Through clear prerequisites, functional requirements, and non-functional requirements, it is possible to specify the main desired characteristics in the proposed solution and establish a reference for the search for related works. Based on the above, this present work aims at a case study to analyze how IIoT can contribute to production lines where there is a low level of automation and which may not be financially attractive. This same case may be what happens in SMEs; in this way, this present study can be useful for this industrial segment and those companies or processes before Industry 3.0. A systematic mapping in the main academic search engines identified and evaluated IEEE, ACM, Springer, and Elsevier.

Finally, the proposal of this work is defined with the application of LPWAN technologies in an environment with traditional automation in a real shop floor scenario.

4 IMPLEMENTATION AND RESULTS

This chapter presents the fundamentals of the implementation environment, the objective scenarios, and the tools that make up the proposed solution. Then, the infrastructure needed to carry out the proof of concept is illustrated, and the process of configuring and executing the sensors and controllers responsible for data acquisition on the shop floor is discussed. The chapter also details the steps for installing and configuring each required endpoint, gateway, and controller and the industrial processes involved in the objective solution in each scenario. Due to the implementation of the proof of concept, it is possible to assess whether the objectives proposed in Section 3.4 were achieved and how this can influence the industrial environment in the ArcelorMittal Vega company.

4.1 PROOF OF CONCEPT

The LPWAN environment was set up using two approaches to carry out the proof of concept. 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 LoRa radio that the author of this work will program. In the first approach, installing two gateways was considered to cover the entire industrial radius of the company, which can be shared with other solutions or in other projects. Using the KORA platform and the Microsoft Azure enterprise environment, these gateways can access the KORE Wireless company's LoRaWAN network. For the second approach, devices can connect to a Raspberry Pi Model 3B device with a LoRa multi-antenna, and a multi-channel shield can also play the gateway role. This approach can serve as redundancy to the leading network, thus ensuring availability. Another point to be evaluated is the isolation from the leading network that this approach can bring, contributing to fewer devices per channel. Thus, generating a lower transfer rate, which can be a benefit to shop floor devices.

For the realization of this PoC, ArcelorMittal Vega is supported with equipment and resources (e.g., gateway LoRa, network installation services, etc.). Figure 23 shows the gateway and antenna installation location; the equipment was installed above the Continuos Galvanizing Line 1 (CGL1) line at approximately 65m.

Figure 23 – Gateway deployed localization.

Source: The Author.

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 to an automation network using Ethernet (RJ45) cable and integration with internal antennas GPS, 4G, and LoRa. If necessary, the communication 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.

4.1.1 Site Survey

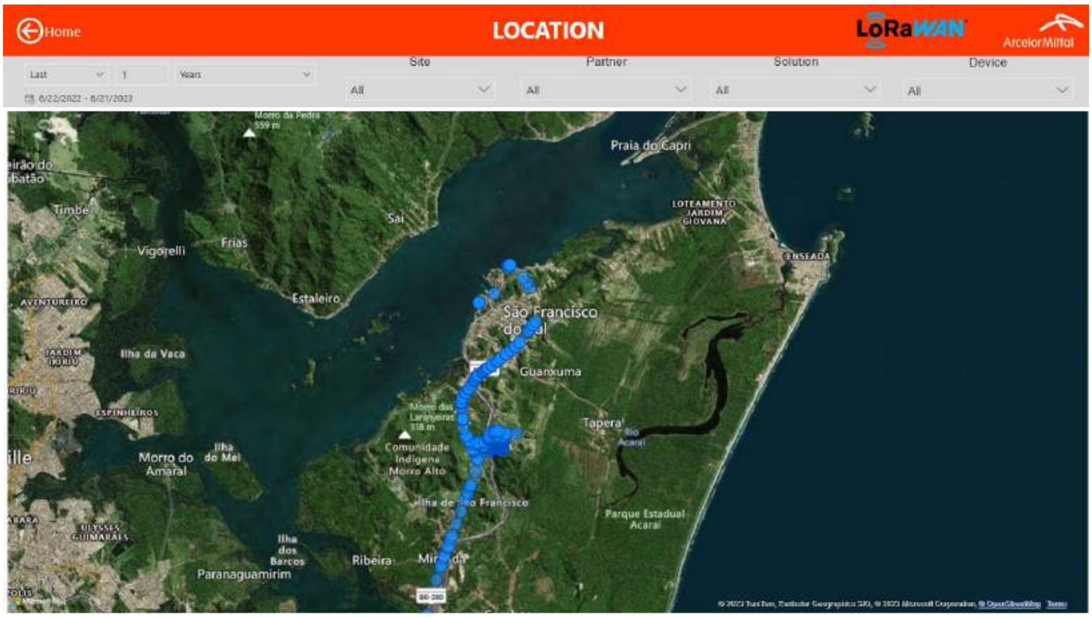
Figure 24 shows the coverage of the LoRa network at ArcelorMittal Vega. The so-called "Site Survey" was carried out with measurement devices that indicate the quality of data transmission from a device to the gateway to determine how much this coverage would be. Three ESP32 micro-controllers with LoRa antenna were used, one of which also had a GPS receiver. Antennas with 1dBi, 3dBi, and 5dBi were used with transmissions between 30 and 60 seconds. The purpose of varying the antenna capacity was to determine the best and worst case in terms of transmission capacity. 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; Figure 24 shows the result of the site survey realized.

Figure 24 – LoRaWAN Coverage - ArcelorMittal Vega.

Source: The Author.

Each colored circle represents a read and transmission data of GPS position. Each color represents a quality of Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR). The valid range is between 7 (best) and 12 (worst). When the values cannot be determined with confidence level, this value was stored with 99 values (error). All possible values and colors are shown in the Table 6. Once the data is stored, Microsoft PowerBI allows the creation of a map with the antenna's entire scope, coverage capacity, 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 site (e.g., underground), but there was LoRa transmission. The measurement was considered valid in these cases, and the nearest GPS location was considered. To determine the reception capacity of the gateway/antenna, during the tests, a car was used to visit part of two cities close to ArcelorMittal Vega, which are: São Francisco do Sul and Araquari, as shown in the Figure 25.

Figure 25 – LoRaWAN Coverage - General.



Source: The Author.

To carry out the tests external to ArcelorMittal Vega, the ESP32 micro-controller was used, which has GPS and which, in this case, had a 3dBi antenna. Each colored circle represents a read and transmission data of GPS position. In this case, the same color (light blue) indicates a value between 7 (best) and 12 (worst) and represents a quality of RSSI and SNR. As described, the range of a single antenna connected to a gateway LoRa is extensive. Using Google Maps, it is possible to note the considerable operational distance in the measured tests, as presented in Figure 26.

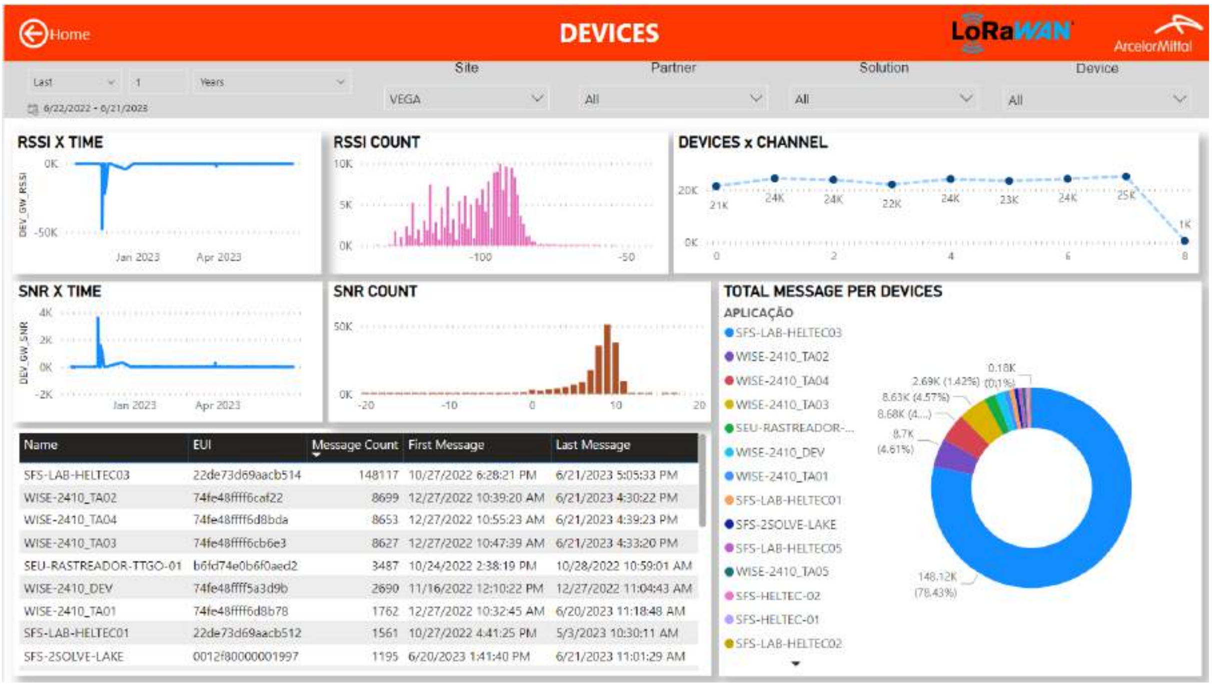
Figure 26 – Maximum Observed Distance.

Source: The Author.

This test reached 17.17km of distance to the gateway; better deals can likely be obtained with a higher capacity antenna connected to the ESP32. However, this is not the purpose of PoC, and the test was carried out as additional information. Thus, Becoming a real test would require several measurements and different atmospheric conditions (e.g., rain). During the tests, another ESP32 equipped with a temperature and humidity sensor was installed in one of the data centers and sent data to the gateway. In total, four ESP32 micro-controllers from three different manufacturers were used (e.g., Heltec, TTGO, and Robocore), but all of them had a LoRa radio.

Figure 27 shows the dashboard created using Microsoft PowerBI specifically for the environment using LoRaWAN technology. The tests were performed from 24 to 27/October/2022, simultaneously employing all LoRa endpoints active.

Figure 27 – Total Messages - General.

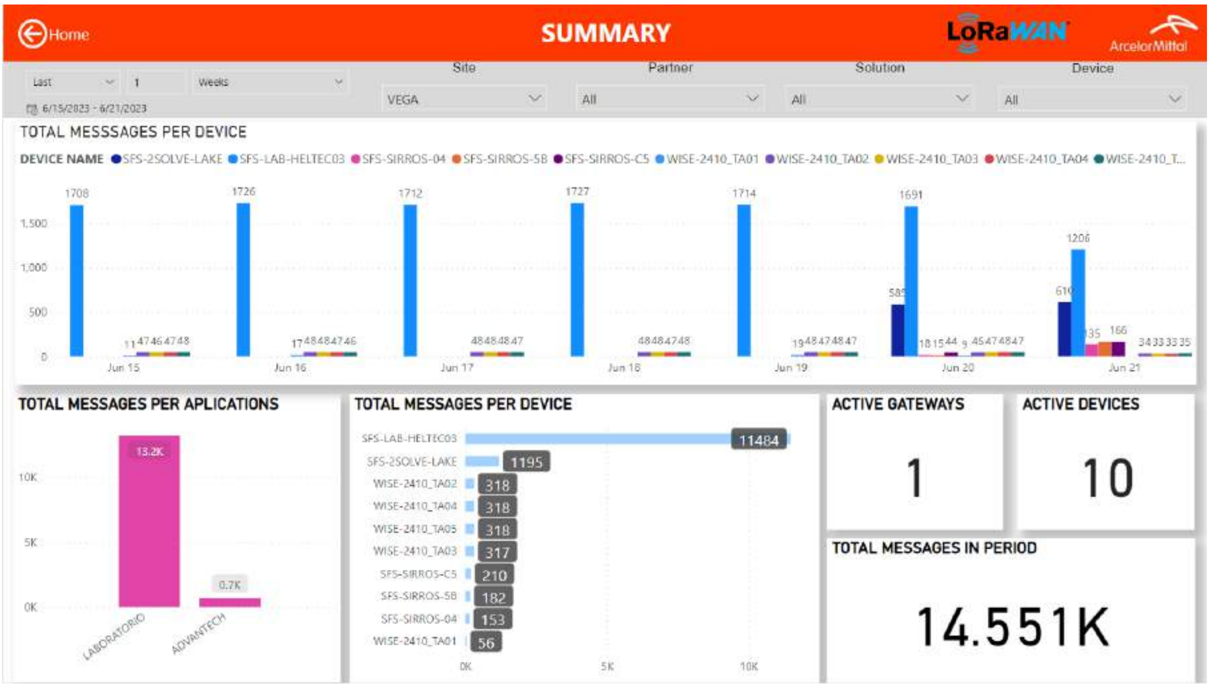


Source: The Author.

In addition to presenting the identification of each device, information related to 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 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.

Figure 28 shows other information per device, such as total messages per device, total messages per day, number of devices, etc. The device identified as SEU-RASTREADOR-TTGO-01 is the one with the highest number of messages because it was the main device used since it is the device that has the GPS module that is the basis for the generation of data from the site survey and was the only one that was used on all test days.

Figure 28 – Total Messages - Per Device.



Source: The Author.

Any new device added to the LoRaWAN network and identified as "Site Vega" will automatically have the information collected and categorized. The dashboard will display the statistics collected according to the examples in Figures 27 and 28.

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 of time 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 the consumption and efficiency of each device and include the control of used radio channels; for this reason, (the balance) was possible to reach 17.17km in the test. Table 6 shows some characteristics of LoRaWAN technology, being the data table was used in Figure 24 and 25 to generate the color indications.

Table 6 – Relationship Between SF, SNR, RSSI, and Size of Message

SF	Required SNR (dB)	RSSI (min)	RSSI (max)	Data Rate (kbps)	Transmission Duration (sec)	User Payload (Bytes)	Color Reference (for site survey)
7	-7	0	-110	5.47	0.036	230	Light Blue
8	-10	-110	-113	3.13	0.064	230	Light Green
9	-12.5	-113	-116	1.76	0.113	123	Yellow
10	-15	-116	-119	0.98	0.204	59	Red
11	-17.5	-119	-120	0.54	0.365	59	Blue
12	-20	-120	-123	0.29	0.682	59	Dark Blue
99	Error - When it is not possible to determine the real measured value of the transmission						Orange

Source: Author.

Part of the information that the gateway receives is the RSSI value per message. Using this value and the references of Table 6, it is possible to determine the value of SF, create a schema of colors, and improve visualization in the map.

As a conclusion of the site survey process, observing the figures with the values for SF, RSSI and SNR, it is possible to conclude that the configuration of this gateway + antenna capacity has the potential to be enough to cover the entire site. Additional tests are suggested regarding some underground electrical rooms and in classified areas where the authors were not authorized to enter because they do not have the appropriate certification (NR-33); in these cases, an in-door gateway may be required.

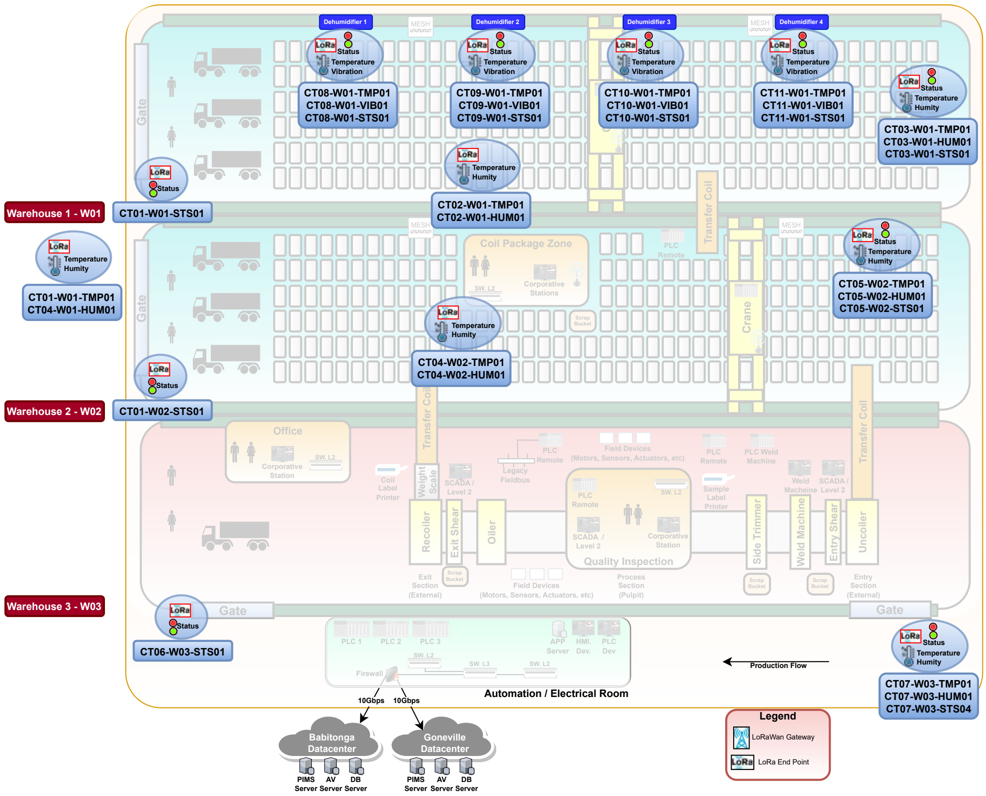
4.1.2 Scenarios

After choosing the area in which the PoC would be carried out, which is the shed of the production line called Recoiling Line (RCL)#1 and which shares the environment with the stockyards for finished products, packaging of coils and dispatch, six possible scenarios were elaborated in which several aspects were taken into account, such as applicability, cost, financial return, safety, scope, replicability, transformation into a product after PoC, among others. Initially, two of the six scenarios evaluated would be addressed as they fully meet ArcelorMittal Vega's needs. However, during development, the company became interested in the potential of the technology and other needs and new scenarios that emerged. Thus, the company invested in acquiring new sensors in partnership with companies that sell products for IIoT and in carrying out further tests.

4.1.3 Scenario 1 - Environmental Monitoring

This scenario is for implementing the environmental monitoring project (temperature and humidity) 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. In this way, 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 if it is necessary or not 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 point to be noted 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; in this way, this monitoring is also important; 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. The dew point is the temperature at which the water vapor present in the ambient air changes to a liquid state in the form of small drops by condensation, which is called dew (NOVUS, 2020). 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. Figure 29 presents 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. These points for monitoring are highlighted in blue boxes (endpoints).

Figure 29 – Based on warehouse, package zone and RCL#1 - ArcelorMittal Vega - Scenario 1.



Source: The Author.

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), which is the same as existing in the systems that will use this information. This is one of the scenarios that were modified during the development of this work. The company invested in acquiring vibration sensors, which monitor a series of engine health parameters, in addition to status and temperature. The chosen manufacturer/model was the Advantech WISE-24-10. Some of the features of this sensor are:

- LoRaWAN wireless connectivity;
- Built-in 3-axis accelerometer and temperature sensor;
- Computing total 8 vibration characteristic values on board;
- Compliant with ISO 10816;
- IP66 with battery-powered, no wiring installation needed;
- Configuration with user-friendly interface;
- Support wide temperature -20 to 85 ℃, and;
- NODE RED Compliance;

Figure 30 shows the installation of the sensor over the dehumidifier motor (red box). In Warehouse 1, there are four motors for the dehumidifier system.

Figure 30 – Advantech - WISE2410.

Source: The Author.

For this type of application, which is the analysis of the vibration of a motor, the manufacturer recommends that the sensor send data every 60 minutes. In this way, the battery duration is up to 2 years. This is a setting, and this time can be changed. However, a cable connection between a computer/notebook and the sensor is required.

All data acquired in the Figure 29, can be visualized in a supervisory system (AVEVA InTouch) generating animation alarms and alerts to the operators from RCL#1 through the PIMS tool, as well as in a corporate network through tools such as Databricks and PowerBI.

The communication environment has the following characteristics:

- Sensor Types: Humidity, temperature, and status; for vibration data 60 min is adequate;
- Acquisition Frequency: Every 10 min for analog data (e.g., temperature), and per event in case of gates opening and status of dehumidifiers;
- Type of Information: Analog - Humidity and temperature / Status: Gates and dehumidifiers; and
- Data Visualization: Databricks (data lake), PowerBI, ERP, PIMS and Supervisory System.

In Table 7, all devices involved in this scenario are shown. In addition to the tagname itself, the table contains sensor types, location, acquisition frequency, etc.

Table 7 – Scenario 1 - Monitoring of Ambiental Enviroment.

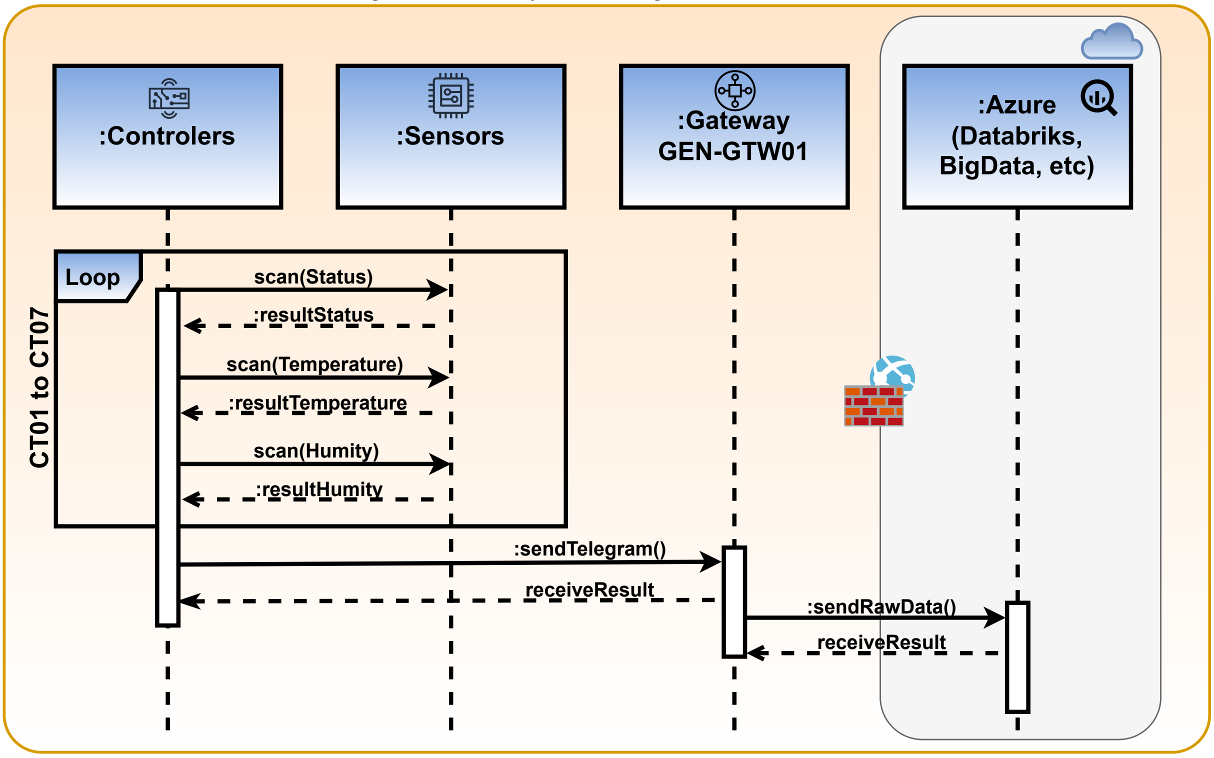
Tagname	Type	Location	Schedule	Controler	Format
GEN-GTW01	General Gateway	External Installation	Ad-hoc	Gateway	Ad-hoc
CT01-W01-TMP01	Temperature	Warehouse 1	10 min	CT01	Float
CT01-W01-HUM01	Humidity	Warehouse 1	10 min	CT01	Float
CT01-W01-STS01	Status	Warehouse 1	Event	CT01	Boolean
CT01-W02-STS01	Status	Warehouse 2	Event	CT01	Boolean
CT02-W01-TMP01	Temperature	Warehouse 1	10 min	CT02	Float
CT02-W01-HUM01	Humidity	Warehouse 1	10 min	CT02	Float
CT03-W01-TMP01	Temperature	Warehouse 1	10 min	CT03	Float
CT03-W01-HUM01	Humidity	Warehouse 1	10 min	CT03	Float
CT03-W01-STS01	Status	Warehouse 1	Event	CT03	Boolean
CT04-W01-TMP01	Temperature	Warehouse 1	10 min	CT04	Float
CT04-W01-HUM01	Humidity	Warehouse 1	10 min	CT04	Float
CT05-W02-TMP01	Temperature	Warehouse 2	10 min	CT05	Float
CT05-W02-HUM01	Humidity	Warehouse 2	10 min	CT05	Float
CT05-W02-STS01	Status	Warehouse 2	Event	CT05	Boolean
CT06-W03-STS01	Status	Warehouse 3	Event	CT06	Boolean
CT07-W03-TMP01	Temperature	Warehouse 3	10 min	CT07	Float
CT07-W03-HUM01	Humidity	Warehouse 3	10 min	CT07	Float
CT07-W03-STS04	Status	Warehouse 3	Event	CT07	Boolean
CT08-W01-TMP01	Temperature	Warehouse 1	60 min	CT8	Float
CT08-W01-VIB01	Vibration	Warehouse 1	60 min	CT8	Float
CT08-W01-STS01	Status	Warehouse 1	Event min	CT8	Boolean
CT09-W01-TMP01	Temperature	Warehouse 1	60 min	CT9	Float
CT09-W01-VIB01	Vibration	Warehouse 1	60 min	CT9	Float
CT09-W01-STS01	Status	Warehouse 1	Event	CT9	Boolean
CT10-W01-TMP01	Temperature	Warehouse 1	60 min	CT10	Float
CT10-W01-VIB01	Vibration	Warehouse 1	60 min	CT10	Float
CT10-W01-STS01	Status	Warehouse 1	Event	CT10	Boolean
CT11-W01-TMP01	Temperature	Warehouse 1	60 min	CT11	Float
CT11-W01-VIB01	Vibration	Warehouse 1	60 min	CT11	Float
CT11-W01-STS01	Status	Warehouse 1	Event	CT11	Boolean

Source: The Author.

Table 7 is also important for the areas that maintain the system and the electrical maintenance of the industrial condominium, which will replace 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 31 shows the diagram of events that make up the system presented in Scenario 1 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. Each request and reception of the sensor values between actors is represented by a scan (request) and result (response) signal in the figure.

Figure 31 – Sequence diagram - Scenario 1.



Source: The Author.

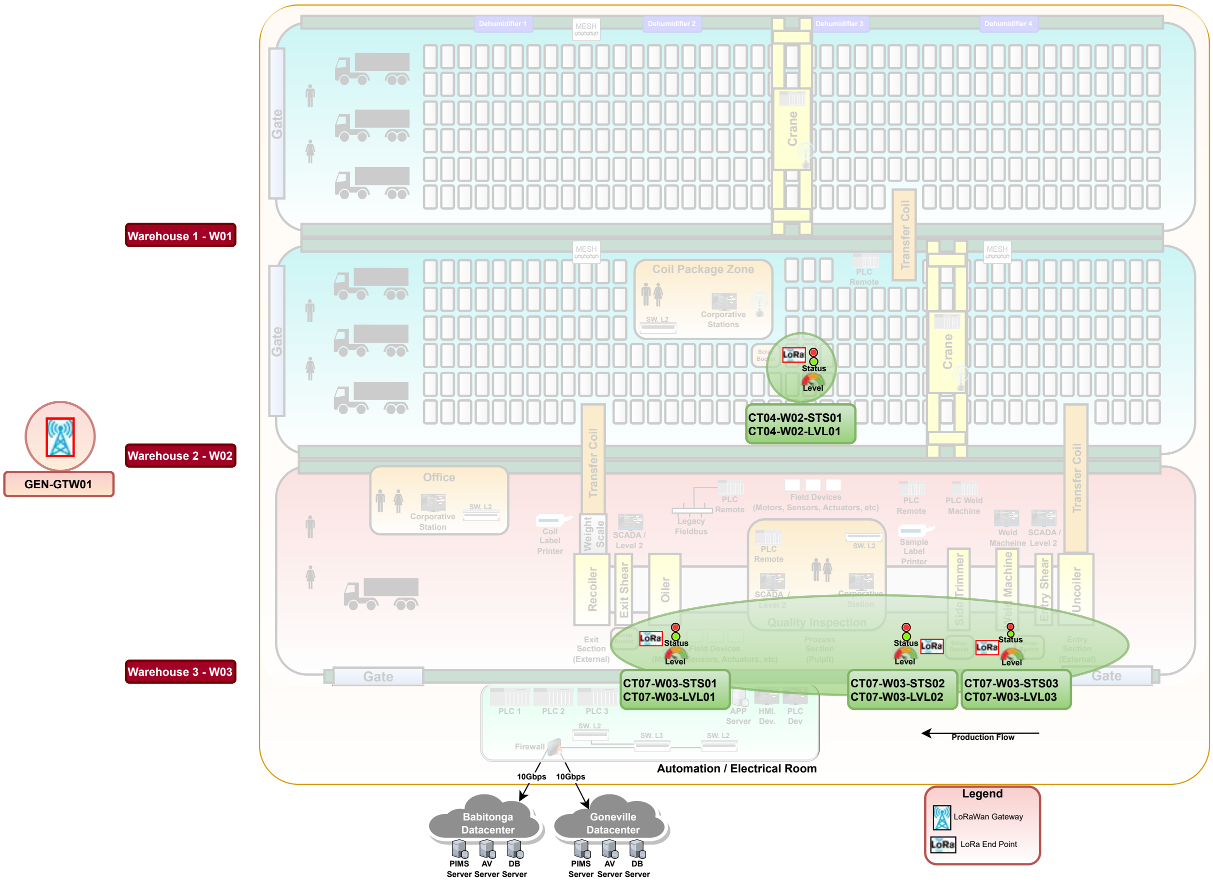
With this figure, it's possible to observe the integration from the shop floor, the interconnection with the general gateway (GEN-GTW01), the interconnection with the corporate firewall, and the connection with Azure Data Bricks that is hosted in Microsoft's computing cloud.

4.1.4 Scenario 2 - Scrap Control

This scenario is for the implementation of a scrap bucket control project. The yard in this region has four buckets for the so-called head, tail, side trimmer, preparation for welding machine, and packaging. These types of scrap are metallic; a considerable amount comes from the steel coils used in the RCL#1 line process. At first, the system will monitor the level of use of the buckets. Alternatively, the system can detect the presence/positioning of scrap buckets. In the first case, the level will be the event that starts the process of changing buckets. For the second case, when the operators move the buckets, this will be the event for the process of changing buckets through the end-of-travel sensors of the tracks on which the buckets are supported. In both cases, the system automatically generates a "ticket" for a truck to be moved to the location to remove the bucket and transferred to the scrap yard.

Figure 32 presents the distribution of the gateway LoRa of the controller and sensors used to control the scrap bucket system. These points for monitoring are highlighted in green boxes (endpoints).

Figure 32 – Based on warehouse, package zone and RCL#1 - ArcelorMittal Vega - Scenario 2.



Source: The Author.

The sensors used are for measuring the level of the buckets and the position (end-stop sensor) in which each bucket is. Each device received an identification (tag) that is the same identification existing in the systems that will use this information.

The data can be visualized in a supervisory system (AVEVA InTouch) generating animation alarms and alerts to the operators from RCL#1 through the PIMS tool, as well as in a corporate network through tools such as Databricks and PowerBI.

The communication environment has the following characteristics:

- Types of Sensors: Endstop and ultrasound;
- Acquisition Frequency: Every 5 min for analog data (e.g., Level), and per event in case of bucket entering/leaving a predetermined position;
- Type of Information: Status - Detection of the presence of the bucket / Analog - Level of the bucket; and
- Data Visualization: Databricks (data lake), PowerBI, ERP, PIMS and Supervisory System.

Table 8 lists all devices involved in Scenario 2. In addition to the tagname itself, the table contains sensor types, location, acquisition frequency, etc.

Table 8 – Scenario 2 - Control of scrap buckets

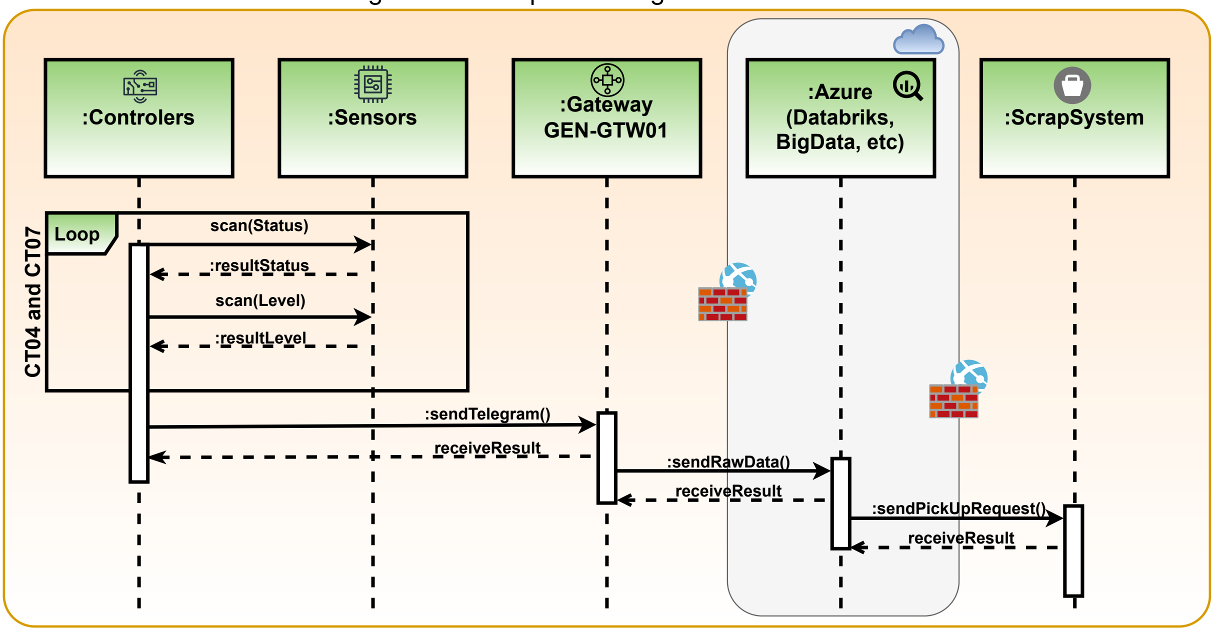
Tagname	Type	Location	Schedule	Controler	Format
GEN-GTW01	General Gateway	External Installation	Ad-hoc	Gateway	Ad-hoc
CT04-W02-STS01	Status	Warehouse 2	Event	CT04	Boolean
CT04-W02-LVL01	Level	Warehouse 2	5 min	CT04	Float
CT07-W03-STS01	Status	Warehouse 3	Event	CT07	Boolean
CT07-W03-LVL01	Level	Warehouse 3	5 min	CT07	Float
CT07-W03-STS02	Status	Warehouse 3	Event	CT07	Boolean
CT07-W03-LVL02	Level	Warehouse 3	5 min	CT07	Float
CT07-W03-STS03	Status	Warehouse 3	Event	CT07	Boolean
CT07-W03-LVL03	Level	Warehouse 3	5 min	CT07	Float

Source: The Author.

As in the first scenario presented, this type of table is important for the areas that maintain the system and the electrical maintenance of the industrial condominium. After the PoC phase, a drawing of the electrical interconnections must be generated and included in this company's archive department.

Figure 33 illustrates the diagram of events that make up the system presented in Scenario 2 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. Each request and reception of the sensor values between actors is represented by a scan (request) and result (response) signal in the figure.

Figure 33 – Sequence diagram - Scenario 2.



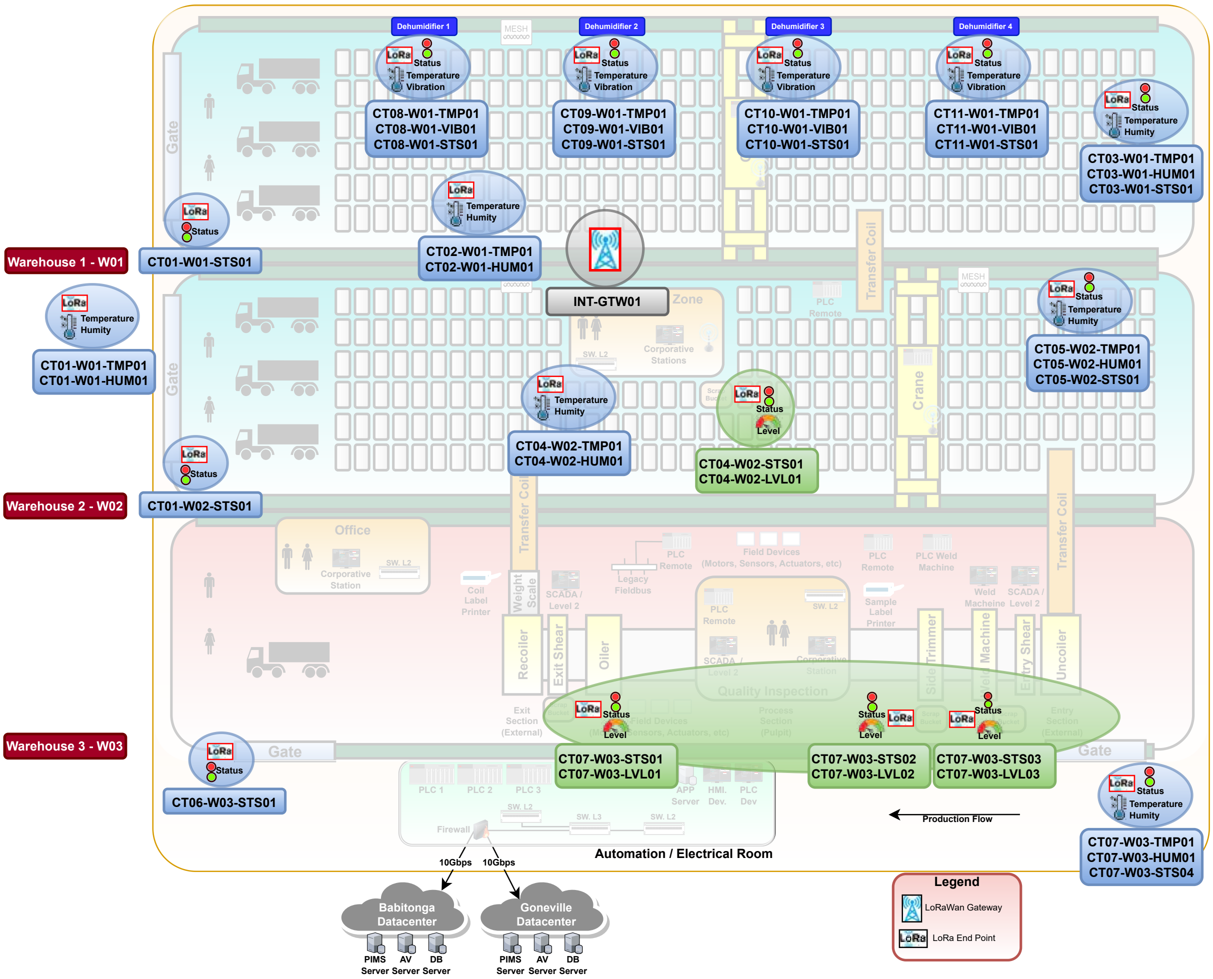
Source: The Author.

Figure 33 allows to observe the integration from the shop floor, the interconnection with the general gateway (GEN-GTW01), the interconnection with the corporate firewall, and the connection with Azure Data Bricks that is hosted in Microsoft's computing cloud.

4.1.5 Scenario 3 - Dedicated Gateway

This scenario is also a proof of concept and implies using a multi-antenna and multi-channel LoRa hub or gateway. Since the initial planning is the installation of 2 gateways aiming to cover ArcelorMittal as a whole, if this does not meet the criteria of shop floor automation, one possibility is installing a device like this dedicated to the test environment. During the site survey, the collected data indicated just one gateway is necessary to cover all factories. For this reason, this scenario will be evaluated and tested if the first experiments indicate a loss of data that indicates a low system performance using the GEN-GTW01 gateway. For testing purposes, opting for a solution with a shield LoRa for Raspberry Pi devices and integrating it into the automation network via WiFi or cabling is possible. Figure 34 shows that the gateway INT-GTW01 replaced the general gateway GEN-GTW01. These points for monitoring are highlighted in blue and green boxes (endpoints).

Figure 34 – Based on warehouse, package zone and RCL#1 - ArcelorMittal Vega - Scenario 3.



Source: The Author.

Figure 34 allows to observe all the sensors and controllers involved in Scenario 3. The focus at this point is the use of a gateway dedicated and exclusive to the systems that make up the shop floor, which can also be known as "industrial systems." The data can be visualized in a supervisory system (AVEVA InTouch) generating animation alarms and alerts to the operators from RCL#1 through the PIMS tool, as well as in a corporate network through tools such as Databricks and PowerBI.

The communication environment has the following characteristics:

- Types of Sensors: Shield LoRa with three radios and three antennas;
- Acquisition Frequency: On demand of each sensor in each scenario;
- Information Type: Depends on the sensor type in each scenario; and
- Data Visualization: Databricks (data lake), PowerBI, and Supervisory System.

Table 9 lists all devices involved in this scenario. In addition to the tagname itself, it presents the types of sensors, location, acquisition frequency, etc. It can be seen that the gateway is dedicated and centrally installed in the shed.

Table 9 – Scenario 3 - Full view of warehouse.

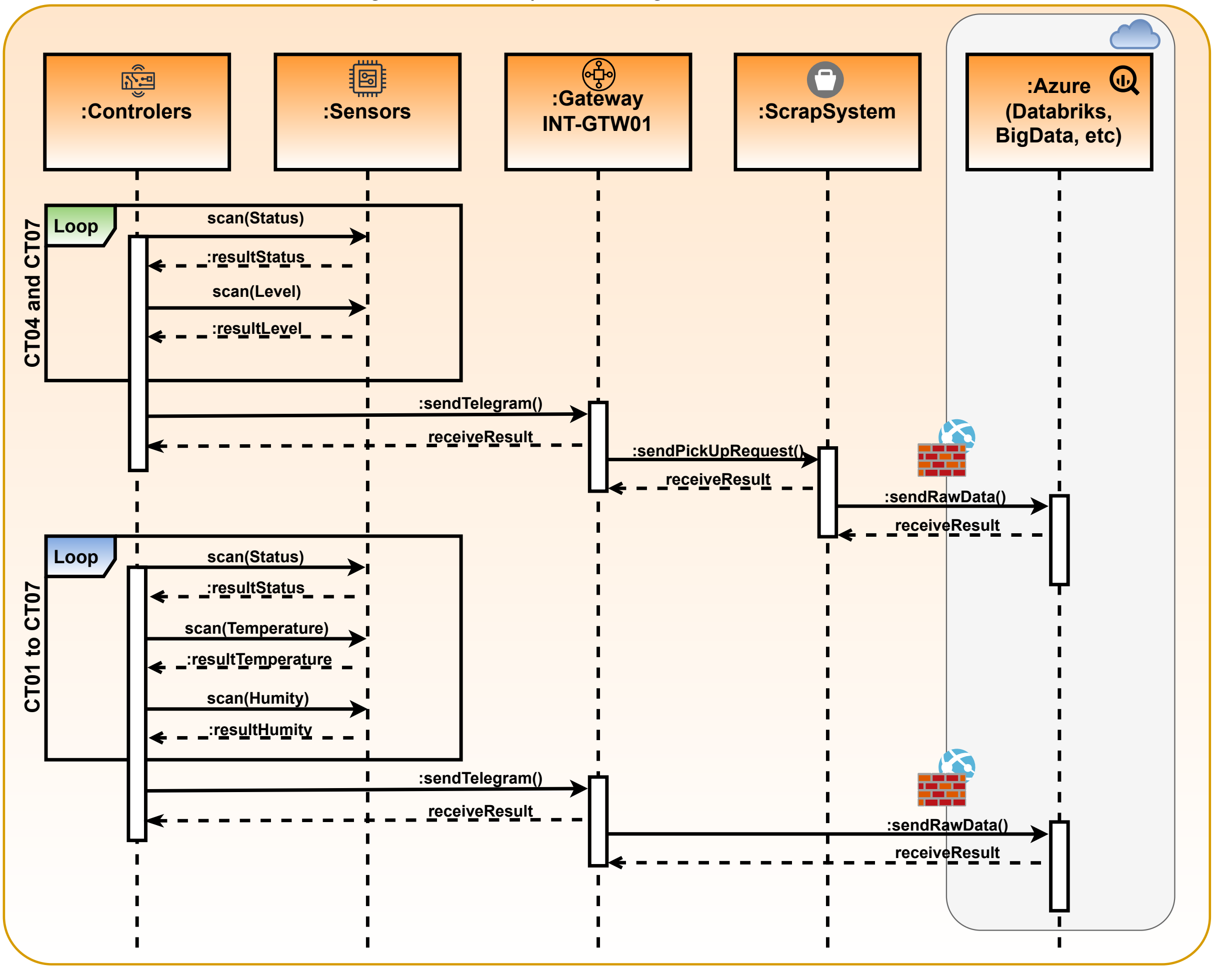
Tagname	Type	Location	Schedule	Controler	Format
INT-GTW01	Internal Installation	Warehouse 2	Ad-hoc	Gateway	Ad-hoc
CT01-W01-TMP01	Temperature	Warehouse 1	10 min	CT01	Float
CT01-W01-HUM01	Humidity	Warehouse 1	10 min	CT01	Float
CT01-W01-STS01	Status	Warehouse 1	Event	CT01	Boolean
CT01-W02-STS01	Status	Warehouse 2	Event	CT01	Boolean
CT02-W01-TMP01	Temperature	Warehouse 1	10 min	CT02	Float
CT02-W01-HUM01	Humidity	Warehouse 1	10 min	CT02	Float
CT03-W01-TMP01	Temperature	Warehouse 1	10 min	CT03	Float
CT03-W01-HUM01	Humidity	Warehouse 1	10 min	CT03	Float
CT03-W01-STS01	Status	Warehouse 1	Event	CT03	Boolean
CT04-W01-TMP01	Temperature	Warehouse 1	10 min	CT04	Float
CT04-W01-HUM01	Humidity	Warehouse 1	10 min	CT04	Float
CT04-W02-STS01	Status	Warehouse 2	Event	CT04	Boolean
CT04-W02-LVL01	Level	Warehouse 2	5 min	CT04	Float
CT05-W02-TMP01	Temperature	Warehouse 2	10 min	CT05	Float
CT05-W02-HUM01	Humidity	Warehouse 2	10 min	CT05	Float
CT05-W02-STS01	Status	Warehouse 2	Event	CT05	Boolean
CT06-W03-STS01	Status	Warehouse 3	Event	CT06	Boolean
CT07-W03-STS01	Status	Warehouse 3	Event	CT07	Boolean
CT07-W03-LVL01	Level	Warehouse 3	5 min	CT07	Float
CT07-W03-STS02	Status	Warehouse 3	Event	CT07	Boolean
CT07-W03-LVL02	Level	Warehouse 3	5 min	CT07	Float
CT07-W03-STS03	Status	Warehouse 3	Event	CT07	Boolean
CT07-W03-LVL03	Level	Warehouse 3	5 min	CT07	Float
CT07-W03-TMP01	Temperature	Warehouse 3	10 min	CT07	Float
CT07-W03-HUM01	Humidity	Warehouse 3	10 min	CT07	Float
CT07-W03-STS04	Status	Warehouse 3	Event	CT07	Boolean
CT08-W01-TMP01	Temperature	Warehouse 1	60 min	CT8	Float
CT08-W01-VIB01	Vibration	Warehouse 1	60 min	CT8	Float
CT08-W01-STS01	Status	Warehouse 1	Event min	CT8	Boolean
CT09-W01-TMP01	Temperature	Warehouse 1	60 min	CT9	Float
CT09-W01-VIB01	Vibration	Warehouse 1	60 min	CT9	Float
CT09-W01-STS01	Status	Warehouse 1	Event	CT9	Boolean
CT10-W01-TMP01	Temperature	Warehouse 1	60 min	CT10	Float
CT10-W01-VIB01	Vibration	Warehouse 1	60 min	CT10	Float
CT10-W01-STS01	Status	Warehouse 1	Event	CT10	Boolean
CT11-W01-TMP01	Temperature	Warehouse 1	60 min	CT11	Float
CT11-W01-VIB01	Vibration	Warehouse 1	60 min	CT11	Float
CT11-W01-STS01	Status	Warehouse 1	Event	CT11	Boolean

Source: The Author.

As observed in the previous scenarios, this type of table is important for the areas that maintain the system and the electrical maintenance of the industrial condominium. After the PoC phase, a drawing of the electrical interconnections must be generated and included in this company's archive department.

Figure 35 shows the event diagram that makes up all the systems presented in Scenarios 1 and 2 and how it relates to all actors, such as sensors, controllers, cloud systems, etc.

Figure 35 – Sequence diagram - Scenario 3.



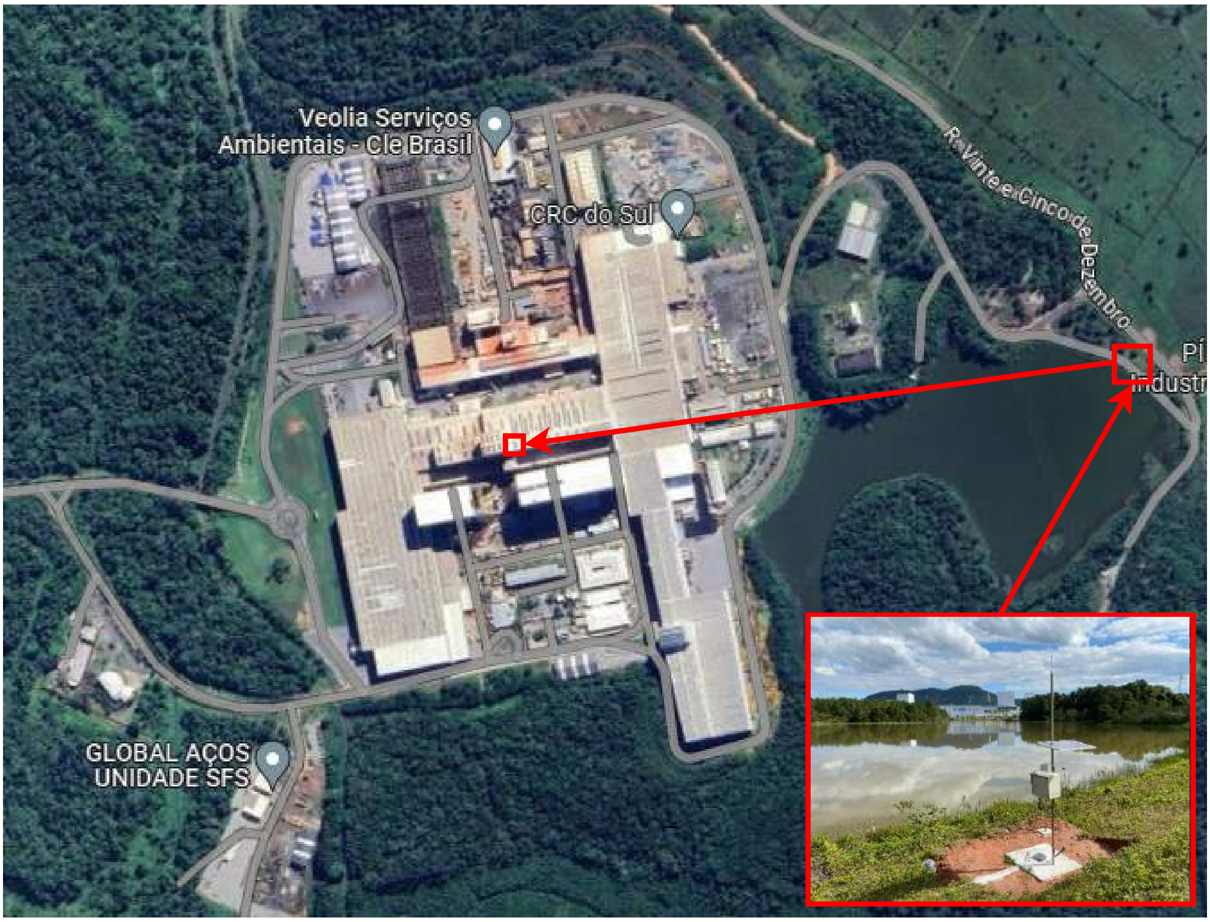
Source: The Author.

Figure 35 presents all the sensors and controllers involved. The focus at this point is the use of a gateway dedicated and exclusive to the systems that make up the shop floor, which can also be known as "industrial systems". For this reason, the data returned from Azure to the scrap system will not be tested in this scenario. Each request and reception of the sensor values between actors is represented by a scan (request) and result (response) signal in the figure.

4.1.6 Scenario 4 - Lake's Data

This scenario is for implementing the environmental monitoring project for the existing lake on the site (e.g., pluviometry, level, flow, and, in the future, the opening status of a gate). Before the company was built, underground water springs turned into a small river flowing through other properties. During the company's construction phase, an artificial lake was created into which this underground water and surplus rainwater were directed as a form of drainage. The company needs to maintain a constant flow of this water to the other properties, which is part of the environmental authorization for the company's operation. A measurement system powered by solar energy was created that received data from the sensors. Due to the lack of electrical infrastructure on site, a system for capturing solar energy with batteries was installed. The company does not want to send this information to the supplier's platform using 4G communication because environmental data is considered sensitive. In this way, communication via LoRaWAN has shown to have the potential to meet this need. In case of failures, the collected data must be stored locally. Through an external partner called 2Solve, a device called FlexDaq was provisionally installed also in PoC format. FlexDaq has all the necessary features, and a permanent installation is being planned. Figure 36 shows the physical scenario and the distance between the sensors/transmitters and the gateway. The gateway and the 2Solve device are highlighted in red boxes.

Figure 36 – Lake view - ArcelorMittal Vega - Scenario 4.



Source: The Author.

The communication environment has the following characteristics:

- Sensor Types: Pluviometry, level and flow;
- Acquisition Frequency: Every 60 min for analog data;
- Type of Information: Analog - Pluviometry, level of lake, and flow of water; and

- Data Visualization: Databricks (data lake), PowerBI, ERP, PIMS and Supervisory System.

Table 10 presents all devices involved in this scenario. In addition to the tagname itself, the table contains sensor types, location, acquisition frequency, etc.

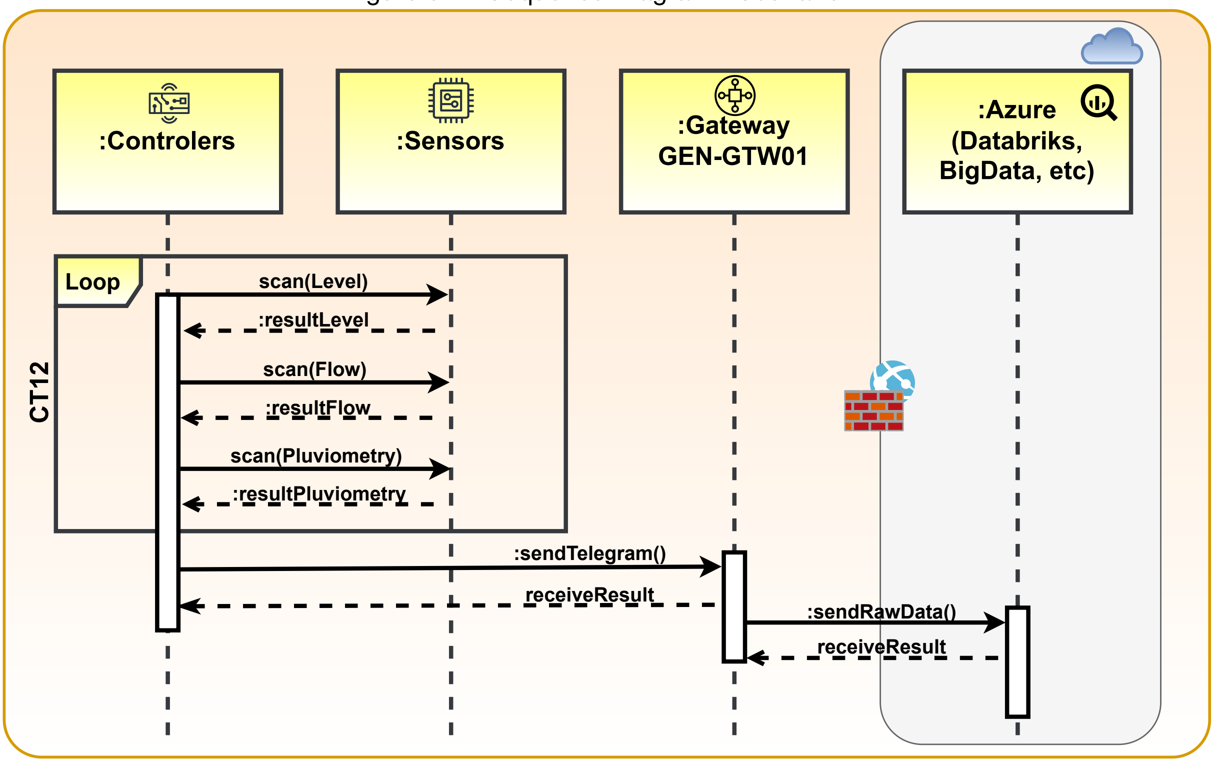
Table 10 – Scenario 4 - Lake's Data.

Tagname	Type	Location	Schedule	Controler	Format
GEN-GTW01	General Gateway	External Installation	Ad-hoc	Gateway	Ad-hoc
CT12-L01-PLU01	Pluviometry	Lake	60 min	CT12	Float
CT12-L01-LVL01	Level	Lake	60 min	CT12	Float
CT12-L01-FLW01	Flow	Lake	60 min	CT12	Float

Source: The Author.

As in the first scenario presented, this type of table is important for the areas that maintain the system and the electrical maintenance of the industrial condominium. After the PoC phase, a drawing of the electrical interconnections must be generated and included in this company's archive department. Figure 37 illustrates the diagram of events that make up the system presented in Scenario 4 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. Each request and reception of the sensor values between actors is represented by a scan (request) and result (response) signal in the figure.

Figure 37 – Sequence Diagram - Scenario 4.



Source: The Author.

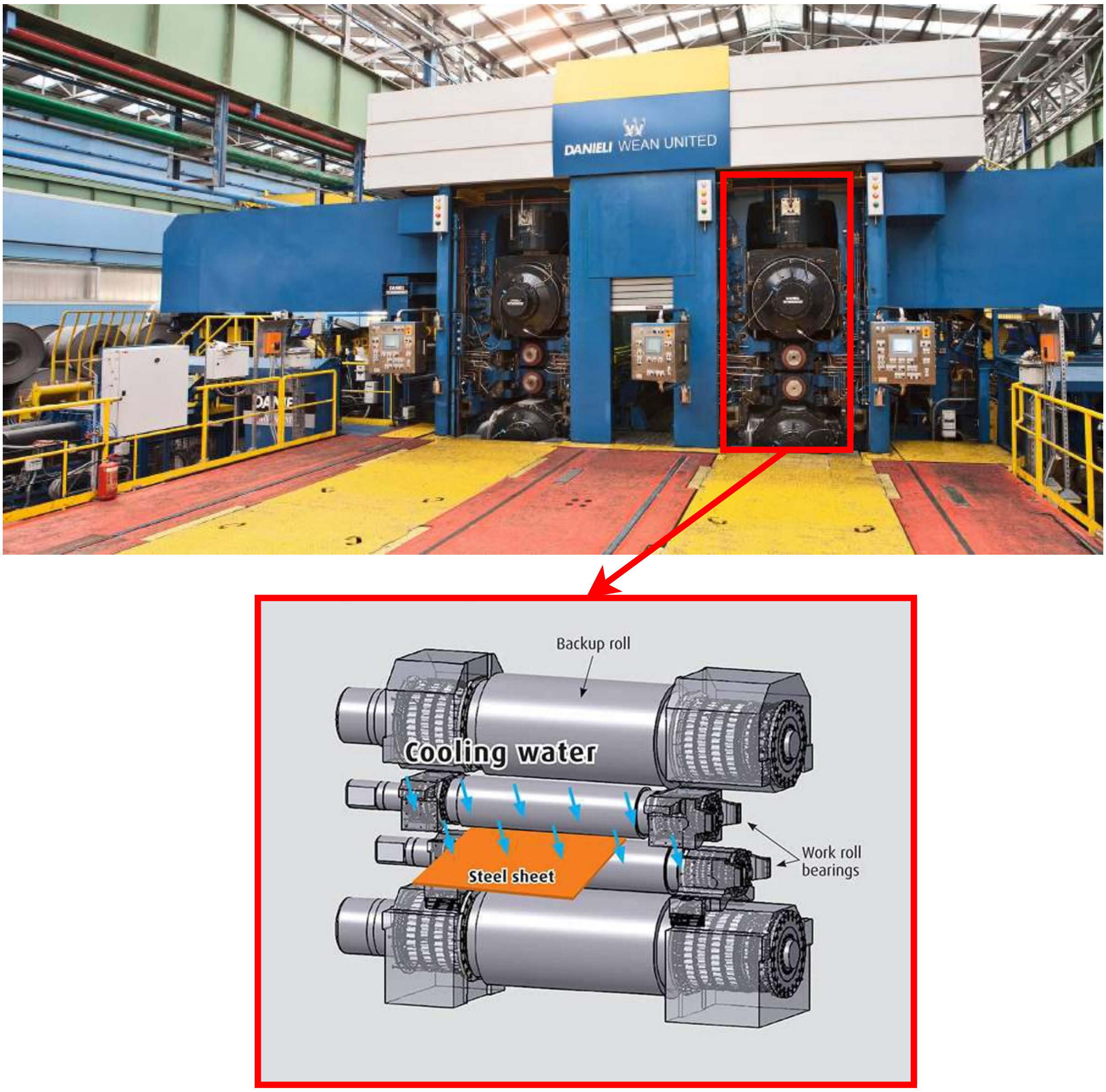
Figure 37 inicates the integration from the shop floor, the interconnection with the general gateway (GEN-GTW01), the interconnection with the corporate firewall, and the connection with Azure Data Bricks that is hosted in Microsoft's computing cloud.

4.1.7 Scenario 5 - Tandem Cold Mill

One of the main production lines is Tandem Cold Mill (TCM). With two or more supports coupled, the reduction is obtained by the tensions between the supports and the compressive force between the work rolls. A TCM can have one or more stands, and the capacity depends on the desired thickness of the final product. With friction, temperature increases in the cylinders where monitoring is desirable. Other variables, such as vibration, are also desirable. The point of contact between the cylinders and the supports is called the bearings. These would be the best spots for installing sensors.

A few years ago, an IoT system with ZigBee technology was installed. The author of this present work was responsible for developing the communication driver and integrating it with the supervisory system. The system consisted of a ZigBee gateway and twenty-four sensors. The system has failed. The data were acquired every five seconds, and the battery must be changed approximately every two months. The second problem is that a liquid called emulsion (which has a large proportion of water and a smaller proportion of oil) is used to lubricate the strip during lamination. This liquid penetrated the housing of the sensor and damaged it. The transmission technology proved to be reliable. However, these problems caused the company to lose confidence in the solution. The operation team requested that we carry out a test with the Advantech glass sensor, and for ten days, the sensor was in operation and communicating. This test was carried out to validate the data transmission since an TCM has a lot of magnetic interference in a function of the existing motors.

Figure 38 – Example of TCM - Scenario 5.



Source: The Author.

The communication environment has the following characteristics:

- Sensor Types: Vibration;
- Acquisition Frequency: Every 60 min for all data;
- Type of Information: Analog - Vibration and temperature / Status; and
- Data Visualization: Databricks (data lake), PowerBI, ERP, PIMS and Supervisory System.

In Table 11, all devices involved in this scenario are shown. In addition to the tagname itself, the table contains sensor types, location, acquisition frequency, etc.

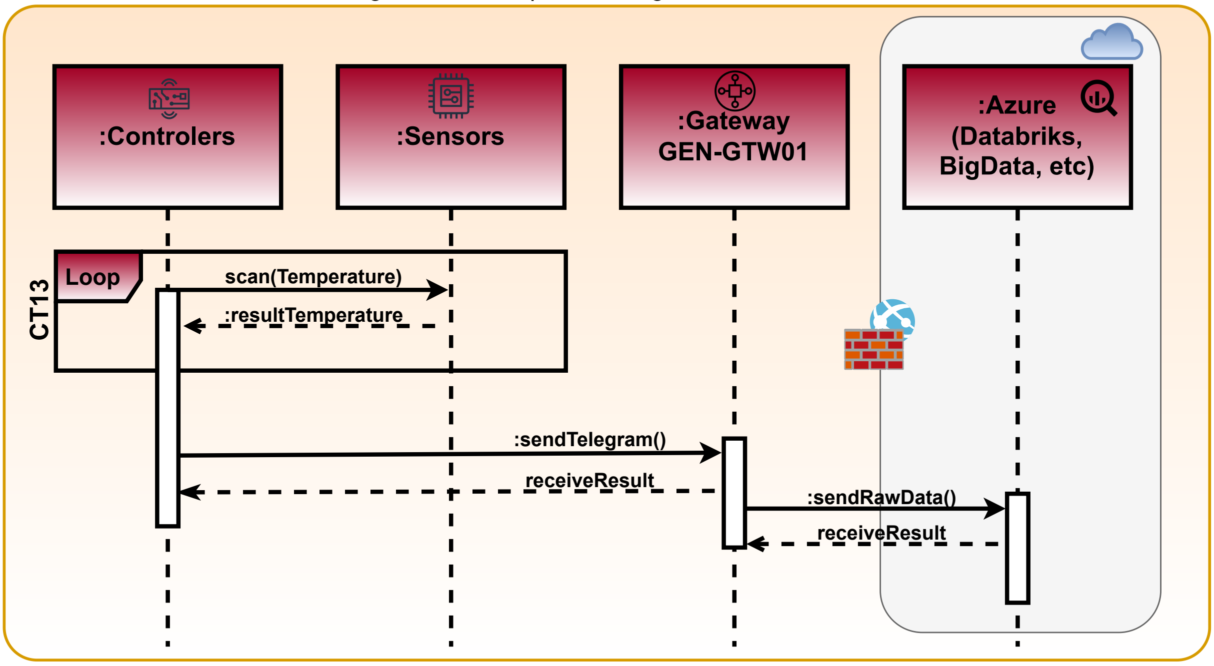
Table 11 – Scenario 5 - Tandem Cold Mill

Tagname	Type	Location	Schedule	Controler	Format
GEN-GTW01	General Gateway	External Installation	Ad-hoc	Gateway	Ad-hoc
CT13-T01-TMP01	Temperature	Each ChockSet	60 min	CT13	Float

Source: The Author.

As in the first scenario presented, this type of table is important for the areas that maintain the system and the electrical maintenance of the industrial condominium. After the PoC phase, a drawing of the electrical interconnections must be generated and included in this company's archive department. Figure 39 illustrates the diagram of events that make up the system presented in Scenario 5 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. Each request and reception of the sensor values between actors is represented by a scan (request) and result (response) signal in the figure.

Figure 39 – Sequence diagram - Scenario 5.



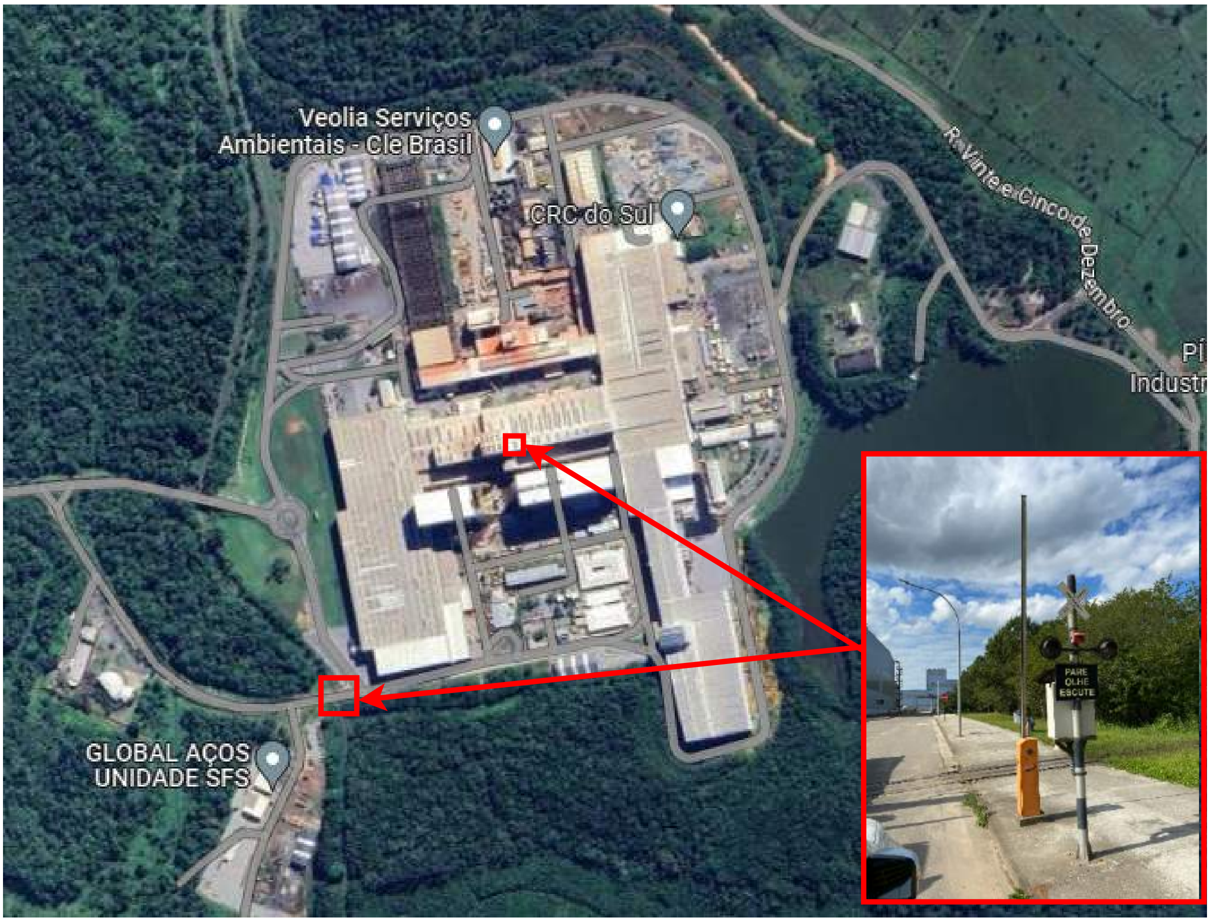
Source: The Author.

Figure 39 describes the integration from the shop floor, the interconnection with the general gateway (GEN-GTW01), the interconnection with the corporate firewall, and the connection with Azure Data Bricks that is hosted in Microsoft's computing cloud.

4.1.8 Scenario 6 - Railway Gate

Inside the ArcelorMittal Vega site is a train track connecting the port of São Francisco do Sul/SC to the state's rail system. Near the site, there is also a locomotive maneuvering area. The train ticket often interferes with internal movement within the company, especially on foot. There is a viaduct that goes over the railway line that is extended from the main pedestrian access route. During the company's expansion work, people were not allowed to cross the viaduct on foot. Sometimes this passage was blocked for up to 30 minutes. Due to this situation, we were asked for a way to identify whether the gates are closed and thus send information to employees (e.g., e-mail, text message, Microsoft Power Automate, etc). An external partner called Sirros lent us some magnetic sensors (proximity) to carry out a PoC. The gateway and the Sirros device are highlighted in red boxes.

Figure 40 – Railway across the site - ArcelorMittal Vega - Scenario 6.



Source: The Author.

The communication environment has the following characteristics:

- Sensor Types: Status;
- Acquisition Frequency: By event;
- Type of Information: Status of railway gate; and

- Data Visualization: Databricks (data lake), PowerBI, ERP, PIMS and Supervisory System.

Table 12 enlists all devices involved in this scenario. In addition to the tagname itself, the table contains sensor types, location, acquisition frequency, etc.

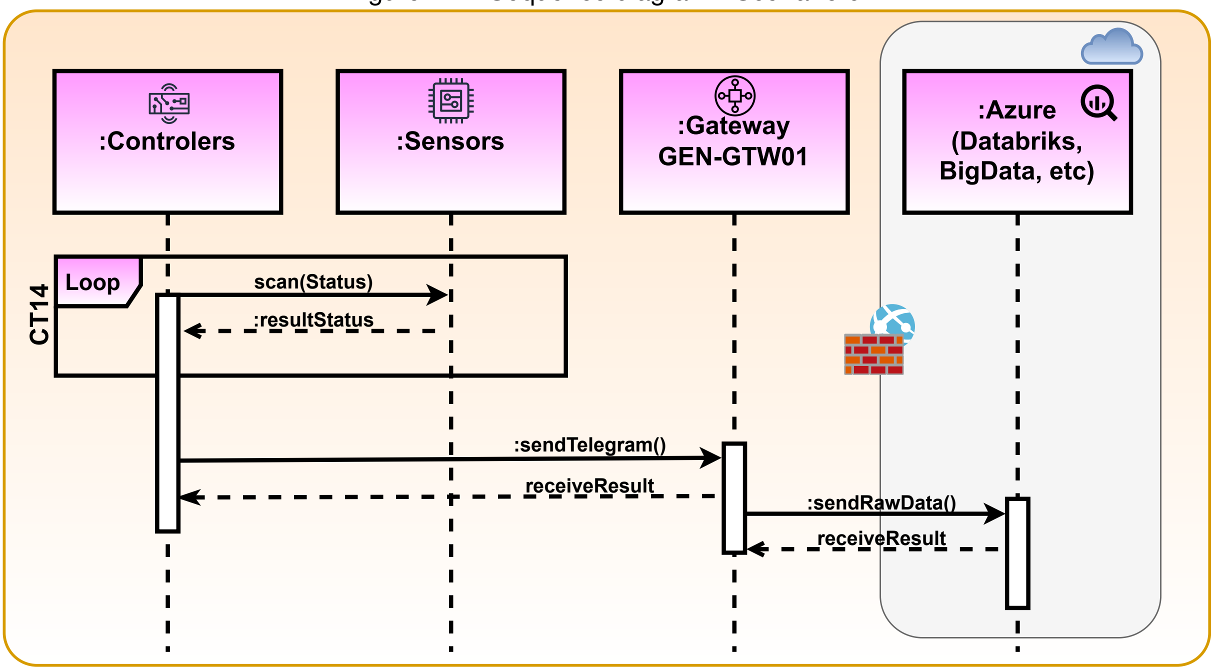
Table 12 – Scenario 6 - Railway gate

Tagname	Type	Location	Schedule	Controler	Format
GEN-GTW01	General Gateway	External Installation	Ad-hoc	Gateway	Ad-hoc
CT14-T01-STS01	Status	Railway Gate	Event	CT14	Boolean

Source: The Author.

As in the first scenario presented, this type of table is important for the areas that maintain the system and the electrical maintenance of the industrial condominium. After the PoC phase, a drawing of the electrical interconnections must be generated and included in this company's archive department. Figure 41 illustrates the diagram of events that make up the system presented in Scenario 6 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. Each request and reception of the sensor values between actors is represented by a scan (request) and result (response) signal in the figure.

Figure 41 – Sequence diagram - Scenario 6.



Source: The Author.

Figure 41 allows to observe the integration from the shop floor, the interconnection with the general gateway (GEN-GTW01), the interconnection with the corporate firewall, and the connection with Azure Data Bricks that is hosted in Microsoft's computing cloud.

4.2 TEST PLAN

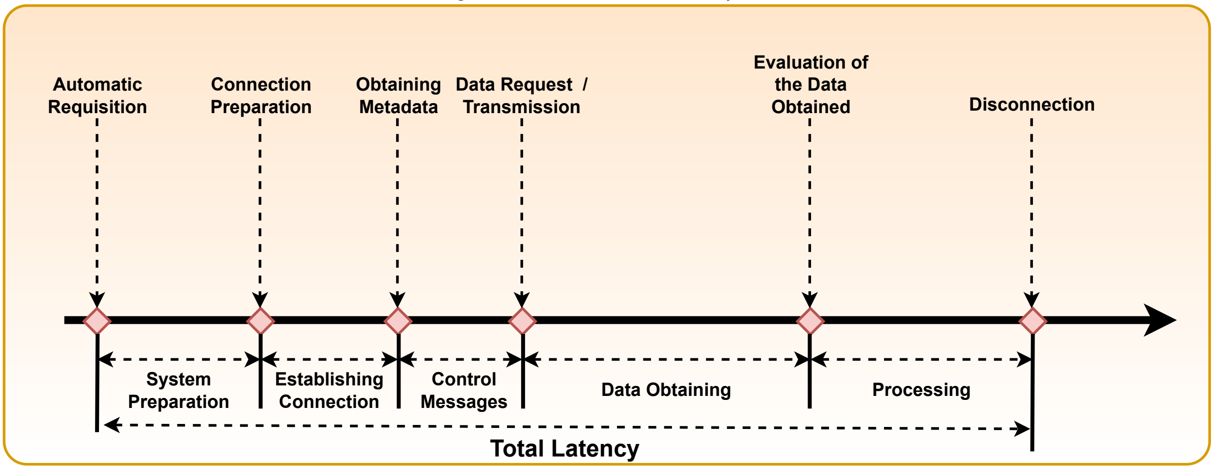
In any project development, it is highly recommended there is a well-defined test plan; and to develop it, adequate planning time and prior knowledge are necessary to develop the tests, the expected results, etc. According (INFORMAÇÃO-BACHARELADO, 2010), the test plan aims at a better organization, planning, and specification of the tests to be carried out in a given project for the people involved in it. A well-organized testing activity presupposes planning. In terms of software, IEEE created the IEEE-829 standard for the documentation of software tests, and this was widely disseminated. This standard is dedicated to documentation; however, it can help the developer plan the entire environment; and organize all necessary documentation, and standardization simplifies reading one of these documents. The version 829-2008 has been replaced by ISO/IEC/IEEE 29119-1-2013, ISO/IEC/IEEE 29119-2-2013, ISO/IEC/IEEE 29119-3-2013, and ISO/IEC/IEEE 29119-4 -2015.

The items that make up the IEEE-829 standard are divided into:

- Test plan;
- Test design specification;
- Test case specification;
- Test procedure specification;
- Test item transmission report;
- Test record;
- Test incident report; and
- Test summary report.

For the development of PoC, the monitoring of the time in each phase since the connection of the microcontroller/sensor to the radio LoRa, passing through the sensor reading (or data collection), general processing, until the disconnection, will be one of the main items of control and study. Figure 42 shows all monitoring points during the data collection.

Figure 42 – General test plan.



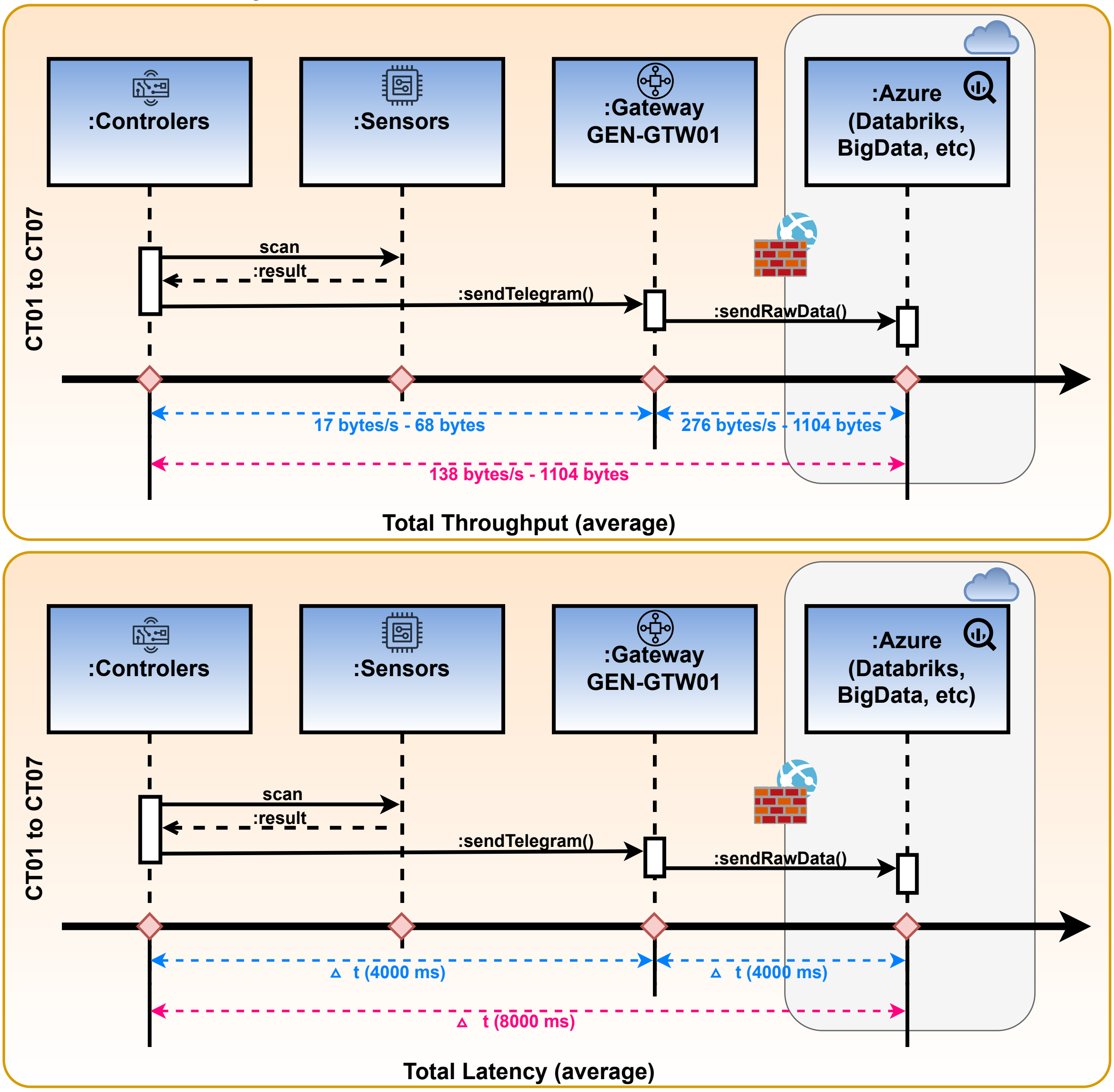
Source: The Author.

In each of the phases presented (Figure 42) an expected and maximum time will be defined and monitored. The sum of all these times is called "total latency". When the total latency exceeds a predetermined value, this can even make a project unfeasible, especially for those needing a wireless infrastructure. In the next subsections, the test plans, description of each experiment, and the objectives and expected results will be discussed.

4.2.1 Scenario 1

Figure 43 and Figure 44, shows the diagram of events that comprise the system presented in Scenario 1 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. This diagram shows the relationship between all sensors and the environment in general. The first figure presents the total throughput of the scenario and the individual throughput, such as between the controller and the gateway and between the gateway and the Databricks. Throughput is represented by the total bytes sent per period of time (e.g., bytes/second). The second figure presents the total latency of the scenario and individual latency, such as between the controller and gateway and between the gateway and Databricks. Latency is represented by the total time taken to send messages and can be represented in seconds.

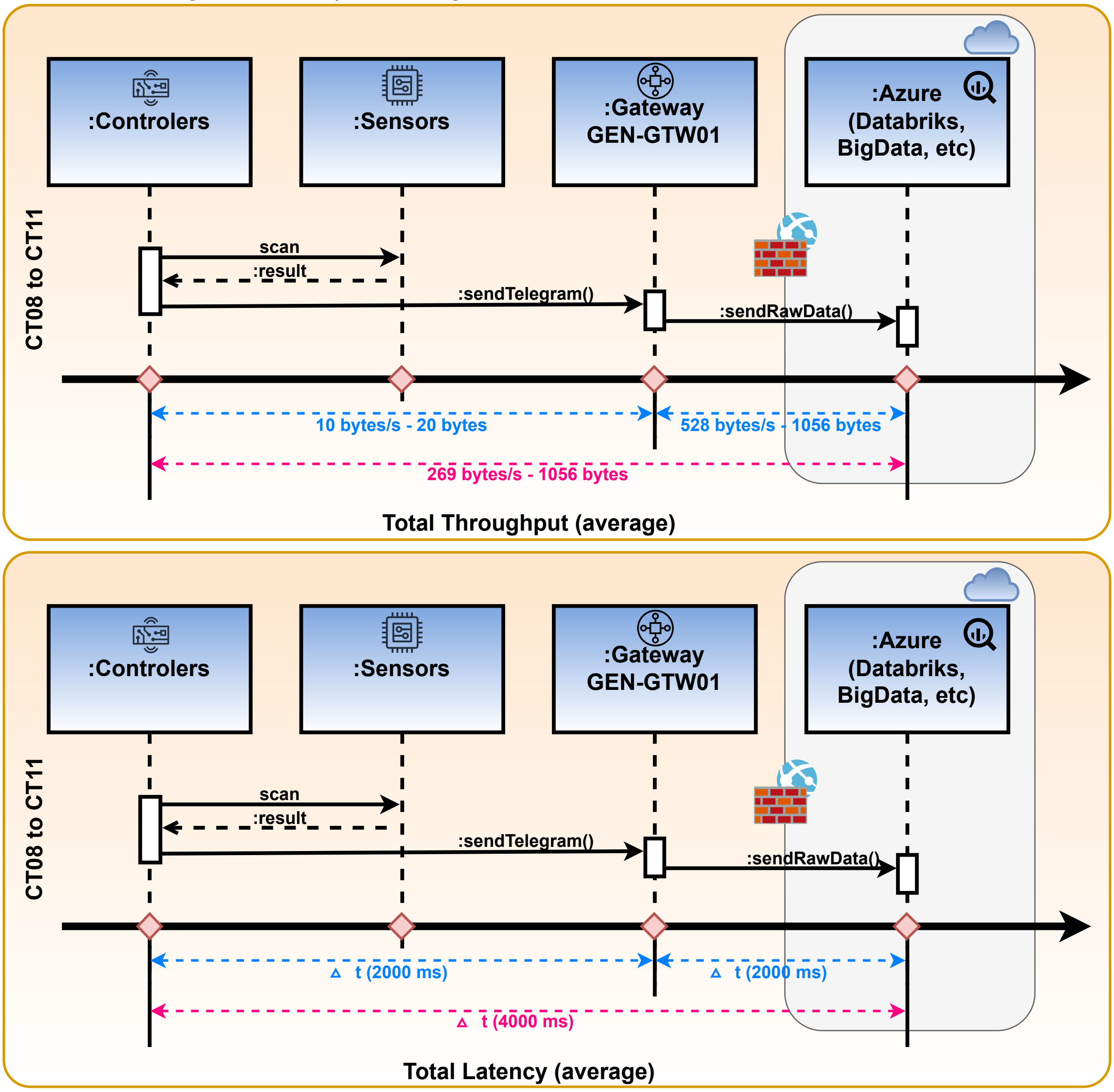
Figure 43 – Results - Scenario 1 - Controllers CT01 to CT07.



Source: The Author.

Figure 43 presents in a simplified way the items contained in Table 7 and indicates the main points of integration and the latency and throughput obtained as a result of the experiment. This image represents a scenario with ESP32 controllers. There are significant differences between ESP32 and Advantech WISE-2410 devices. This difference has an impact on total latency and throughput. For this reason, Figure 44 was created. Concerning this point, the requirements and applicability are different, reinforcing the need to divide into two images.

Figure 44 – Sequence Diagram - Scenario 1 - Controllers CT08 to CT11.



Source: The Author.

in order to carry out the experiment, the physical installation of all the devices necessary for this scenario must be completed as indicated in Figure 29. The objective of the experiment is to determine if the result obtained within the observed prerequisites follows the classification of (BROWN et al., 2018) as a "Process Monitoring" system and if the functional requirements and non-functional requirements were reached. Table 13 the main points to observe during the test are shown and used as a reference. These items must be observed for each step of tests or group of tests.

Table 13 – Scenario 1 - Test Proposal

Scenario 1	
Type	Functional, Contingency and /or Simulation
Objective	Evaluate the environmental monitoring scenario and how LPWAN technologies can contribute to industrial automation systems
Motivation	Increase monitoring of coil and packaging yards, reducing the possibility of coil oxidation and customer complaints
Requirements	FR1 to FR5
Expected Results	Total latency below 10 seconds
Resources	Sensors, micro-controllers and gateway

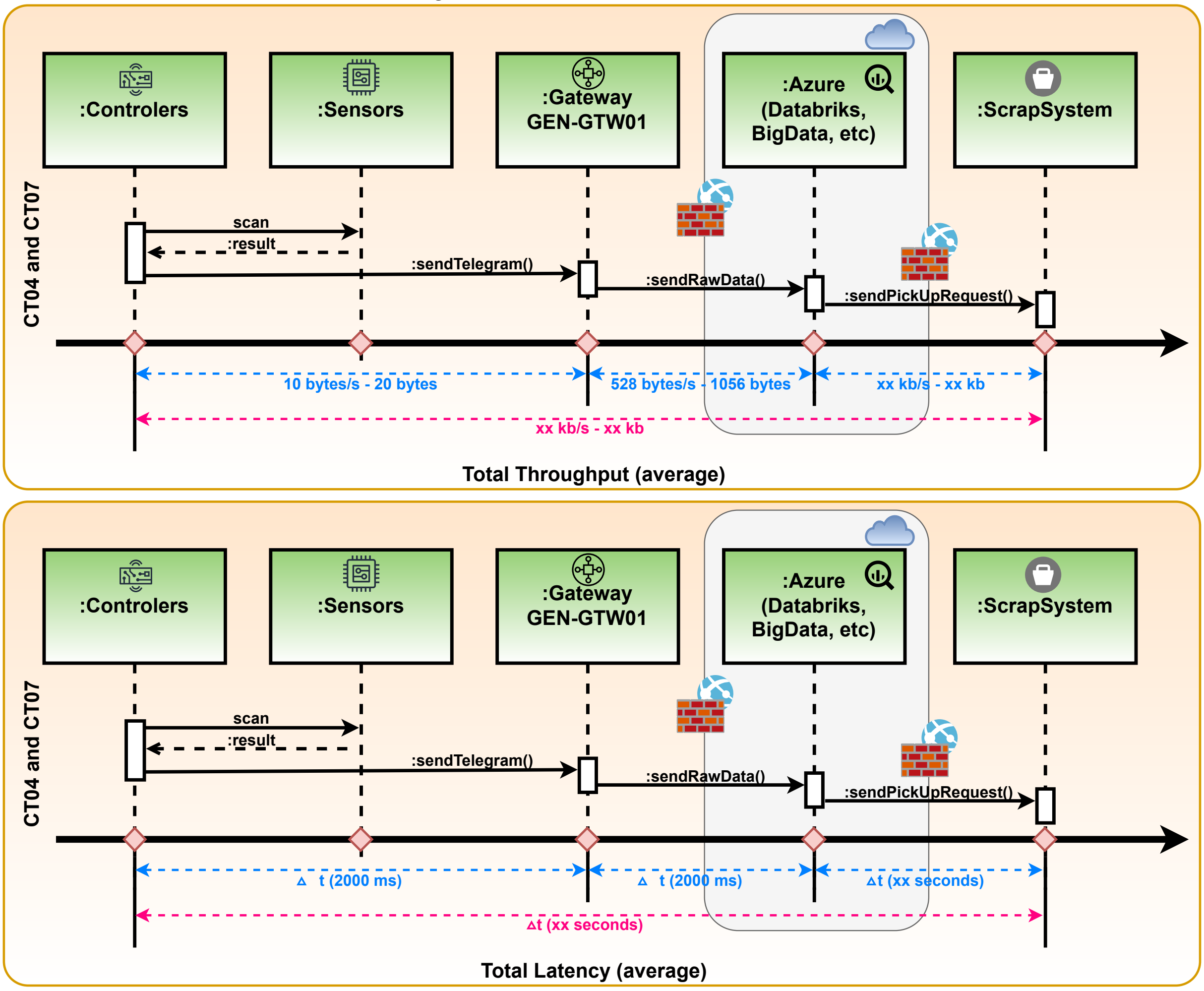
Source: Author.

For the correct monitoring of all points of interest as exemplified in Table 13 it is important to understand all connection points of the solution, e.g., how the sensors and controllers work, how the communication with the gateway works (both receiving messages and sending data to Datalake), the payloads in each phase, etc.

4.2.2 Scenario 2

Figure 45 shows the diagram of events that comprise the system presented in Scenario 2 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. This diagram shows the relationship between all sensors and the environment in general. The first figure presents the total throughput of the scenario and the individual throughput, such as between the controller and the gateway and between the gateway and the Databricks. Throughput is represented by the total bytes sent per period of time (e.g., bytes/second). The second figure presents the total latency of the scenario and individual latency, such as between the controller and gateway and between the gateway and Databricks. Latency is represented by the total time taken to send messages and can be represented in seconds.

Figure 45 – Results - Scenario 2.



Source: The Author.

The image presents in a simplified way the items contained in Table 8 and indicates the main points of integration and the latency and throughput obtained as a result of the experiment. To carry out the experiment, the physical installation of all the devices necessary for this scenario must be completed as indicated in Figure 32. The objective of the experiment is to determine if the result obtained within the observed prerequisites follows the classification of (BROWN et al., 2018) as a "Process Monitoring" system and if the functional requirements and non-functional requirements were reached. Table 14, the main points to observe during the test are shown and used as a reference. These items must be observed for each step of tests or group of tests.

Table 14 – Scenario 2 - Test Proposal

Scenario 2	
Type	Functional, Contingency and / or Simulation
Objective	Evaluate the environmental monitoring scenario and how LPWAN technologies can contribute to industrial automation systems
Motivation	Automation of the scrap bucket exchange process
Requirements	FR1 to FR5
Expected Results	Total latency below 10 seconds and the possibility the connection between Databricks and cloud and internal systems in shop floor
Resources	Sensors, micro-controllers and gateway

For the correct monitoring of all points of interest as exemplified in Table 14 it is important to understand all connection points of the solution, e.g., how the sensors and controllers work, how the communication with the gateway works (both receiving messages and sending data to Datalake), the payloads in each phase, etc. For this scenario, it is also important to understand how the data contained in the cloud can serve as input or trigger into the scrap management system.

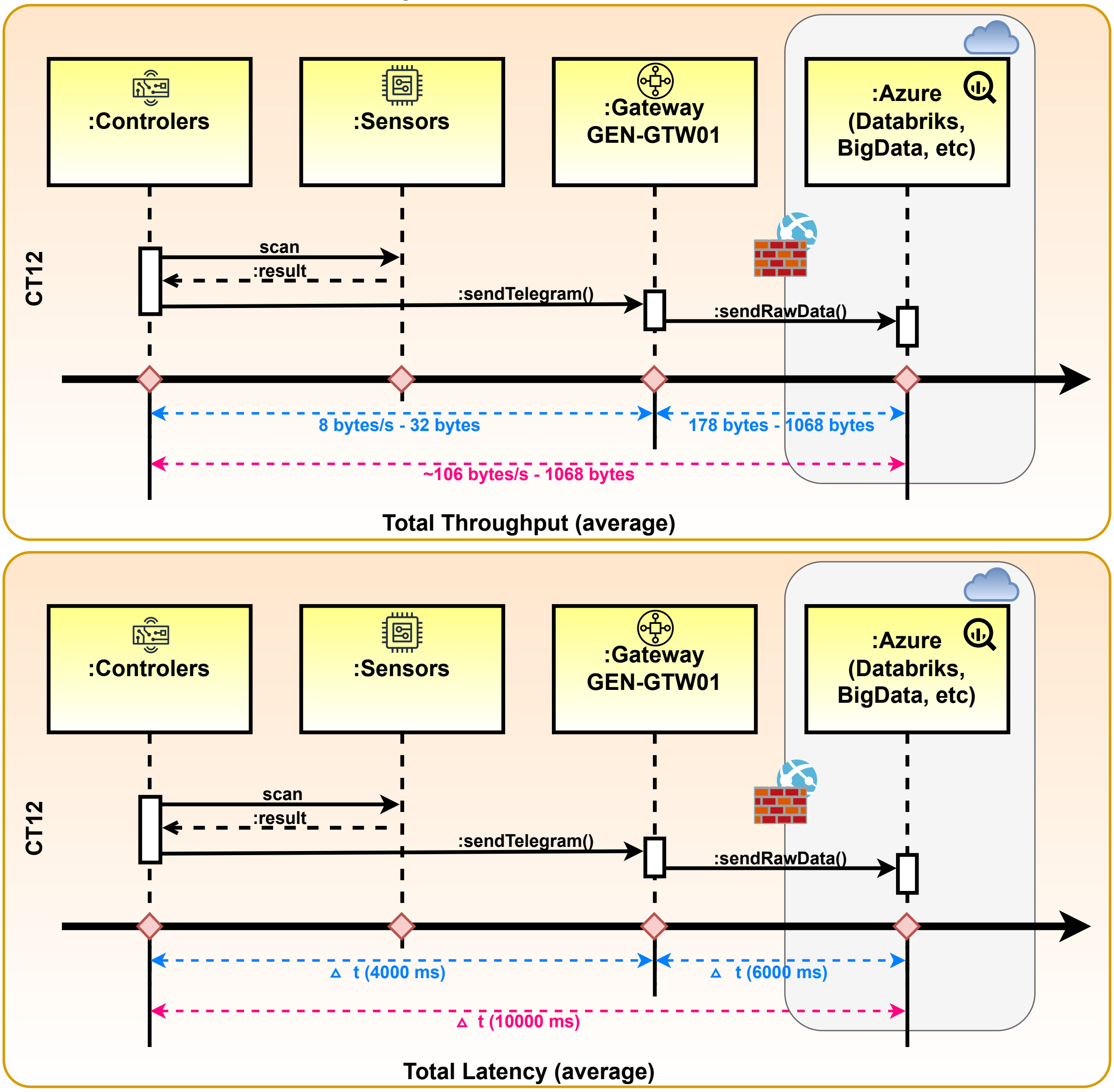
4.2.3 Scenario 3

Scenario 3 is a contingency or replacement in case Scenarios 1 and 2 cannot be served by the GEN-GTW01 gateway. In this case, the gateway would be replaced by the INT-GTW01 gateway. In this case, a second gateway would be installed to supply some deficiency of the first one. These deficiencies could be coverage, adequate performance, packet loss, etc. This scenario comprises all the steps, needs, objectives, tests, requirements, graphs, and diagrams in Scenarios 1 and 2.

4.2.4 Scenario 4

Figure 46 shows the diagram of events that comprise the system presented in Scenario 4 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. This diagram shows the relationship between all sensors and the environment in general. The first figure presents the total throughput of the scenario and the individual throughput, such as between the controller and the gateway and between the gateway and the Databricks. Throughput is represented by the total bytes sent per period of time (e.g., bytes/second). The second figure presents the total latency of the scenario and individual latency, such as between the controller and gateway and between the gateway and Databricks. Latency is represented by the total time taken to send messages and can be represented in seconds.

Figure 46 – Results - Scenario 4.



Source: The Author.

The image presents in a simplified way the items contained in Table 10 and indicates the main points of integration and the latency and throughput obtained as a result of the experiment. To carry out the experiment, the physical installation of all the devices necessary for this scenario must be completed as indicated in Figure 36. The objective of the experiment is to determine if the result obtained within the observed prerequisites follows the classification of (BROWN et al., 2018) as a "Process Monitoring" system and if the functional requirements and non-functional requirements were reached. Table 15, the main points to observe during the test are shown and used as a reference. These items must be observed for each step of tests or group of tests.

Table 15 – Scenario 4 - Test Proposal

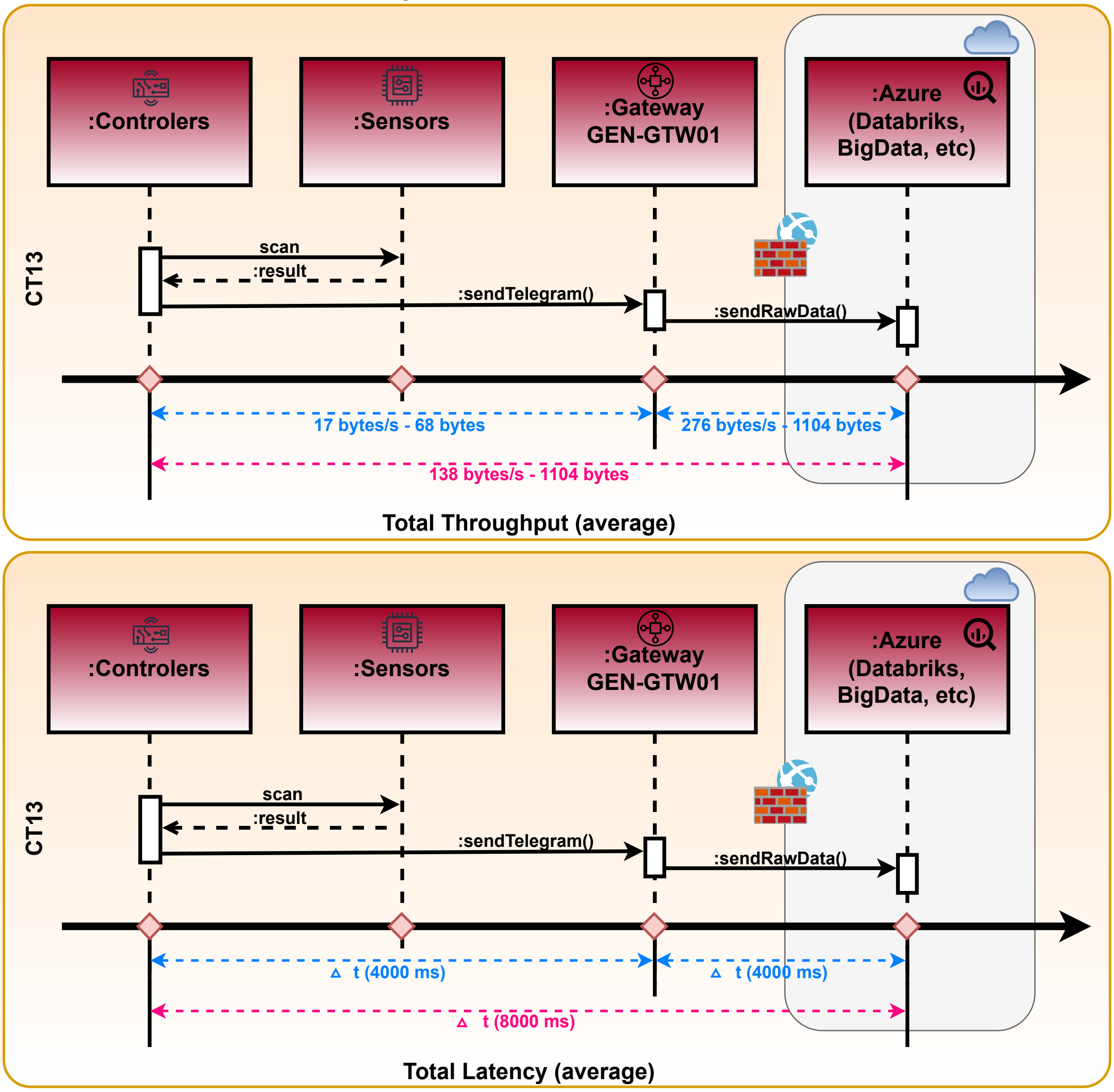
Scenario 4	
Type	Functional, Contingency and / or Simulation
Objective	Evaluate the environmental monitoring scenario and how LPWAN technologies can contribute to industrial automation systems
Motivation	Automation of acquisition data from Lake's sensors
Requirements	FR1 to FR5
Expected Results	Total latency below 10 seconds and the possibility the connection between Databricks and cloud and internal systems in shop floor
Resources	Sensors, micro-controllers and gateway

For the correct monitoring of all points of interest as exemplified in Table 15 it is important to understand all connection points of the solution, e.g., how the sensors and controllers work, how the communication with the gateway works (both receiving messages and sending data to Datalake), the payloads in each phase, etc.

4.2.5 Scenario 5

Figure 47 shows the diagram of events that comprise the system presented in Scenario 5 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. This diagram shows the relationship between all sensors and the environment in general. The first figure presents the total throughput of the scenario and the individual throughput, such as between the controller and the gateway and between the gateway and the Databricks. Throughput is represented by the total bytes sent per period of time (e.g., bytes/second). The second figure presents the total latency of the scenario and individual latency, such as between the controller and gateway and between the gateway and Databricks. Latency is represented by the total time taken to send messages and can be represented in seconds.

Figure 47 – Results - Scenario 5.



Source: The Author.

The image presents in a simplified way the items contained in Table 11 and indicates the main points of integration and the latency and throughput obtained as a result of the experiment. To carry out the experiment, the physical installation of all the devices necessary for this scenario must be completed as indicated in Figure 38. The objective of the experiment is to determine if the result obtained within the observed prerequisites follows the classification of (BROWN et al., 2018) as a "Process Monitoring" system and if the functional requirements and non-functional requirements were reached. Table 16, the main points to observe during the test are shown and used as a reference. These items must be observed for each step of tests or group of tests.

Table 16 – Scenario 5 - Test Proposal

Scenario 5	
Type	Functional, Contingency and / or Simulation
Objective	Evaluate the environmental monitoring scenario and how LPWAN technologies can contribute to industrial automation systems
Motivation	Automation of acquisition data from Tandem Cold Mill (TCM)
Requirements	FR1 to FR5
Expected Results	Total latency below 10 seconds and the possibility the connection between Databricks and cloud and internal systems in shop floor
Resources	Sensors, micro-controllers and gateway

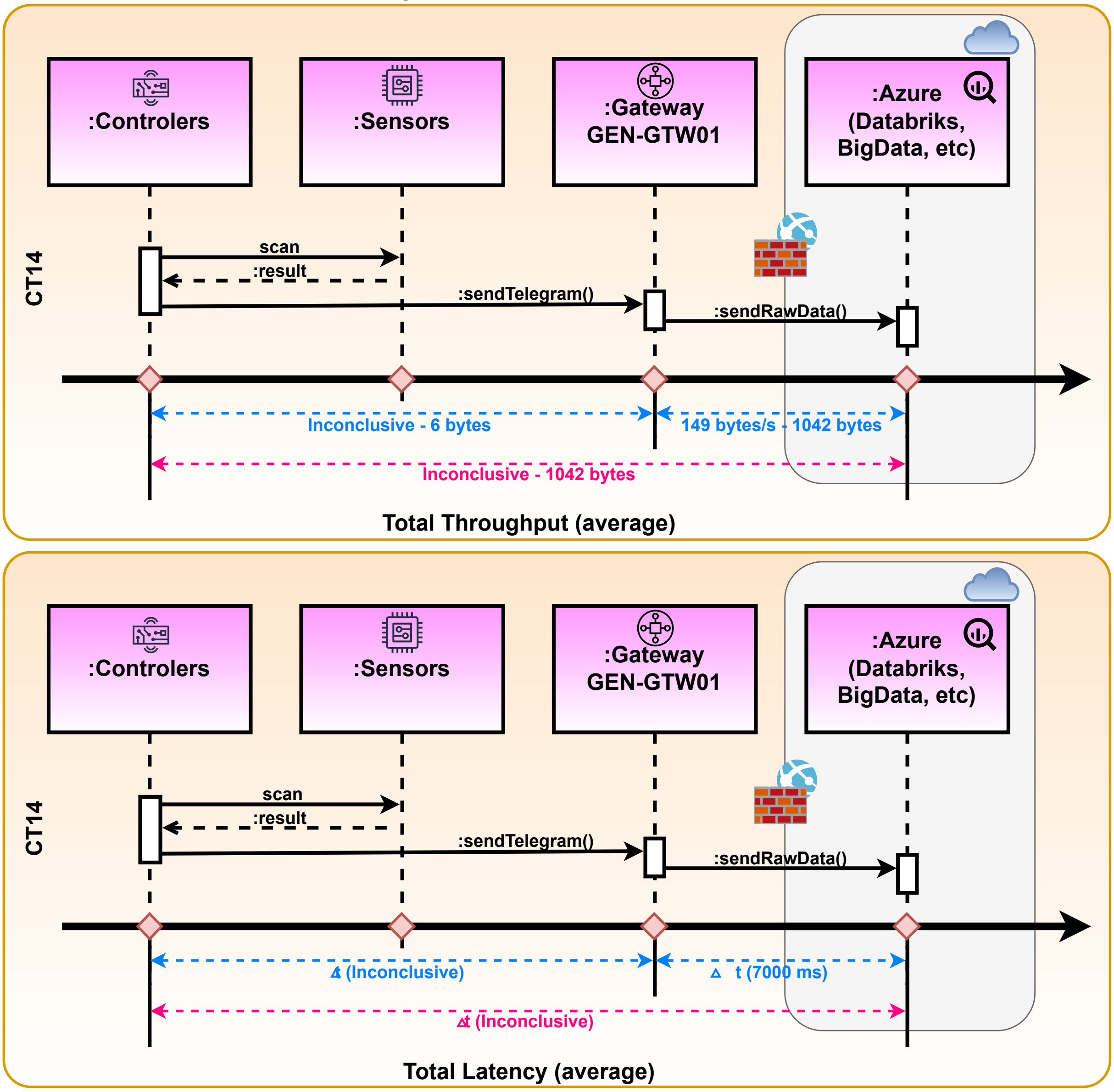
For the correct monitoring of all points of interest as exemplified in Table 16 it is important to understand all connection points of the solution, e.g., how the sensors and controllers work, how the communication with the gateway works (both receiving messages and sending data to Datalake), the payloads in each phase, etc.

4.2.6 Scenario 6

Figure 48 shows the diagram of events that comprise the system presented in Scenario 6 and how it relates to all actors, such as sensors, controllers, cloud systems, etc. This diagram shows the relationship between all sensors and the environment in general. The first figure presents the total throughput of the scenario and the individual throughput, such as between the controller and the gateway and between the gateway and the Databricks. Throughput is represented by the total bytes sent per period of time (e.g., bytes/second). The second figure presents the total latency of the scenario and individual latency, such as between the controller and gateway and between the gateway and Databricks. Latency is represented by the total time taken to send messages and can be represented in seconds.

With the use of such a simple sensor that only indicates the opening/closing of a door or a simple dry contact, this sensor does not contain in the payload the date/time of transmission. Thus, it is not possible to accurately assess the time between the time of transmission and the time when the message arrived at the gateway.

Figure 48 – Results - Scenario 6.



Source: The Author.

The image presents in a simplified way the items contained in Table 12 and indicates the main points of integration and the latency and throughput obtained as a result of the experiment. To carry out the experiment, the physical installation of all the devices necessary for this scenario must be completed as indicated in Figure 40. The objective of the experiment is to determine if the result obtained within the observed prerequisites follows the classification of (BROWN et al., 2018) as a "Process Monitoring" system and if the functional requirements and non-functional requirements were reached. Table 17, the main points to observe during the test are shown and used as a reference. These items must be observed for each step of tests or group of tests.

Table 17 – Scenario 6 - Test Proposal

Scenario 6	
Type	Functional, Contingency and / or Simulation
Objective	Evaluate the environmental monitoring scenario and how LPWAN technologies can contribute to industrial automation systems
Motivation	Automation of acquisition data from Railway Gate
Requirements	FR1 to FR5
Expected Results	Total latency below 10 seconds and the possibility the connection between Databricks and cloud and internal systems in shop floor
Resources	Sensors, micro-controllers and gateway

For the accurate monitoring of all points of interest as exemplified in Table 17 it is essential to understand all connection points of the solution, e.g., how the sensors and controllers work, how the communication with the gateway works (both receiving messages and sending data to Datalake), the payloads in each phase, etc.

4.3 IMPLEMENTATION

The devices evaluated in the IoT vision were designed to be easy to install with minimal effort. In this way, implementing sensors from partner companies did not represent a challenge after understanding the best sensor for each application. Some of these sensors have a multi-purpose but specific use. As an example, the Sirros proximity sensor can be used to detect the opening of doors, equipment, gates, etc. However, if it is also necessary to measure temperature or humidity, this sensor will not fit (e.g., measurement of the environment in an electrical room, or data center, etc.). In this way, the biggest work was in the analysis phase. Another problem was the variety of manufacturers on the market with similar solutions, with differences in price, delivery time, support, etc. If items like these are not analyzed in deep, any company can run the risk of having an environment with different solutions, which can compromise maintenance, stability, and an increase in inventory for sensor replacement. Even using controllers with more features (e.g., 2Solve FlexDaq), easy installation is still a feature. This device has a series of analog and digital inputs, a pulse counter, communication in other protocols (e.g., Modbus), etc. These features include an easy-to-fit terminal block for sensors and power supply via solar energy, 12v/24v, and battery.

A positive highlight during the development of this work was the integration with other companies in the group that was looking to develop experiments with IoT. Due to this synergy, development became collaborative, and from the separate initiative of two companies (ArcelorMittal Vega - São Francisco do Sul/SC and ArcelorMittal Tubarão - Vitória/ES), the installation of LoRaWAN gateways is already being planned at ArcelorMittal Contagem - Contagem/MG and ArcelorMittal Pecém - São Gonçalo do Amarante/CE.

The company has used Microsoft's Azure platforms as a cloud and the Databricks platform as Big Data. The fact that Kora's LoRaWAN network is integrated with the cloud environment used was also an accelerator for the adoption of this technology by ArcelorMittal. Using the same platform when some rule is implemented, a new sensor model, or a new "decoder," all companies using the platform will have access.

The first benefit of using microcontrollers for prototyping (e.g., Arduino, ESP32, Raspberry Pi, etc.) is the freedom to test at a low cost. However, it is necessary to evaluate and study all possible failure conditions. For tests in an industrial environment, it is also required to assess if the protection for the device is adequate or if a specific sensor is the most suitable. However, prototyping is a great way to understand all the needs within this type of project. Figure 49 presents three types of sensors that was tested in an industrial environment.

Figure 49 – Example of LoRaWAN sensors.

Source: The Author.

The sensors shown in Figure 49 are the three models used in the development of this present work. Each one has a characteristic that differentiates it from the other. In terms of scope, the Advantech and 2Solve models have shown to be more adherent to the needs of ArcelorMittal Vega, and studies are being conducted for the use of other models from these manufacturers. The fact that they have friendly software to configure has a differential.

4.4 EXPERIMENTS & RESULTS

One of the ways to assess whether all objectives have been achieved is the analysis and comparison of items that are part of the functional and non-functional requirements. Tables 18 and 19 show each requirement's evaluation and results.

Table 18 – Compliance with requirements - Initial plan.

Requirements	Scenario 1	Scenario 2	Scenario 3
FR1: Shop floor environment	Yes	Yes	Yes
FR2: Directly access to the sensors / actuators	Yes	Yes	Yes
FR3: Adequate baud rate	Yes	Yes	Yes
FR4: Security of communication	Yes	Yes	Yes
FR5: Automation systems integration	Partially - Necessary adopt MQTT broker or API		
NFR1: Parameterizable	Yes	Yes	Yes
NFR2: Clearly metrics for communication	Yes	Yes	Yes
NFR3: Adherence to ISA95	Yes	Yes	Yes
NFR4: Easy to add new devices	Yes	Yes	Yes
NFR5: Communication upper level systems	Yes	Yes	Yes

Source: Author.

Table 19 – Compliance with requirements - Aditional scope.

Requirements	Scenario 4	Scenario 5	Scenario 6
FR1: Shop floor environment	Yes	Yes	Yes
FR2: Directly access to the sensors / actuators	Yes	Yes	Yes
FR3: Adequate baud rate	Yes	Yes	Yes
FR4: Security of communication	Yes	Yes	Yes
FR5: Automation systems integration	Partially - Necessary adopt MQTT broker or API		
NFR1: Parameterizable	Yes	Yes	Yes
NFR2: Clearly metrics for communication	Yes	Yes	Yes
NFR3: Adherence to ISA95	Yes	Yes	Yes
NFR4: Easy to add new devices	Yes	Yes	Yes
NFR5: Communication upper level systems	Yes	Yes	Yes

Source: Author.

Tables 18 and 19 indicates all objectives were satisfactorily achieved. The FR5 requirement has limitations because the gateway used itself is limited. The chosen gateway is a model that does not include an internal application server. In this way, messages, when the gateway receives them, are immediately transferred to the " Kora cloud platform," which does the first processing and routing of data to Databricks in the Microsoft Azure cloud. Even if an internal system (hosted at ArcelorMittal Vega) needs some information from a sensor, the data must be received from the cloud. This situation would not happen with an internal gateway or another one that supports the installation of an application server; this situation would not happen.

Table 20 shows the values obtained in the experiment in which the times were classified as mean, best case, and worst case.

Table 20 – Results per device family.

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	35000	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
2Solve Device	Average	4000	6000	10000	3600000	32
	Best	2000	1000	3000	3600000	32
	Worse	8000	58000	66000	3600000	32
Sirros Devices	Average	0	7000	Inconclusive	Event	6
	Best	0	1000	Inconclusive	Event	6
	Worse	0	48000	Inconclusive	Event	6

Source: Author.

Considering the average value of the total latency, the results are compatible with the expected range and adequate for the type of application. For Advantech vibration sensors, two messages are sent, one complementing the other. Thus, the message can only be decoded after receiving the second message. The total latency is the sum of the time of the two messages. The differences in times between Advantech, ESP32, 2Solve, and Sirros devices can be explained precisely by the size and need of the complement message in the Advantech case.

4.5 ANALYSIS

Using high-level tools such as Databricks and PowerBI makes it possible to automate part of the analysis during the treatment/processing of the so-called "decoder" of the message. The reports generated in PowerBI for the site survey were the basis of the analysis.

In order to analyze total latency and throughput, all data is downloaded from Databricks and viewed via an Excel spreadsheet. Small functions were developed to aid in the study of the worksheet. Once the data is reliable and new sensors are acquired, the automatic analysis will be performed in Databricks. These reports are being shown day-by-day in the automation room on a dashboard using PowerBI.

4.6 CHAPTER CONSIDERATIONS

Throughout the chapter and the experiment, it was possible to observe the adherence of this type of technology to industrial processes. The monitored processes are considered slow; therefore, the total latency is perfectly accepted since the sending frequencies are 10 minutes for temperature and humidity, 60 minutes for vibration, and lake data. The status of the gates and railway gate occurs by eventual opening, and there is no real-time but is considered an event, and the values were corrected 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." In this way, we can conclude that the two main objectives were achieved, which is the possibility of using LPWAN technologies on the factory floor, being a quick response (no need for a complex infrastructure or with high implementation costs) and also serving as a modernization platform for SME. In both cases in situations where real-time communication is not required.

A difficulty encountered during the tests and the attention point that should also be observed is the correct choice of sensors. The correct choice does not depend on whether the transmission technology is LoRaWAN or another IoT technology. The tests on which they were based on the ESP32 were all adequate as the platform supports a series of sensors and the possibility of integration/transmission in the most varied technologies. As the payload was customized for the needs of the tests, the messages were even sent using an Real-Time Clock (RTC) sensor, but this flexibility was not seen in all devices. The 2Solve sensor is the most complete and has the largest number of analog/digital inputs and outputs, Ethernet network connection (cable and Wi-Fi), Bluetooth, Modbus, etc. In addition, it also has RTC which facilitates measurements because once synchronized with the gateway time, the accuracy in the real-time of sending the message and receiving it at the gateway. The Advantech sensor is the temperature and vibration sensor (built-in 3-axis accelerometer). Even though it has a type of internal timer, it doesn't have RTC. With time, the synchronism of time tends to be lost. This would not be a problem for the sensor's functioning, but for the purpose of analyzing in this present work, this is a problem. The Sirros sensor is the simplest of all those evaluated and has only a dry contact. Since it does not have an internal clock or access to an RTC, it was impossible to evaluate the message trigger time until receipt at the gateway. For the functioning of the sensor, this is also not a problem, but for the analysis in this present work, it is a problem. But as discussed in this work, one of the most important phases is the analysis of requirements and resources to be used.

5 CONSIDERATIONS & NEXT STEPS

Adopting Industry 4.0 and IIoT concepts is a competitive differential for several organizations. 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. However, increasing competitiveness and new market demands make IIoT mandatory rather than optional. 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 more significant 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.

In this context, ArcelorMittal Vega (a multinational company and a respective unit in São Francisco do Sul/SC - Brazil) has been investing massively in automation and solutions that reflect the context of Industry 4.0 and IIoT. Thus, the present proposal meets ArcelorMittal Vega's wishes to increase the degree of IIoT in its facilities to improve its manufacturing processes.

The process automation proposed in this work is a starting point for a new approach that will enable other automation. Sensors using wireless networks with targeted IIoT protocols (e.g., LoRa, NB-IoT, etc.) and gateways with cloud and data lake integration alone already provide data that can be useful for various optimizations that the company demands. Using the scientific method and respecting industry standards (e.g., ISA-95) provides the best of two worlds (i.e., business and academia). Thus, it is possible to prove that even austere environments (which could initially be discarded due to lack of knowledge) can be used as long as the rules and technical aspects are met.

The shop floor analysis and categorization proved to help identify target areas in which a proof of concept can be applied and that results can be analyzed scientifically. Here the unique opportunity lies in solving some information-gathering problems using IIoT and analyzing the process and technology involved.

The proposal to use the coil yard to monitor temperature and humidity may seem simple. However, considering the latency and resilience requirements required by the IIoT in light of ISA-95 and other standards presents a scientific and technical challenge. There is a question of scientific research applied to a real need for an industrial application.

Future works, complains a project for the adoption/conversion of the PoC to industrialization using more robust hardware. Other points to develop:

- Sharing the same infrastructure for different scenarios. The objective is to assess whether the number of devices and messages can degrade the environment;
- Develop scenarios for testing with a dedicated gateway/internal server and assess whether there are benefits from using an internal application server, including redundancy;
- Implementation of the integration with bucket system;
- Creation of Message Queuing Telemetry Transport (MQTT) server as a way of integration between the various Level 2 systems, including legacy systems;
- Communication with the supervisory systems (SCADA), because in this type of system, wireless sensors are not yet used; and
- Develop scenarios for testing with an indoor gateway. Tests in shadow areas, such as basements and underground electrical rooms.

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."

Some publications have already been carried out in this research, which helps in the research problem's foundation and definition. Publications presented:

- Danilo Farias de Carvalho and Charles Christian Miers. 2022. Uma proposta de análise comparativa de desempenho entre NB-IoT e LoRaWAN para aplicação em redes IIoT privadas. In Anais da Escola Regional de Alto Desempenho da Região Sul (ERAD-RS), SBC, 61–62. <https://sol.sbc.org.br/index.php/eradrs/article/view/19162>. DOI: <DOI:https://doi.org/10.5753/eradrs.2022.19162>

- Danilo Carvalho and Charles Miers. 2021. Uma proposta de estudo comparativo de NB-IoT vs LoRaWAN para aplicação em redes IIoT privadas para automação e monitoramento de processos. In Escola Regional de Redes de Computadores (ERRC) 2021 - Fórum PG, SBC. <https://sol.sbc.org.br/index.php/errc/article/view/18536>. DOI: <https://doi.org/10.5753/errc.2021.18536>

- Danilo Farias de Carvalho and Charles Christian Miers. 2023. Process Automation and Monitoring Systems Based on IIoT Using Private LoRaWAN Networks: A Case Study of ArcelorMittal Vega Facilities. IoTBDS 2023: 8th International Conference on Internet of Things, Big Data and Security <https://www.insticc.org/node/TechnicalProgram/iotbds/2023/presentationDetails/120393>. DOI <https://doi.org/10.5220/0012039300003482>. Qualis A4.

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