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Master Degree in
Connected Industry 4.0

Industry 4.0 in the Theme Park Sector: Design of a Real-Time Monitoring System for Queue Management

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ABSTRACT

The theme park industry is a consolidated sector where different industrial technologies and management procedures are present. However, the Industry 4.0 paradigm aims at disrupting how industrial processes are conceived. In this thesis, we perform a thorough investigation of key relevant features of theme parks and how industry 4.0 could be applied within the theme park sector.

Our methodology is as follows. First, we analyse the technology used in the most innovative attractions. Afterwards, we focus on the most recurrent problem within the sector: queue management at attractions. As part of the solution, a system is designed to allow real-time monitoring of waiting times through an IoT infrastructure. Radio Frequency Identification and Bluetooth Low Energy are the chosen technologies for people counting. They allow users to be located in the park in addition to counting. This system gives precise waiting times estimates, and park managers can obtain precious data about user behaviour and preferences.

Finally, we develop a proof of concept to test the designed solution and detail the benefits of applying industry 4.0 to the theme park sector.

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LIST OF ACRONYMS

- AGV: Automated Guided Vehicle
- AMQP: Advanced Message Queuing Protocol
- AWS: Amazon Web Services
- BLE: Bluetooth Low Energy
- CAGR: Compound Annual Growth Rate
- CoAP: Constrained Application Protocol
- DBMS: Database Management System
- GDP: Gross Domestic Product
- GDPR: General Data Protection Regulation
- HTTPS: Hypertext Transfer Protocol Secure
- PLC: Programmable Logic Controller
- PoC: Proof of Concept
- IoT: Internet of Things
- IIoT: Industrial Internet of Things
- MQTT: Message Queuing Telemetry Transport
- NFC: Near Field Communication
- RAMI 4.0: Reference Architectural Model Industrie 4.0
- RPI: Raspberry Pi
- RFID: Radio Frequency Identification
- RTLS: Real Time Location System
- SCADA: Supervisory Control And Data Acquisition
- TCP: Transmission Control Protocol
- UDP: User Datagram Protocol
- UHF: Ultra High Frequency
- UUID: Universally Unique Identifier

1. INTRODUCTION

1.1. Industry 4.0: a brief overview

In recent years, the industry has undergone a major technological transformation. The automated production system model developed during the second half of the last century is turning toward an intelligent industry model. This transformation is known as Industry 4.0 [1].

Industry 4.0 combines cutting-edge production and operational methods with intelligent digital technologies to build a digital enterprise that is connected and self-sufficient and can communicate, analyse, and use data to motivate further intelligent action in the physical world. It is characterised by emerging technologies like robotics, artificial intelligence and cognitive technologies, analytics, nanotechnology, quantum computing, wearables, the Internet of Things, additive manufacturing, and advanced materials. It represents how intelligent and connected technology would become embedded within organisations, people, and assets [2].

Since this concept was first discussed in Germany in 2011 to make the industry more competitive, many companies have adopted this new philosophy of understanding the production process. The objective of Industry 4.0 is to carry out a digital transformation at all levels of the production system to turn the industry into a smart factory thanks to an enabling technology that becomes even more sophisticated. Industry 4.0 aims to combine the digital and physical world by merging operational and information technologies. Companies, people, and assets will benefit from a new revolution combining cutting-edge production and operations methods with intelligent technologies.

Companies that invest in innovation are 10% more productive. In 2021, Industry 4.0 was expected to grow the Spanish GDP by 3.6% [3]. However, COVID-19 changed this scenario to a more conservative one. The report "The Industry 4.0 paradox: Overcoming disconnects on the path to digital transformation", carried out by Deloitte and based on a global survey answered by more than 350 executives in 11 countries in America, Asia and Europe, indicates that 90% of those surveyed affirm that their organisations collect information from the physical world but far fewer say they can analyse the data collected, and only half of them say they can act on this data in real-time to optimise operations and make decisions [4].

Even though industry 4.0 is an ongoing process that has not yet been fully implemented, some authors are already talking about Industry 5.0 or Society 5.0. After all, each one represents a subjective point of view based on how they perceive or classify the changes that are taking place in the industry. However, one thing is clear: all these concepts suggest that the industry is undergoing a major technological transformation at all its structural levels, and the ultimate goal of this transformation is to improve profits, reduce costs, optimise resources throughout the value chain, improve and customise the user experience and achieve a more efficient and sustainable industry.

1.2. Theme park industry: a brief overview

The theme park industry is present all over the world. This concept of leisure parks dates back to the pleasure gardens of the 19th century, venues that began as places for walks and recreation and included attractions, shows, games and food and beverage offerings over the years. The oldest theme park in the world dates from 1583. It is called Bakken, located in Denmark, and today it is still in operation, being one of the biggest tourist attractions in the country [5].

The concept of theme park and amusement park is often confused. The first differs from the second in terms of theming. These venues usually have a specific theme and do not necessarily need to have attractions: they can range from show parks to water parks, zoos or adventure parks. However, reference is usually made only to the amusement park sector when discussing theme parks. For this project, the theme park concept will be used as equivalent to an amusement park.

The Walt Disney Company was the first company to create the theme park concept as it is known today, with the opening of Disneyland Anaheim in 1952. This milestone marked a before and after in the leisure sector worldwide. Many parks began to copy this model all over the world, and from that moment, the industry experienced significant economic growth [6].

In terms of attendance, North America holds a 42% global market share in the sector, followed by Europe (18%), Asia (36%), and Latin America (4%). The three companies with the most significant global market shares are Walt Disney Parks & Resorts (35% of the market share), Merlin Entertainment Group (16% of the market share), and Universal Parks & Resort (10% of the market share). These companies have control over multiple theme park operations worldwide [6].

The Europe theme park market was valued at USD 992.0 million in 2019. Due to COVID-19, all parks reduced their attendance significantly, and growth prospects receded. However, in 2022, most parks recovered to attendance levels before the pandemic. This market is expected to expand at a compound annual growth rate (CAGR) of 2.0% from 2020 to 2027 [7]. Globally, the Theme Park Tourism Market is estimated at US$ 49.1 Billion in 2022 and is projected to reach US$ 166.67 Billion by 2032, at a CAGR of 13% from 2022 to 2032 [8].

1.3. Industry 4.0 and theme park sector: a promising duo

Industry 4.0 arises as a need to improve the production process within the industrial sector. However, its field of application extends far beyond the industry. There are many sectors at a social level that are nourished by the advantages of industry 4.0: the automotive, transport, agri-food, pharmaceutical, energy and textile sectors, among many others. The literature lists many situations of industry 4.0 in all these sectors. However, the articles are very scarce when the concepts of industry 4.0 and the entertainment and theme park sectors are mixed. Therefore, is it possible to apply Industry 4.0 to the theme park sector? How can this sector benefit from the advances of Industry 4.0? The different chapters and sections will answer this question throughout this project. However, before going into detail, comparing the industry's and theme park operations is interesting to understand the similarities and differences between both environments.

An industrial production system typically has an input flow of material that, after passing through a series of stations, is successively transformed until the desired good is obtained. Ideally, the product is intended to pass through the established stations following the production pace, avoiding bottlenecks and material stacked in buffers waiting to be processed. In addition, we must prevent machines from failing to avoid the production process to stop.

Theme parks are great works of engineering where cutting-edge technology is brought together to create complex machines that serve to entertain users. As their purpose is the amusement of the clients, the vision of an engineering machine is often lost.

If the production system model is transferred to a theme park, it can be seen how certain relationships exist. A theme park has a certain number of attractions (stations) and a flow of people (products) passing through those attractions. Just as in a flexible production system each product goes through certain stations, in a theme park, each person will go through certain rides depending on their tastes. If too many people accumulate in front of the stations (bottlenecks) or if the attractions stop working due to technical problems (production stops), visitors are upset, and the final service is unsatisfactory. The production system and the operation of a theme park are related in the way they manage assets and people respectively.

1.4. Objectives

Just as Industry 4.0 philosophy can be applied to the production system, this master's thesis will study the possibilities offered by Industry 4.0 to theme parks: what technologies are involved today and what improvements can be achieved within the theme park industry. Thus, the main objectives of this project are:

1. Study of the literature to understand which Industry 4.0 technologies are used in the theme park sector.
2. Expose the advantages of applying industry 4.0 to theme parks.
3. Analyse the problems associated with the maintenance of attractions and people flow control.
4. Design a solution to provide real-time information on waiting times at attractions.

These objectives lead to a set of challenges:

1. Explore several technologies for people detection and choose the most suitable one.
2. Analyse advantages and drawbacks from each technology.
3. Adapt the designed solution to the chosen park.

1.5. Cost estimation

Table 1.1 shows the cost estimation of this thesis

Item	Cost
Raspberry Pi 3 Model B V1.2	50€
RFID RC522 Module	2€
Wires and protoboard	2€
AWS Subscription	FREE
Computer	900€
Personnel costs	12.5 €/h
Total hours	300 h
Total cost	**4704€**

Table 1.1. Thesis total cost estimation

1.6. Methodology and contents

This project follows an exploratory and descriptive methodology to analyse industry 4.0 and the theme park sector, going from a generic approach to delve into the designed solution. Extensive research is carried out to learn how industry 4.0 is applied in theme parks. As a result from the research, the problems are exposed and a solution is proposed. Tools for designing the best solution are defined. Finally, the chosen tool is tested in a proof of concept.

The thesis is organised as follows:

1. Chapter 1: introduction of industry 4.0 and theme park sector.
2. Chapter 2: literature review about technological improvements in theme park attractions. Main problems to solve, focused on attraction maintenance and people flow management.
3. Chapter 3: design of an IoT infrastructure to provide real-time waiting time information at attractions.
4. Chapter 4: development of a proof of concept to test the technologies used in the designed solution.
5. Chapter 5: enquire into the concept of connected park and virtual queues.

2. LITERATURE REVIEW

This literature review chapter is deep research on relationships between Theme Park Industry and Industry 4.0. In the first section, a brief overview of industry 4.0, its architecture and the technologies that are part of it is made. Next, a technological review of the evolution of attractions is performed to understand the basic principles of their operation and how they have benefited from industry 4.0 technologies. Subsequently, the main problems of the theme park industry are analysed: the maintenance of attractions and queue management in rides. Finally, a deep research of the necessary technology is made to develop this project: an IoT infrastructure that measures the waiting times in the attractions in real-time.

2.1. Industry 4.0 overview

Connected Industry 4.0 and the fourth revolution are often interchangeable terms. Some authors consider this new revolution a continuation of the third industrial revolution. However, most articles in the literature agree that implementing industry 4.0 will entail a significant change within the industry to acquire a revolutionary entity. In this first section, the different milestones and disruptive discoveries within the industrial field are analysed [9].

In the **First Industrial Revolution** (1784-1870), the steam machine's invention radically changed how the production process was understood. It went from using human and animal labour to using machines powered by steam and coal. This revolution gave rise to the construction of factories.

The **Second Industrial Revolution** (1870 - 1969) set the arrival of a new energy source, electricity, and allowed the development of mass production and the creation of the assembly line. The electric motor was an important invention in this period.

The **Third Industrial Revolution** (1969 - today) marked the introduction of electronics and information technology (IT) systems to automate the production system. Computers, networks, robotics, and PLCs were the technological elements that made this change possible. The Invention of the Internet set the seeds for the next revolution.

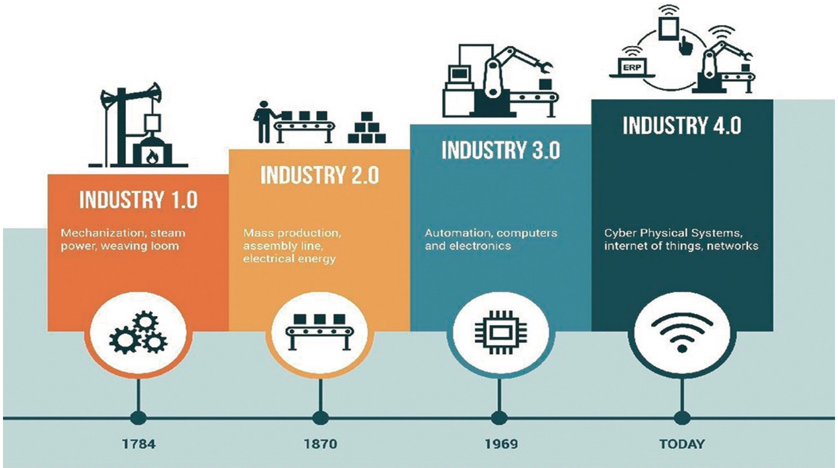


Fig. 2.1. Industrial revolutions and their chronology [10]

The fourth industrial revolution, or Connected Industry 4.0, is associated with words like smart factory, intelligence, autonomous, connectivity, or ubiquitous. In order to seek a global unification of the standards associated with Industry 4.0, the Industrial Internet Consortium (IIC) created a standard architecture known as IIRA (Industrial Internet Reference Architecture). On the other side, the German Platform Industrie 4.0 developed the Reference Architectural Model Industrie 4.0 (RAMI 4.0) to define the standards of Industry 4.0 in Europe.

Industry 4.0 represents a disruption in the way of understanding how the industry works. This has been possible thanks to a series of enabling technologies that have made cyber-physical systems a reality. These technologies are the core and engine of Industry 4.0. The essential features of each of them are explained below [11].

Autonomous robots: Unlike classical robots programmed to perform specific sequential movements, these robots can detect the environment through various sensors to gather information and act accordingly based on much more flexible non-sequential rules. They can work long periods without human supervision. They are designed to perform tasks ensuring the safety of workers even in changing environmental conditions. These robots can use from infrared sensors to avoid obstacles to stereo vision, depth cameras and software that allows the classification and detection of objects in real-time [12].

Internet of Things (IoT) and **Industrial Internet of Things (IIoT):** this concept refers to the billions of physical devices connected to the Internet. They can connect between other devices or users through dedicated Internet platforms. The Industrial Internet of Things refers to IoT applications within factories. These applications encompass a larger amount of data transferred in real-time, more robust devices, and critical processes requiring specific safety measures. More profound research will be performed later in this chapter.

Big Data Analytics is the process of analysing and processing vast amounts of data to obtain hidden patterns or make data classifications to extract valuable information for the end user. These processes are often performed in real-time using artificial intelligence algorithms such as machine learning or deep learning approaches. Data processing is fundamental to extracting helpful information since structured and unstructured data might coexist within a dataset.

Cloud Computing is the process of storing and managing data directly on the Internet, in a specific place called the cloud. This technology allows virtualisation and resource storage without implementing a server infrastructure that requires physical connections. Clouds can be either private, when service is controlled by a single organisation and not shared with others, or public, when services are offered to every customer who wants a similar service. Examples of them are Amazon Web Services or Google Cloud. The primary services offered by Cloud Computing are infrastructures, platforms or software. When all the raw resources of the server are offered, and the user is in charge of carrying out the corresponding installations, configurations and maintenance of the cloud, it is known as Infrastructures as a Service (IaaS). The action of deploying and developing platforms on the server for remote access is known as virtualisation, and the service is called Platform as a Service (PaaS). Finally, when access to software is only provided through a browser interface or program by the cloud itself, it is known as Software as a Service (SaaS) [13].

Augmented Reality (AR) integrates the virtual world with the real world so that users can either interact or just view graphics from the virtual world through devices such as glasses or screens into the real world. These devices contain a graphics engine and an artificial vision. Virtual Reality (VR) only transfers the user to a virtual environment, but there is no visual integration with the physical world [14]. AR and VR have been widely used within the entertainment sector. However, augmented reality technology has extensive uses within the industry. It can be used to train employees, visualise the internals of a complex machine, test designs and envisage them at full scale on-site, see dashboards, or perform maintenance tasks.

Simulation and **Emulation:** simulation tools arise during the third industrial revolution. They are used to recreate the behaviour of a system at a computational level to analyse it without the need to recreate a physical copy of it. Emulation tools intend to make an exact copy of the system using software tools to recreate it identically with all its variables and physical characteristics. This concept, also known as Digital Twin, emerge with Industry 4.0. A Digital Twin is an exact computer replica of a physical system. The model takes the real values of the existing system through its sensors and sends them to the emulation program as inputs for the model. Thus, the real behaviour of a system is analysed and can control while visually appreciating everything happening. Both simulation and emulation allow testing systems and studying different possibilities without having to build the real system, with the corresponding savings that this entails. These tools are used within the industry to optimise production systems and to develop the so-called Flexible Manufacturing Systems (FMS) [15].

Additive manufacturing, also known as 3D printing or rapid prototyping, uses computer-aided design (CAD) tools or 3D object scanners to create three-dimensional objects. These parts are created by adding material layer by layer until the shape is achieved. The process is carried out automatically through the so-called 3D printers, which use a 3-axis movement system to build the piece [16]. This technology is beneficial for manufacturing complex parts that require specific materials. It is widely used in the medical, transportation, aerospace, energy and consumer sectors.

Cybersecurity is the practice of protecting sensitive information and critical systems from digital attacks. In a connected industry, it is an essential part of ensuring the integrity and security of the company's physical and digital systems. Cybersecurity systems use a layered strategy based on adding small elements that protect the network at each level. The most common elements are Firewalls, which filter and reject unregistered network addresses. Cybersecurity is one of the matters that most concern the industry today since it is not possible to know what new attacks can be developed or whether they come from outside or inside the company despite all the implemented countermeasures [17].

2.2. From mechanical rides to cutting-edge technology "experiences"

This section aims to give a perspective on how technology helped develop cutting-edge attractions in today's theme parks. Although the purposes are entirely different, much of the most revolutionary technology within the industry is also used to develop new attractions: from AGVs and robotic arms to augmented and virtual reality systems. This section will detail the most remarkable technological advances in the leisure park sector, showing how this technology is also part of the industrial processes known today as Industry 4.0.

2.2.1. Technological evolution in theme parks

As seen in the first section, different industrial revolutions have occurred throughout history. These different revolutions are the result of the discovery or development of new sources of energy that have allowed the appearance of new technologies that, in turn, have facilitated, improved and professionalised the production system.

This process can also be seen in attractions' evolution throughout history. The first attractions consisted of merry-go-rounds and little train rides powered by steam engines. It was during the late 19th and early 20th centuries when the first roller-coasters were created. They were structures made of wood where the trains were initially pulled to the top using a mechanical system powered by steam engines and electric motors later on. With the arrival of the third industrial revolution and the introduction of automation, rides got more sophisticated. Before this time, the rides were solely electromechanical systems without any controller. The arrival of industrial automation marked a turning point in the development of amusement rides.

2.2.2. Industrial automation

Industrial automation can be defined as the control of machinery and production processes by autonomous systems through technologies such as programmable computers and robotic systems. This industry automation allows industrial processes to be operated and controlled without much human supervision and more efficiently than manually controlled [18]. To better understand how an industrial automation system works, the hierarchy of its different levels is explained [19]:

Level 0 (Field Level): sensors and actuators are part of this level. Sensors are the input of information to the system. They are responsible for transmitting the situation of the environment to the next level, sending parameters in real-time to carry out monitoring. On the other hand, actuators are the final links in the chain, as they are responsible for converting the electrical signals sent by the controllers into mechanical means.

Level 1 (Control Level): devices at this level are responsible for controlling the system's logic. They receive the information from the sensors, execute the relevant program and send the corresponding signals to the actuators. The controller par excellence within the industry is the PLC, which stands for Programmable Logic Controller. PLCs are programmed following the ladder structure, although other languages such as SFC, Structured Text or Function Blocks can also be used. PLCs usually follow a sequential logic, which is why there are more flexible controllers such as PAC (Programmable Automation Controller) or Industrial PCs, which allow programming in C/C++ and develop object-oriented programs [20].

Level 2 (Supervisory Level): The objective of this level is to integrate all possible controllers in the plant into a single platform. SCADA (Supervisory Control And Data Acquisition) is responsible for carrying out this task. It is software that allows access to remote data and control system parameters in a unified way. SCADA is in charge of alerting if there is any problem in the installation using alarms and monitoring everything that happens by employing logs. As it is software, it usually runs on PCs or Industrial PCs [21].

Level 3 (Planning Level): the objective of this level is to plan all the operations in a plant. Manufacturing Execution Systems (MES) are computer management systems that monitor and control, for instance, several SCADA systems. The user can control the process from start to end, planning all the activities and managing the data.

Level 4 (Management Level): the topper layer includes programmes that manage the entire flow of information in the company, both at the level of industrial processes and the level of planning, finance, sales and marketing. For this purpose, programmes such as ERP (Enterprise Resource Planning) are used, which allow all the information to be unified and automated in a single programme with different modules.

This industrial automation approach was developed during the third industrial revolution and is still used in many companies. This approach follows a hierarchy structure where all levels are well differentiated and follow a strict order. However, Industry 4.0 approach deletes the barriers between levels, creating an architecture where all these levels are mixed and interconnected, as figure 2.2 illustrates:

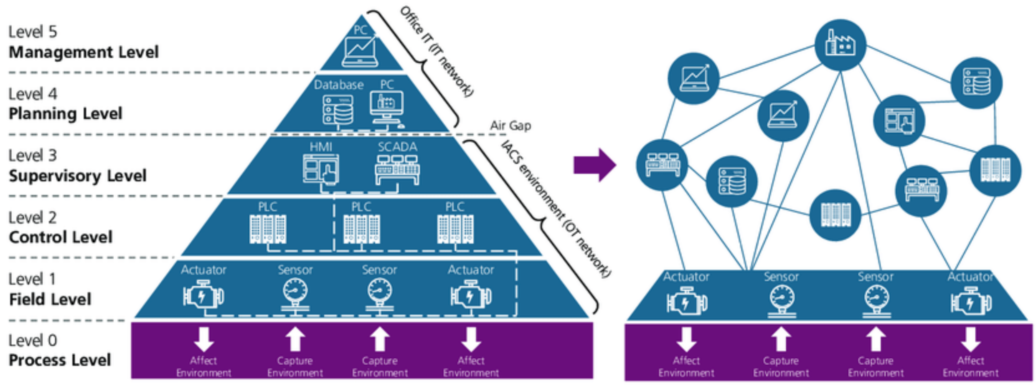


Fig. 2.2. Industrial automation: Industry 3.0 approach vs Industry 4.0 approach [22]

2.2.3. Attractions automation

The industrial automation approach developed in industries controls today's attractions. Just as the technology used in production processes has evolved over the years, so have attractions. Modernising ride systems is not merely a whim or a trend because the technology exists, but because technology has enabled existing needs to be met.

Before the advent of PLCs, production systems and complex rides used hard-wired relay logic to control processes. Relays are electromechanical devices used to redirect current and electrical signals to control machinery. Modifying these systems was tedious and expensive due to the complexity of the system and all the hard-wired connections between relays. The more complex the system, the more relays and connections were needed.

This all changed with the invention of the PLC, developed by Dick Morley and General Motors. Over the years, PLCs have become more sophisticated and allow for complex mathematical calculations for specific movements on rides, for instance, programming a linear synchronous motor (LSM) launch in a roller coaster.

Today, rides are complex systems full of sensors and actuators to guarantee safety during the ride cycle. Rides, either roller coasters are divided into several sections, called "block sections". They are a piece of track where only one vehicle can stay at a time in order to avoid collisions. Once the vehicles live the section, another vehicle can enter to this one. The rule behind block sections is that within a roller coaster, the maximum number of trains is the number of block sections minus one. Figure 2.3 shows an example of a track divided into four block sections (two block brakes, one station and one lift) and two trains. This system allows several vehicles running simultaneously; hence ride capacity is increased. This scenario cannot be possible without a controller that warranties vehicles not to crash against each other.

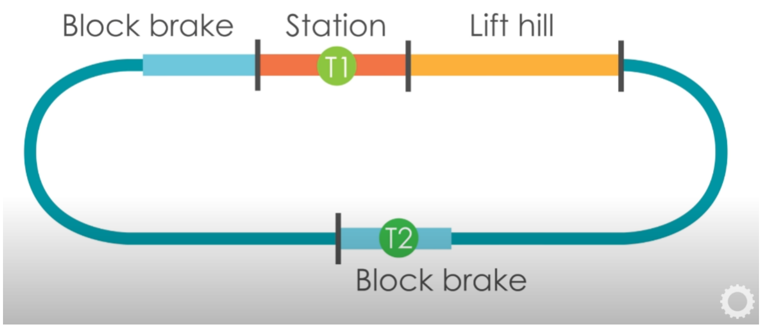


Fig. 2.3. Roller coaster schema with 4 block sections and 2 trains [23]

Proximity sensors and brakes are used in each block section to ensure the following vehicle can not enter before the previous vehicle has left it. Position sensors are also used to ensure all restraints are safely fastened. All this information is updated every PLC scan cycle, as figure 2.4 illustrates.

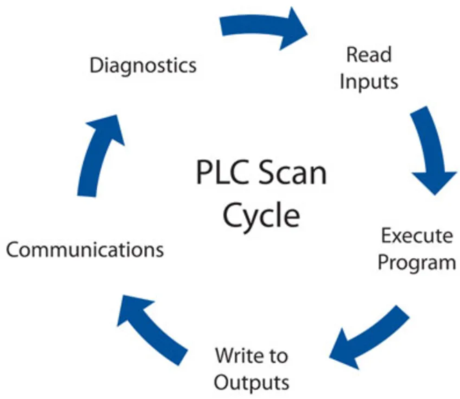


Fig. 2.4. PLC Scan Cycle [24]

There are two definitions to take into consideration. One is cycle time, which is the time it takes to execute one time all actions in the PLC program plus all extra tasks carried out by the PLC (communication, I/O update). It usually takes milliseconds but depends on the CPU capacity. The other one is reaction time, which is the time that elapses from when the state of a signal changes to the activation of the corresponding physical actuators [25].

Inputs can be either digital or analogue. Digital inputs might be proximity sensors and push buttons. The value for this input will be 0 or 1, depending on whether it is activated or deactivated. Analogue sensors encompass a range of values set between two figures. Pressure sensors and optical encoders are analogue sensors. Therefore, thanks to these sensors, the system can turn on a motor, set a block zone or trigger a special effect in the ride. Apart from the central PLC controller, which is the brain of the ride, PLCs can also be found in the wagons. They are used to report to the ride control system, the vehicle speed, position on the track and trigger any kind of special effects such as onboard audio or lighting effects.

Safety on attractions is of paramount importance, and the factor around which attractions are designed and constraints are set. For this reason, the type of PLC controller used in attractions is the so-called Safety PLC. It has a main processor and a co-processor that work in tandem and act as a redundant system. Figure 2.5 shows the difference between the modules of a standard PLC and a Safety PLC. The assembly that integrates the PLC, sensors, and actuators is called SIS (Safety Instrumented Systems), which is the whole assembly that must be considered when designing a safety system [26]. Figure 2.5 shows the difference between a standard PLC and a safety PLC.

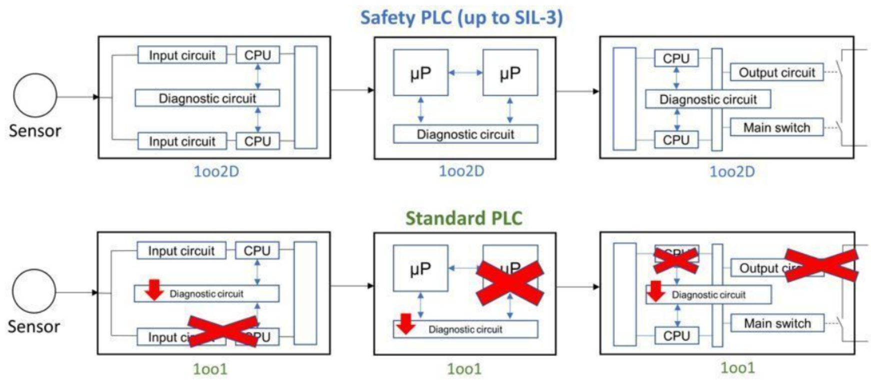


Fig. 2.5. Standard PLC vs Safety PLC [27]

2.2.4. Industry 4.0 technology for 21st century attractions

Basic ride functioning has been defined in the previous section. Automation control is the core of any ride, where all the logic is set, and the sequence is defined. However, as technology improves, new sophisticated systems arise. Technology from the so-called Industry 4.0 is being used nowadays in theme parks to develop astonishing experiences for guests. In this section, a review of the most revolutionary technology systems within theme park rides will be performed.

2.2.4.1. AGV autonomous trackless system: Pooh's Hunny Hunt at Tokyo Disneyland

This ride dates from 2000. AGVs, which stand for Automatic Guided Vehicles, have been used in industry for some decades as part of flexible manufacturing systems. At Epcot's Walt Disney World Resort theme park, Universe of Energy was one of the first rides introducing AGV technology back in 1982. These vehicles usually move along a wire embedded in the floor. However, for this new ride based on Winnie Pooh's movie, Walt Disney Imagineering developed a trackless system where the vehicle could move autonomously over a surface, similar to what AMR (Autonomous Mobile Robots) do. The system uses an array of sensors managed by a local positioning system (LPS) [28].

The patented control system sends directional information from a master control computer directly to the vehicles designed to resemble honey pots. The particular honey pot car is then moved using this information through a complex matrix built into the real floor tiles. The vehicles are told where to go since the master computer creates a random path and steers the honey pot in real-time every few seconds. Since this technology operates in real-time, the necessary adjustments must be made in a few milliseconds. As a result, random movements and beautiful choreographies are created, being every journey a unique experience. This ride had a cost of USD 130 million.

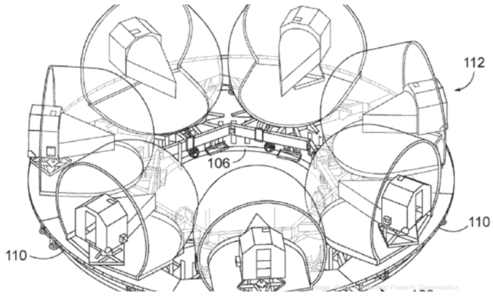
Fig. 2.6. Autonomous Vehicle at Pooh's Hunny Hunt [29]

2.2.4.2. Real-time massive data computing processing: Millennium Falcon Smugglers Run at Walt Disney World

This ride simulates the experience of piloting the Millenium Falcon from Star Wars movies. In order to immerse guests in this adventure, the cabin is mounted onto an eight-arm motion base, where electric linear actuators work together to move and jostle the cabin. This cabin is enveloped by a huge dome screen where the video is projected using five QuadroSync projectors offering ultra-high resolution pictures [30]. Moreover, this cabin is mounted in a large rotating carousel along with six more cabins to increase ride capacity. There are four carousels in total, which means 28 cabins working at a time.

Nevertheless, this was not the most challenging part of this ride. Since customers are in charge of controlling the spaceship using more than 200 buttons, they can decide in real time what will happen through the simulation, like in a video game. The motion base, the UHD projection, and the special effects must change in real-time according to the users' decisions. There was no such demanding technology to process all this data in real-time. They had to work with Nvidia and devise a solution to satisfy their requirements: multiplying horsepower between four and six times. The final solution involved using eight NVIDIA Quadro P6000 GPUs in one single computer and adapting this tailor-made solution to their game engine, Epic's Unreal Engine 4 [31].

(a) Cabin

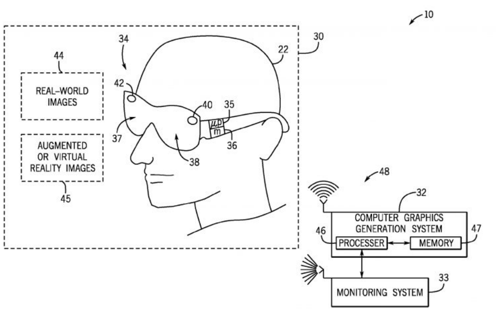


(b) Carousel platform system

Fig. 2.7. Millennium Falcon Smugglers Run [32]

2.2.4.3. Augmented reality: Mario Kart - Koopa's Challenge at Universal Studios Japan

This ride is one of its kind since it is the first time Augmented Reality is incorporated into a motion-guided vehicle. Universal Studios patented an augmented reality goggles system shown in figure 2.8. This system allows tracking the external environment in real-time and adapting the superposed images in the correct position considering the movements and different heights of users. The user can interact with these graphics thanks to onboard triggered buttons, so images are processed and updated in real-time into the glasses. The ride combines projections, 3D video mapping and physical animatronics to create an immersive experience where guests do not distinguish between reality and the digital world [33].



(a) AR goggles patented system

(b) Ride vehicle

Fig. 2.8. Universal Studios' patent for AR goggles in Mario Kart ride [33]

2.2.4.4. Real-Time Local Location System: Pangea at Movieland Italy

The user drives a real Jeep through rugged earth roads in this attraction. Even children can drive it without a driver's licence. That is possible because the system is designed using a local positioning system with internal and external sensors that allow the vehicle's position to be located at all times with millimetre precision. This way, as soon as the vehicle drifts a little off the road, the system stops the car and tells the user how to return to the correct position. Assisted driving is possible thanks to a computer on board the vehicle, a Siemens Simatic industrial PC, and an HMI where the attraction's storytelling is displayed. The data is synchronised via telemetry with the Suzuki brand Jeep. During the tour, checkpoints update the attraction's audio system. The vehicles move within an immersive environment filled with visual effects and dinosaur animatronics [34].

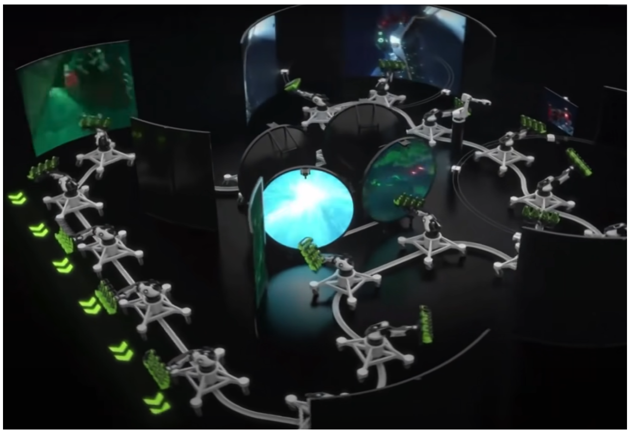
(a) Siemens Simatic HMI

(b) Ride vehicle

Fig. 2.9. Pangea's vehicle and monitor system [34]

2.2.4.5. Kuka Robots: Harry Potter and the Forbidden Journey at Universal Studios Florida

This ride was also a world class attraction. It uses the model called RoboCoaster G2 from the English ride manufacturing company Simworx Robocoaster [35]. Users are mounted in 4-seat cabins at the head of a gigantic robotic arm from the German manufacturer KUKA. This robotic arm moves along a two-dimensional track throughout a show building. This ride was a revolution in terms of adding robotic arms to a moving car. Figure 2.10 illustrates the robotic system.



(a) Ride system

(b) RoboCoaster G2

Fig. 2.10. Harry Potter and the Forbidden Journey Ride System [35]

2.2.4.6. Audio-Animatronics

Audio-animatronics are a registered brand by Walt Disney Imagineering and is used today in thousands of attractions worldwide. Audio animatronics consist of robotic characters able to move and perform a series of movements. Although they have been used for over 50 years, the latest improvements set up a new generation of animatronics. Complex robotic mechanisms allow all the movements of a human being to be replicated. Thanks to real-time movement capture, this data is sent to the robot without the need to program the movements manually. The result is seamless humanoids where the user cannot tell whether it is real. Although the movements are programmed, and they do not have in-built intelligence, their success relies on their realistic, almost human movements.

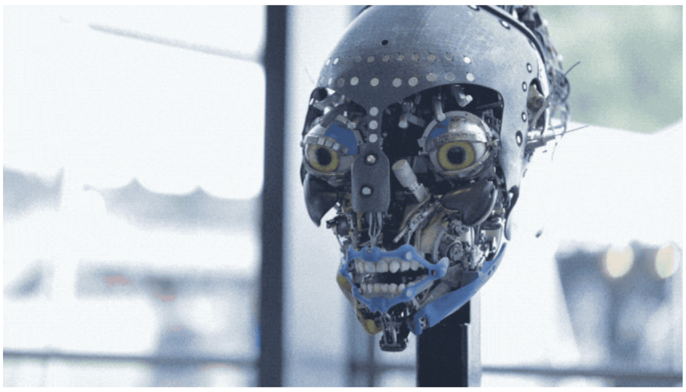


Fig. 2.11. Audio-Animatronic for Disney's Navvy River Journey ride in Animal's Kingdom [36]

2.3. Industry 4.0 practices in theme park management

The previous section aimed to analyse the generic functioning of attractions at a technological level to see which Industry 4.0 technologies are used within the sector. Attractions are just one part of the vast ecosystem of theme parks. An attraction on its own can give a park a particular value. However, it is the set of all the services that defines their essence: restaurants, shows, shops, attractions, theme sets, immersive experiences or games. All these facilities are interconnected by a continuous flow of people who make use of them.

After deep research on customer's thought and complaints, there are two main problems within the theme park industry that are often the biggest reason for customer dissatisfaction: rides undergoing maintenance or out of service and long waits at rides. For theme park managers, it is also essential to know how people move along the parks, which areas do they visit and what they do every time to optimise resources.

Hence, in this section, deep research about attraction maintenance and how Industry 4.0 can solve this problem will be carried out, followed by an analysis of queue management, which is the main topic of this project.

2.3.1. Attraction maintenance

Maintenance is a primary task when talking about rides. Every machine or station within an industrial process must go under scheduled maintenance tasks to ensure proper functioning. The attractions are machines that process people instead of objects, so the maintenance tasks are much stricter. Maintenance costs, for any kind of industry, can vary between 15% and 60% of the cost of assets produced [37].

According to the DIN EN 31051 standard, the maintenance concept is defined as *the combinations of all technical and administrative actions as well as actions of management in the lifetime of a unit, in order to be in the fully functional state or to recover in this one, so that this unit can fulfil his requirements.* [38]

A theme park ride is thoroughly checked every day before opening to ensure the perfect functioning of the system. Every ride has different test programs to guarantee safety. Besides daily revisions, there exists other maintenance performed either when there is a failure or to ensure well-functioning over time. These maintenance strategies are defined in DIN EN 13306 maintenance standard, and they are corrective maintenance, preventive maintenance, condition-based maintenance, and predictive maintenance. [38]

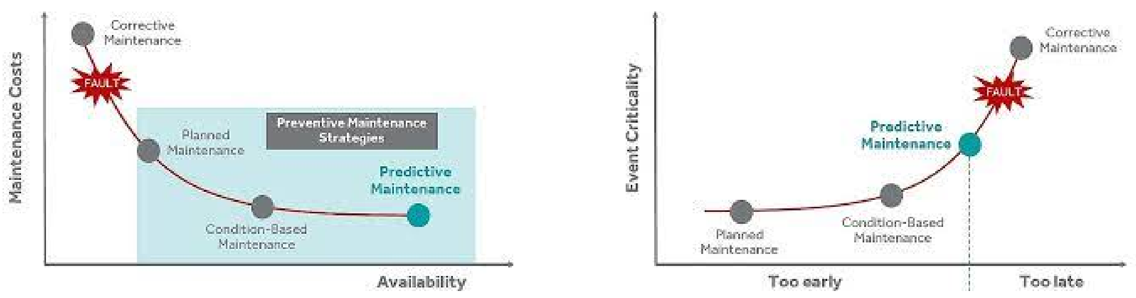
Corrective Maintenance is carried out after fault recognition. Items are used until the end of its service time, reducing efforts to replace or inspect items. However, failing at any unknown time might cause higher costs than the total usage of its wear margin.

Preventive Maintenance is carried out at predetermined intervals and intended to reduce the probability of failure. Each item has an estimated operational time before it is worn out. Costs can stay low if the item is used close to the asset lifetime and just replaced before it fails. This type of maintenance reduces breakdown frequency and increases service life. However, determining the exact lifetime of an asset is not always a trivial task.

In **Condition-based Maintenance** multiple sensors are used to monitor the asset to determine whether it has normal or abnormal behaviour. Based on this information, operations can anticipate before failure occurs.

Predictive Maintenance: is encompassed in condition-based maintenance. This variant processes both recent and historical data along with machine learning algorithms to provide accurate results of the future behaviour of an asset or machine.

In figure 2.12a, the relationship between Maintenance Costs and Availability is analysed, while in Figure 2.12b, a comparison between strategies and event criticality is performed [39].



(a) Maintenance costs (b) Event criticality

Fig. 2.12. Maintenance strategies and fault points [38]

2.3.1.1. Predictive maintenance for theme park rides

Maintenance of rides is a complex task; therefore, the proper strategy must be chosen to ensure users' safety. Corrective maintenance is not an option since there is no room for failure. A ride is designed to stop when an anomaly in the system is detected. However, changing a wagon's wheel after it breaks, for instance, is useless since the accident will be fatal. Therefore, every item must be changed or replaced before its lifetime cycle is due, as it suggests preventive maintenance. Nevertheless, predictive maintenance and monitoring operations through sensors increase the chances of detecting anomalies and preventing fatal errors. For that reason, predictive maintenance is starting to arise within the theme park industry as a complement to preventive maintenance.

In this section, a pioneer study in the field of predictive maintenance for the entertainment sector carried out by the Department of Information Engineering in Padova, Italy, together with ride manufacturer company Antonio Zamperla S.p.A. is analysed [40].

Maintenance procedures are still carried out manually nowadays, following government regulations or riding manuals, no matter what the current conditions of the machinery are. This situation suggests that maintenance is frequently carried out inadvertently, wasting time, labour, and materials. Despite being cautious and sturdy, this approach is incredibly ineffective. A paradigm shift from the current conservative strategy to a greener and more effective one would be possible with the help of smart monitoring systems. Anticipating a failure will be possible, as well as considering different choices while testing prototypes, thanks to insights provided by this data. Last but not least, automated supervision systems would ensure the safety of the rides by spotting minute irregularities that a human supervisor would probably miss.

The project is based on a Machine Learning-based emerging technology: Unsupervised Anomaly Detection (AD). This technology seeks to offer improved diagnostic capabilities. These unsupervised AD tools use both multivariate and univariate approaches. The first one is based on tabular data and can detect multivariate anomalous behaviour typically missed by traditional chart-based monitoring tools. However, when applied to time-series data, these approaches require feature extraction procedures, which can be laborious for developers and result in data loss. Univariate approaches work with time-series. They usually work by predicting residuals, for example, comparing actual and anticipated time-series and triggering an alarm when the difference between them exceeds a predetermined threshold. Figure 2.13 shows the functional schema of the anomaly detection approach they proposed.

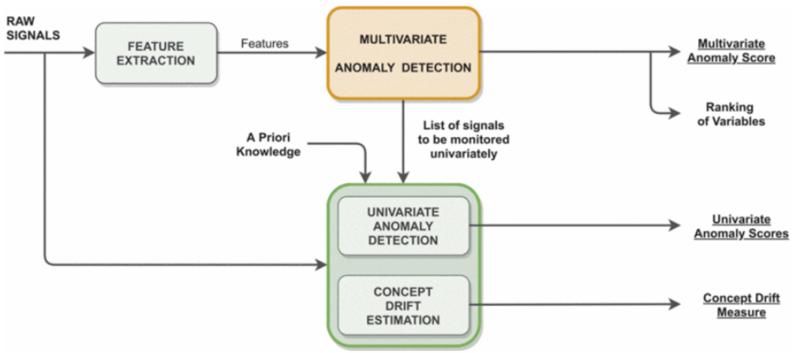


Fig. 2.13. Functional schema for anomaly detection. [40]

Consequently, a big data architecture has been developed to support this project. It combines cutting-edge univariate and multivariate AD approaches with recently proposed techniques in the area of eXplainable Artificial Intelligence (XAI), which are intended to achieve improved monitoring capabilities and optimise service operation.

Zamperla's DangleZ roller coaster model has been used for this case study, as figure 2.14 shows. Data is acquired with an irregular sampling rate through an onboard PLC. Each time series speaks for a different signal which is used to track the behaviour of the machine. There are signals for monitoring the vehicle's position along different locations along the track; describing voltages, frequencies and currents for consumption and movement; describing weather conditions; and signals for ensuring the proper functioning and the security of the ride.

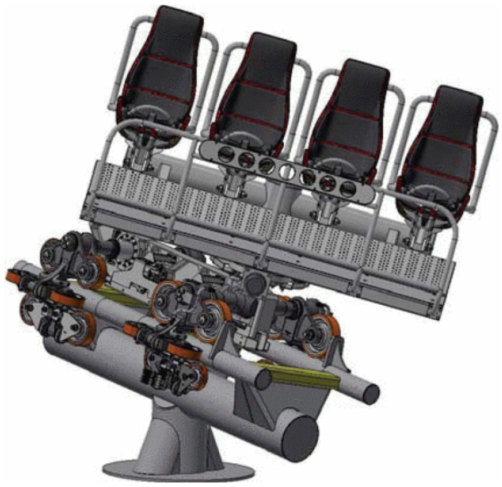


Fig. 2.14. Zamperla's DangleZ model [40]

The next step is to analyse which variants are the most significant ones for detecting anomalies. Multivariate approaches usually tend to redundancy. Hence, it is essential to see the correlation between variants and choose the most important ones. For the multivariate analysis, Isolation Forest is used to detect anomalies, while GWR (Grow When required Network) has been used for the univariate approach. The mathematical algorithms behind the project are pretty complex and exceed the purpose of this project, which is showing the technology used. Therefore, it is recommended to consult the project if interested in more information [40]. Finally, a relational database is created to store and compare data, not only from one ride but from similar rides.

The coaster has been tested by changing the number of passengers and the internal and external conditions, such as the amount of lubricant, temperature of the rail and weather conditions, to tell the algorithm what is considered a normal functioning situation from an abnormal one. The results were promising, and the system could identify when the conditions were different from the normal situation, i.e. snowing conditions. Moreover, it was possible to see the correlation between parameters. For instance, the electrical consumption was lower when the ride was more lubricated. All these features let the operators not only detect failures in advance but better understand the functioning of the ride and implement maintenance improvements.

2.3.2. Queue management

When talking about theme parks, it is inevitable to think about queuing. Since theme parks became increasingly popular, queuing for long times became a standard practice when visiting these places. It is not a secret that waiting in line for a long time is the main reason for customer dissatisfaction and complaints. Most negative comments on review web pages for many theme parks are related to long waiting times and ride breakdowns.

However, queueing is not only related to theme parks. Waiting is a common practice at hospitals, post offices, traffic jams or ticket purchasing. Even queueing is a hot topic in communications and computer science. Queuing has been a well-studied topic for many years. Agner Krarup Erlang, a Danish mathematician, statistician and engineer, developed the so-called "queuing theory" when he created models to explain the system of Copenhagen Telephone Exchange company in 1917 [41]. This theory aims to predict queue length and waiting times using a model based on statistical algorithms. Erlang's formula separated the system into variables that explain how the queuing system works and how it can be made more efficient. More researchers have joined over the years to contribute to this topic. Richard Larson, an American operations researcher and educator at MIT, also known as "Doctor Queue", is an expert in the psychology of waiting lines [42].

With simulation's rise in the late 1990s and the beginning of the 2000s, researchers started using this tool to simulate scenarios and put into practice the principles of queuing theory. Theme parks are considered perfect scenarios for carrying out this kind of simulation. They are enclosed spaces with a defined population inside. This population moves along predefined waiting lines during a specific period (park schedule). For that reason, this scenario has been vastly used in this topic. For example, Disney Research Zurich developed software called ParkSim where they could simulate the mobility of visitors around the park [43]. OpenStreetMap is used to define the theme park surface. Then, visiting areas, i.e. rides and shows, and walking areas, i.e. paths and squares, are differentiated. The model is created and validated based on GPS track movements previously recorded along the park. The model establishes three possible states: walking, visiting or queuing, as diagram in figure 2.15 illustrates. Visitors change between these states in a probabilistic or deterministic way, depending on the situation. The tool will make it possible to research the effects of modifications to mobility patterns brought on by adopting new crowd balancing techniques.

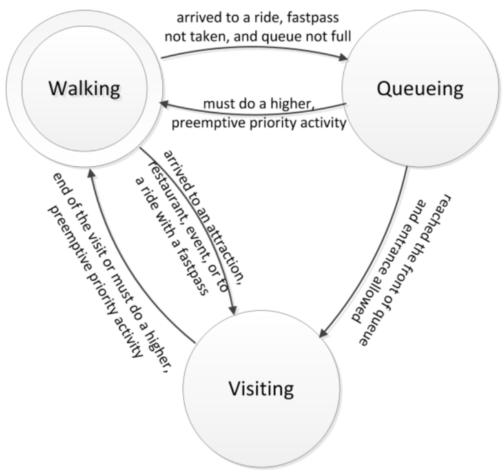


Fig. 2.15. Model used by Disney to simulate people flows in theme parks [43]

Back to the beginning of this section, waiting time has been proven to affect customer satisfaction negatively. There are three main parameters to consider related to satisfaction in queue lines [44]. The first one is the perceived time, which is a subjective measure of the objective time based on someone's perception of reality. The second one is information about waiting time. Finally,the third parameter is the waiting environment, how the queue looks physically and how it is managed. Since it is inevitable to eliminate waiting time, it makes sense to improve the overall experience while waiting. Major theme parks such as Disney or Universal Studios are making efforts to design fascinating queues with the latest technology, interactive assets, great decoration or even mobile phone apps to entertain customers. Since this project is oriented toward technology over management, the focus will be on obtaining real-time information from waiting times. It is demonstrated that the lack of waiting time information when entering a ride might cause stress or anxiety even if the line is short, as the customer does not know how much time they will have to wait. Providing this information is an excellent way to let customers decide whether they want to invest their time in this or that ride.

Some theme parks already have panels offering estimated waiting times for the main rides. Even apps where clients can check that information in real-time. However, this information is usually based on estimations, and there are no counting systems providing real-time data. Disney, for instance, gives NFC cards to users every certain amount of time to track the queue. When the user arrives at the end, that person's waiting time is considered the ride's new waiting time. However, this system presents some drawbacks and lacks accuracy. While sometimes time estimations are accurate, others can vary up to several tens of minutes, and when users have to wait more than previously established, they might start to get angry or anxious.

For that reason, in the next chapter, a system providing real-time data about waiting time in queue lines will be designed using Industry 4.0 technology and principles. For that system, an Internet of Things infrastructure will be developed. Hence, some technical knowledge is shown and discussed in the following section before designing the system itself.

2.4. Real-time monitoring system for queue management

This final section from the literature review chapter aims to provide insights about the different tools that are going to be used to design the real-time monitoring system: Internet of Things, cloud computing, data and network protocols, and databases.

2.4.1. Internet of Things

The Internet of Things describes a world where almost everything can be networked and communicated more intelligently than ever before. There is an overall premise where "connectivity" only refers to electronic devices such as servers, computers, tablets, cell phones and smartphones. In the so-called Internet of Things, sensors and actuators embedded in physical objects are connected via wired and wireless networks, often using the same Internet IP that connects to the Internet. These networks generate vast amounts of data that flow to computers for analysis. When objects can sense their environment and communicate, they become tools for quickly understanding and responding to complexity. [45]. The European Parliament defines IoT as [46]:

“A distributed network connecting physical objects capable of sensing or acting on their environment and able to communicate with each other, other machines or computers. The data these devices report can be collected and analysed in order to reveal insights and suggest actions that will produce cost savings, increase efficiency or improve products and services.”

2.4.1.1. IoT architecture

IoT architecture will vary depending on the specific application. During the latest years, an effort to standardise IoT architecture has been made. For instance, the International Telecommunication Union (ITU) has defined a standard under the siglum ITU-T Y.2060. It states that IoT is a global infrastructure for the information society. It enables advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies. The standard architecture defined by ITU for the IoT network resembles the structure of the OSI layer architecture [47]. The IoT World Forum Reference Model defines a total of seven layers, as figure 2.16 illustrates:

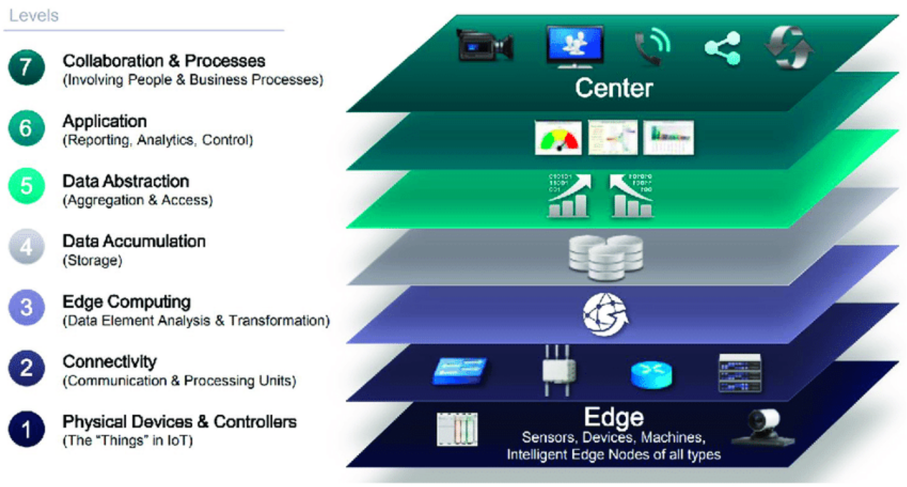


Fig. 2.16. IoT seven-layer model [48]

The usage of these layers will vary depending on the application. However, there are a set of critical blocks that are always present no matter the conditions [49] [50]. Figure 2.17 shows this model:

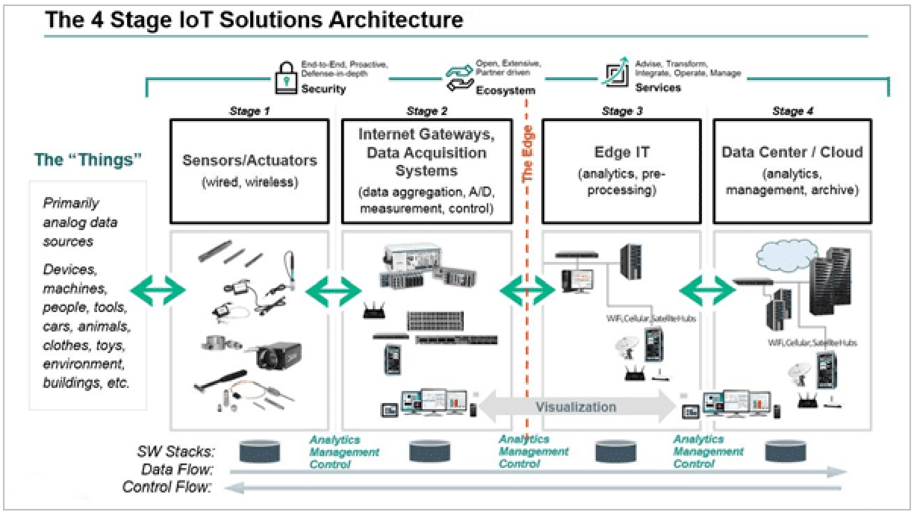


Fig. 2.17. IoT four-layer model [49]

1. **Perception Layer**

   This layer encompasses the so-called devices, endpoints or things that link the physical world and the digital one. On the one hand, sensors collect physical parameters to turn them into electrical signals sent to the IoT system. On the other hand, actuators translate electrical signals into physical actions. These devices must be linked to a controller, which is the system's brain. It is a connection point between the sensor and the network layers and frequently executes local computations. That is the case of the so-called "edge computing", where data is processed close to the data sources thanks to improved controllers in terms of memory and processing power. However, there are some devices which already have a built-in controller. In this situation, there is no need for an external controller.

2. **Connectivity or Transport Layer**

   This layer is responsible for communications between the device or controller and the network, cloud, database or other devices. The connection between devices and the cloud must be performed directly through TCP or UDP/IP stack or via gateways, which are in charge of performing translation between different protocols and encryption of data. The communication between IoT devices and the cloud services, databases or gateways is performed by several technologies that will be analysed in the next section. Over these network protocols, data needs a messaging protocol that will also be explained in the coming section.

3. **Processing Layer**

   This layer accumulates, stores and processes data from the preceding layer. Data accumulation component stage serves as a transition point between data generation based on events and the consumption of data based on queries. The stage determines, among other things, whether and where data should be placed concerning business requirements. It stores data in various storage platforms, including event stores, telemetry databases, and data lakes. The objective is to efficiently sort through a lot of different data and store it. Data abstraction component gathers the data all together. Data from different sources, such as ERP or CRM is combined and formatted to unify the data. Virtualisation is often used in this stage for data aggregation. Similarly, data coming from the application layer is combined and transformed here to send it forward to the physical devices.

4. **Application Layer**

   In this last step, data is analysed to provide insights and helpful information regarding business questions. From mobile apps to device monitoring and control software, these solutions help understand the IoT system, send information back to the physical devices to generate actions and use machine and deep learning to find hidden patterns in data.

2.4.1.2. Edge computing vs Cloud computing

Edge computing is defined as a distributed information technology (IT) architecture in which client data is processed as near as feasible to the network's edge at the source of the data [51].

Cloud computing delivers computing services, including servers, storage, databases, networking, software, analytics, and intelligence over the Internet to offer faster innovation, flexible resources, and economies of scale [52].

Edge computing complements cloud computing by placing cloud services close to end-user devices for data-intensive applications that demand quick roundtrip reaction times that cannot be guaranteed by a cloud computing service centred in a certain geographic area [53]. Depending on how fast the data needs to be processed, it will be necessary to add this extra layer to the architecture or cloud processing will suffice.

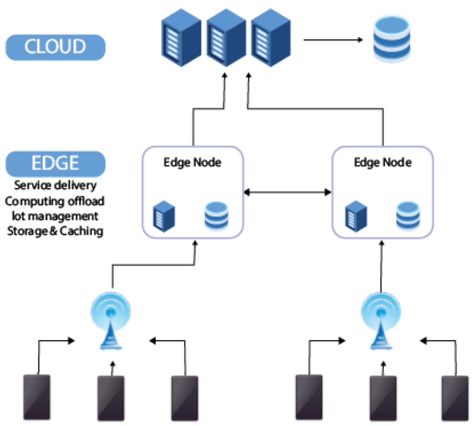


Fig. 2.18. Edge pre-processing data schema [53]

Table 2.1 summarises the differences between the two approaches.

Cloud vs Edge computing		
Parameter	**Cloud Computing**	**Edge Computing**
Time to insight	Delayed: due to network latency.	Near real-time: eliminates slow response.
Cost	High: large amounts of data travel long distances.	Low: data processed locally, backhaul costs reduced.
Scalability	High.	High.
Security	High: adhere to high security standards.	High: adhere to high security standards.
Compliance	Complex: new regulations in geofencing.	Easy: provides geofencing, data processed locally.
Data quality	High: data backhaul to a central location.	High - Medium: only if Conflict-free Replicated Data Type.
Storage	Unlimited storage.	Unlimited storage if qualified provider.

Table 2.1. Main differences between cloud and edge computing.

2.4.1.3. Internet of Things vs Industrial Internet of Things

Finally, this section aims to provide an overview of these two concepts to understand when it is better to use each of them.

IIoT stands for Industrial Internet of Things. As its name suggests, it is an IoT application brought to the industry. Although its architecture will be the same, its operation will be much more robust: more significant extension, more complex operability conditions, and greater security conditions mainly focused on the production process.

While IoT has a profile oriented to customer experience and improving users' lifestyles, IIoT effectiveness is linked to business objectives: reduce operating or maintenance costs, less downtime or increase efficiency. The concept "Overall Equipment Effectiveness" (OEE) relates to IIoT. It can also be assessed in terms of how simple it is to monitor equipment and operator productivity [54]. Table 2.2 summarises the main differences between the two systems:

	IoT	**IIoT**
Use cases and applications	Linked to life quality of end-users.	Linked to production objectives
Effectiveness evaluation	User experience or value-for-money.	Production metrics
Uptime requirements	Nominal	Stringent
Precision and Reliability	Nominal.	Very high in harsher conditions
Scale and volume of data	Usually low	Higher orders of magnitude
Security	Important	Crucial

Table 2.2. Main differences between IoT and IIoT

2.4.2. Network protocols

- **Ethernet** is the traditional technology to connect devices in a Local Area Network (LAN) or Wide Area Network (WAN) using a cable and a standard protocol IEEE 802.3 [55]. Ethernet defines the formatting and transmission of data by network devices such that other devices connected to the same campus or local area network segment can recognise, receive, and process the data. Data is transmitted by physical, encased cabling known as an Ethernet connection.

- **WiFi** is the most common and extended protocol worldwide for small IoT applications. It allows wireless connection between devices and the network. It is ruled by the standard IEEE 802.11.
- **Bluetooth** is an industry-standard for personal wireless networks (WPAN). It enables voice and data transmission between various devices over a radio link in the 2.4 GHz ISM band. With the arrival of IoT and low-power devices, a new protocol, Bluetooth Low-Energy (BLE), was developed to transfer small packages of data with very little energy consumption. [56]
- **NFC** stands for Near Field Communication. It is a wireless technology that works in the band of 13.56 MHz, free of charge, and a licence is not needed. It can transmit up to 424 kbit per second, which is ideal for low-density instant communication. The maximum range is 20 cm. It can be either active, where both types of equipment generate an electromagnetic field and change data, or passive, with only one active equipment. NFC is considered a subgroup inside RFID technology.
- **ZigBee** is a wireless network that uses low power to transport small data packets over close ranges. It uses standard IEEE 802.15.4 [57]. It works well for secure communications with low-rate data transfer and long-lasting batteries.
- **LPWAN** stands for Low-Power Wide-Area Network. It was created for IoT applications. It offers wireless connectivity over a great distance while using little power and having a battery life of at least ten years. The technology satisfies the requirements of smart cities, smart buildings, and smart agriculture by sending data periodically in small parts (field monitoring).
- **Cellular Networks** have almost global coverage and are perfect for applications deployed in several regions or vast areas. There are two primary cellular standards developed for IoT. LTE-M (Long Term Evolution for Machines) allows direct connection to the cloud for high-volume data exchange. NB-IoT (Narrowband IoT) sends small data packages over low-frequency channels. This technology has a longer range but consumes a lot of energy.

In table 2.3, a comparison between the reviewed network protocols is illustrated:

Network	Connectivity	Pros	Cons	Use Cases
Ethernet	Wired, short-range	High speed and security	Limited mobility	Fixed equipment
WiFi	Wireless, short-range	High speed and compatibility	Limited range, high consumption	Smart home
NFC	Wireless, ultra-short-range	Reliability, low power	Limited range	Payment systems
BLE	Wireless, long-range	High speed, low power	Limited range and bandwidth	Wearables
LPWAN	Wireless, long-range	Long range, low power	Low bandwidth, high latency	Smart city
ZigBee	Wireless, short-range	Low power, scalability	Limited range, compliance issues	Healthcare, Industrial
Cellular networks	Wireless, long-range	Reliability, high speed, global coverage	High cost and power	Drones sending video

Table 2.3. IoT networking protocols

2.4.3. Data transfer protocols

IoT systems usually work under resource-constrained conditions, such as processing power, storage, memory or power consumption. For this reason, conventional protocols like HTTPS are unsuitable for these architectures. HTTP has a synchronous exchange, request-response exchange paradigm and client-server architecture.

The client must open the connection because HTTP is a one-way protocol. This one-to-one protocol is not appropriate for broadcasting because it is one-to-one. It requires more resources and is unsuitable for networks with limited resources due to its higher message overheads and more restrictions. With what the IoT requires, this is incompatible.

Most Internet of Things (IoT) messaging is asynchronous and uses one-to-many broadcasting, publish-subscribe, and publish-consume paradigms. In order to be a practical IoT messaging system, HTTP simply has excessive overhead. For this reason, the following three protocols are a better option for IoT applications [58].

2.4.3.1. MQTT

It stands for Message Queueing Telemetry Transport. It was designed for the lightweight transfer of information from edge devices and sensors to SCADA systems. MQTT is appropriate for embedded devices used for equipment monitoring and infrequent message transmission across networks with limited capacity. Compared to AMQP, MQTT ensures seamless data delivery, uses low bandwidth and has fewer CPU and RAM resources. It also offers a fast response time. Many hundreds or even millions of devices can be connected via MQTT. For this reason, this is the most used protocol for IoT applications.

MQTT follows the publish/subscribe strategy. Devices can act as publishers or subscribers and there is a “broker” is between these roles. Inside, messages are exchanged according to topics. A topic is a string used by the MQTT broker to filter messages. Devices can either subscribe to a topic to receive information or publish the topic by sending information. As figure 2.19 illustrates, every device subscribed to a topic will receive all the messages arriving at that topic. Therefore, many devices can subscribe or publish to a topic [58].

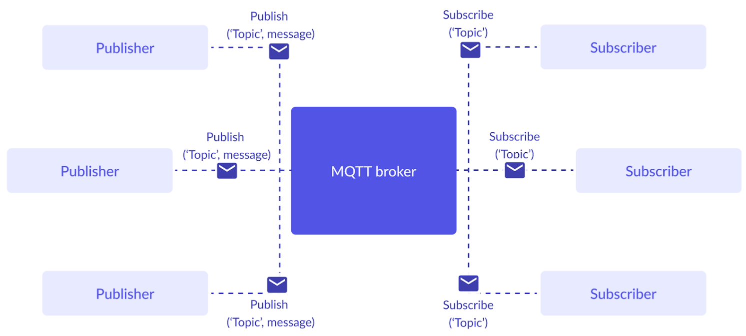


Fig. 2.19. MQTT publish/subscribe schema [58]

2.4.3.2. AMQP

It stands for Advanced Message Queueing Protocol. This protocol is suitable for large, enterprise-scale projects with specific security, reliability and interoperability requirements. It is a binary messaging protocol, which is more efficient than text protocols. It runs over TCP/IP. The banking industry created it for large datasets and secure transmissions. Therefore, it has more features than MQTT, including reliable queuing, flexible routing, various types of messaging, security, and transactions.

AMQP supports "publish/subscribe" messaging as well. However, it also supports other patterns like publish-consume, lifetime, as-long-as-connected or nobody-is-using-this-queue. Consequently, AMQP is a more sophisticated protocol for complex situations or tailor-made projects. Figure 2.20 shows an example of publish-consume architecture [58].

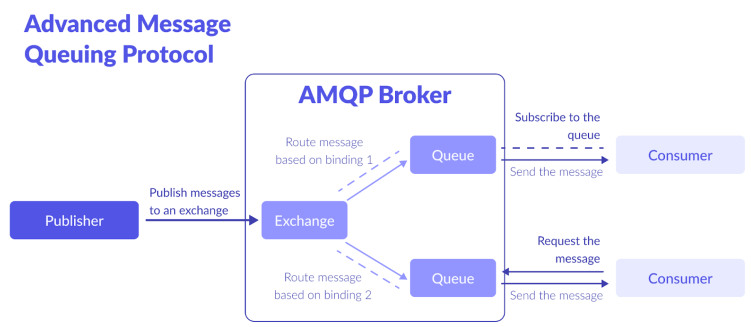


Fig. 2.20. AMQP publish/consume schema [58]

2.4.3.3. CoAP

It stands for Constrained Application Protocol. It is a document transfer protocol like HTTP, but, as its name suggests, it is designed for constrained devices. Therefore, CoAP packets are considerably smaller compared to HTTP TCP ones. Another difference is that CoAP runs over UDP. CoAP uses client/server architecture. Servers receive requests from clients and respond with responses. Resources may be GET, PUT, POST, and DELETE by clients. CoAP can be summarised as a low-weight extension of HTTP for constrained-device situations with limited resources. For this reason, this protocol is often used along with HTTP as an HTTP-CoAP interface, as figure 2.21 shows [59].

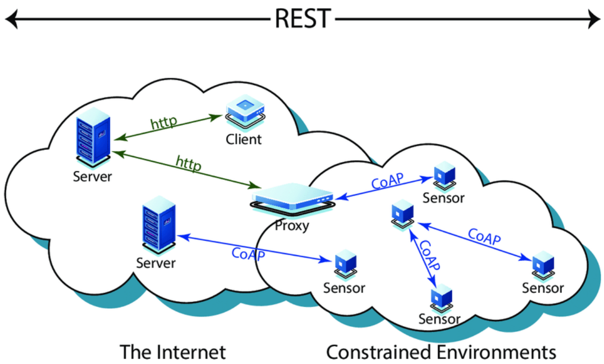


Fig. 2.21. CoAP schema [59]

Finally, table 2.4 shows a comparison summary between the protocols.

	MQTT	AMQP	CoAP
Type	Lightweight M2M	Middle-ware messaging	Web Transfer Protocol
Communication Protocol	Publish/Subscribe	Point to Point + Publish/Subscribe	Request/Response
Transport Layer Protocol	TCP/IP	TCP/IP	UDP/IP
Security	SSL/TLS	SSL/TLS, SASL	DTLS
QoS	Provided	Provided	Provided
Data Exchange	Broker based	Broker based	Broker based
Header and Payload	2-Bytes header size + payload	8-bytes header, total size = 60 Bytes	4-Bytes header size + payload

Table 2.4. MQTT vs AMQP vs CoAP

2.4.4. Databases

A database is a structured group of data that is electronically accessible and stored in computing. Small databases can be kept on a file system, whereas large databases are kept on computer clusters or in the cloud. Database design encompasses formal methodologies and pragmatic factors, such as data modelling, effective data representation and storage, query languages, security and privacy of sensitive data, and distributed computing issues, such as concurrent access support and fault tolerance. In order to collect and process data, a database management system (DBMS) communicates with applications, end users, and the database itself. The DBMS software also includes the primary tools offered to manage the database. A database system is a collective name for the database, the database management system, and any related applications. When creating a database, there are two main structures: relational and non-relational.

A **relational database** is a form of database that stores and offers access to data elements connected to one another. The relational model, a straightforward method of representing data in tables, is the foundation of relational databases. Each row in a table is a record with a distinct ID, or key, in a relational database. The attributes of the data are contained in the columns of the table. Since each record typically contains a value for each attribute, it is simple to establish relationships between the data points. The most famous relational databases are MySQL, Oracle, SQL Server and PostgreSQL [60].

Non-relational databases, also known as NoSQL, feature flexible schemas for creating new applications and are made specifically for particular data models. NoSQL databases are well known for their construction, usefulness, and scalability simplicity. They are usually JSON files containing all the attributes following a schema. These databases are much newer and less popular than relational databases. Typically, Cloud services include non-relational databases as well, like DynamoDB from Amazon Web Services [61].

3. CASE STUDY: DESIGN OF A MONITORING TOOL FOR REAL-TIME WAITING ESTIMATIONS

This thesis's chapter aims to create a system to count people in queue lines in order to obtain information about ride waiting time. Two aspects must be defined before designing the solution. First, it is mandatory to set all the requirements and limitations of the system. Second, establish the different parts of the IoT infrastructure and technologies involved. The system requirements will be analysed through a set of parameters:

Type of data: only data about the number of people inside the queue will be collected. This collection might be either counting the people at the entrance and exit of the queue or counting people within a defined region, depending on the technology used. Other information, which is necessary for determining the waiting time value, such as ride capacity, number of trains/vehicles operating, breakdowns and failures, will be provided by operators according to ride conditions at the moment.

Data transfer rate: it will depend on each attraction, based on ride capacity and popularity. To dimension the system, the worst scenario must be chosen, which is a continuous flow of people entering the attraction at the pace of the ride capacity. That means the ride's capacity will limit people's flow. Therefore, the ride capacity will be critical for taking this decision. Let us assume the system is sizing using the highest ride capacity of the park. The average ride's capacity can vary from 500 to 2000 people per hour. There are rides which can go up to 4000 people per hour. That means the average pace of entering and exiting the ride is around one person per second in the worst scenario.

Data refresh rate: it is essential to differentiate between data collection frequency and information update rate. Data is collected continuously. The system is constantly monitoring the entrance and exit of people. However, updating this information to the final user at the same pace is not necessary. Since this is not a critical application, where real-time data processing is crucial, i.e. car sensors collecting information from the environment for autonomous driving, there is no need for low latency infrastructure. Rides' waiting time information will not vary significantly in a short time. It is similar to a continuous function where the variation is gradual since a big crowd cannot instantly move from one side of the park to the other. The variation in waiting will change gradually; hence, updating data every 1-2 minutes is enough to provide a quality service.

System scalability: the system will be designed for one attraction and can be easily extrapolated to the other attractions. Hence, new rides can be added or removed from the system according to the park's needs. The infrastructure will be designed to allow for these expansions.

Physical limitations: this constraint will be defined during this section when each possible technology to collect the data is analysed.

User-system interaction: it will depend on the technology used. Thus, it will be analysed during this section.

This system is intended to work for any amusement park since it is generically designed for any attraction. However, it is interesting to choose a park to define the size of the system and visualise what the system might look like. PortAventura Park will be chosen for this project because it is the largest theme park in Spain and is part of a hotel resort, allowing the solution to be extended to other fields. In addition, it is the theme park with the longest queues in Spain; hence, develop queue management solutions is of vital importance. Table 3.1 shows useful data for later cost estimation

PortAventura Park	
Total Area	52 ha
Park Maximum Capacity	35.000 people
Number of Attractions	43
Ride Capacity	500 - 2000 pph

Table 3.1. PortAventura Park capacity data

3.1. Understanding the system's logic

The idea of the system is simple: counting people. There are two possible solutions to knowing the number of people in the queue. The first is by counting the number of people entering and leaving the attraction. By doing the subtraction, the number of customers waiting in line is obtained. The other way is by counting the people inside the queue area using location and position systems. A series of technologies will be proposed to solve the counting people problem during the first part of the design.

However, knowing the number of people is insufficient to determine the waiting time. Each attraction has a particular flow of movement, known as the hourly capacity and measures how many people an attraction can hold each hour. Let us take the following model as an example. There are two roller coasters with the same path, but one train has a capacity for 32 people while the other has a capacity for 16. If there are 100 people in both queues, the queue will move twice as fast in the first case compared to the second one. Therefore, the waiting time is different for the same number of people.

It is then mandatory to consider other parameters besides the number of people in the queue, such as the ride capacity per hour. Then a simple transformation is performed to obtain the waiting time. If the ride capacity is 2000 persons/hour and there are 2000 persons in a queue, then the waiting time is 1 hour. This scenario would be the idyllic situation where everything runs smoothly. However, the charging cycles are not always the same, and sometimes it takes longer than others. In addition, the attractions do not always operate with the same number of trains. The attraction's capacity will vary depending on how many vehicles are operating.

Hence, it is essential to understand the attraction's actual behaviour to know the attraction's real capacity for each scenario. Another thing to consider is emergency stops and faults. These breakdowns are usually unpredictable and might cause the ride to stop for several minutes. However, this is not something that must be taken into consideration. Since the queue is not moving, the waiting time will not decrease and remain the same during this period.

To summarise, it is necessary to know the number of trains in operation for each attraction, apart from the number of people in the queue. A preliminary study to determine the actual hourly capacity of the attraction based on the operations and the number of vehicles must be performed. Figure 3.1 shows a schema of the system proposed:

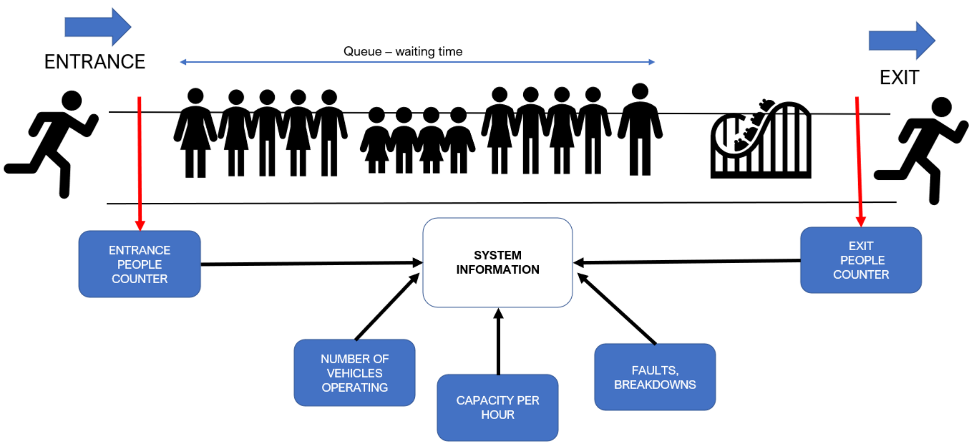


Fig. 3.1. System schema for getting waiting times

3.2. Designing the IoT infrastructure

3.2.1. Perception layer

In this first stage, the technology that will be used to capture data from abroad is chosen. When defining the best technology for the system, differentiation will be made between people-tracking technologies and non-people-tracking technologies. The analysis starts with the second one. The technologies described below allow counting the number of people entering and leaving a particular space. However, they do not allow monitoring dwell time as they do not have a way to identify people.

3.2.1.1. No-tracking technologies

- **Turnstile**

Fig. 3.2. Self-powered turnstile [62]

Turnstiles are one of the simplest but accurate ways of getting people to count. This system allows the controlled entry and exit of people thanks to a rotating mechanism capable of accounting for people entering and leaving depending on the turning direction of the turnstile. A built-in electronic mechanism must be needed to transform movement into a counter. Some solutions in the market are even self-powered thanks to a energy harvesting generator that produces electricity from the mechanical movement [62]. This is the model figure 3.2 shows:

- **CCTV cameras**

  Security cameras are installed all over the park, ready to use without investing. Machine learning face-detection software can be installed on-premises to detect people entering and exiting the ride automatically. However, these cameras are usually placed pointing to critical places. There is unlikely that cameras will be at all entrances and exits of the attractions. These cameras might not be in the correct position as well; hence, blind points might impede the camera from capturing all persons. As this solution relies on the position on the cameras rather than its technological capabilities, is not going to be considered for the analysis. However, it might be an affordable solution if cameras are properly placed over the entrances and exits of rides.

- **3D Camera**

  A stereovision technique is used by 3D people counters to count congested traffic accurately. The digital signal processor receives the image from the two graphic sensors, computes the tridimensional image, converts it into a mathematical 3D model, and uses the embedded algorithm to locate and identify the customers' heads. In the coverage area, the processor keeps track of customers while discounting external factors such as shadows, lights or objects.

Fig. 3.3. 3D camera sensor [63]

- **ToF - Infrared Sensors**

  ToF, known as Time of Flight, calculates distances between bodies using the time it takes for a beam of infrared light to go and come back - from emission until the reception. This time delay equals twice the distance between the camera and the object. Therefore, depth can be estimated. These systems are mounted on the ceiling pointing straight to the floor, and can work under no light conditions thanks to infrared technology. Therefore, visibility is quite extensive, and there are no blind spots. However, performance at congested entrances can be subpar compared to other technologies since ToF sensors may struggle to distinguish things from people or adults from children.

Fig. 3.4. Irisys Vector 4D ToF people counter sensor [64]

- **Thermal Sensor**

  Thermal counters gauge foot traffic by measuring a person's body heat using infrared radiation. Sunlight negatively impacts people's thermal imaging since it emits the full light spectrum. Since thermal counters cannot distinguish between objects due to their varied temperature signatures, crowded groupings can also reduce accuracy. Thermal counters cannot distinguish between people when the surrounding temperature is near that of the human body. One positive aspect is that thermal sensors can count in complete darkness.

Table 3.2 shows a comparison between the technologies mentioned considering the most relevant parameters:

	Turnstiles	**3D Camera**	**ToF Sensor**	**Thermal Sensor**
Model	Self-powered Green Pass	Megacounter 3D People Counter	Irysys Vector 4D	Irisys Gazelle 2
Energy Consumption	0W	6W	12W	2W
Accuracy	100%	99%	99%	99%
Aesthetics	Obstrusive	Unobstrusive	Unobstrusive	Unobstrusive
Durability	Long	Long	Long	Long
Installation	Easy-medium	Easy	Easy	Easy
Devices/ride	4	2	2	2
Cost/unit	400€	1000€	1000€	350€
Total cost/ ride	1600€	2000€	2000€	700€

Table 3.2. No-tracking technologies comparison

After this research and considering all the different fields, the most convenient solution might be installing turnstiles at the entrance and exit of the rides. It has 100% accuracy and can be obtained at a very affordable price. The main problem regarding the other sensors is that there must be a ceiling over two metres at the ride's entrance to ensure these devices' great operability. However, suppose the park prefers a seamless option where users do not interact with the counter. In that case, a thermal sensor is a great option due to its low energy consumption and affordability. Nevertheless, the election of the technology might depend on the park's preferences since all of them will provide good results, and their functionality is very similar.

These technologies have something in common: they can count people precisely but cannot track people along the different rides or even during the same ride to obtain dwell times. Imagine the park not only provides accurate waiting times but is able to know when a certain person enters or leaves a ride, how many attractions they ride, in which order they go into the different attractions or how many times they ride an attraction. This information provides endless possibilities for the park to understand the client's behaviour. Users are getting useful information about waiting times, and park managers acquire useful information about their customers. For this reason, this project will focus on tracking technologies to provide a solution to real-time waiting times. They all have something in common: the user must wear "something" to be tracked.

3.2.1.2. Tracking technologies

All users have **mobile phones**. For this reason, parks are starting to use these devices to track people around the park. One possible way to track the devices is to analyse the strength of the WiFi signal using the access points from the built-in park WiFi network. Mobiles are detected while moving to different locations. Using GPS is another option, although it might be imprecise. In order to get this information from mobile phones, parks have their own applications where useful information about the park is provided, such as the map, show schedule, and waiting times among others. When the user enters the app, they must accept some terms and conditions, permitting the park to track the WiFi or GPS signal.

This solution seems to be a great option: the investment is very little and only app development is needed. However, the reality is that not so many people use these applications, either because they do not know they exist or because it is enough with the theme park's physical map. Sometimes, users run out of battery or simply do not want to use the mobile phone during their visit to the theme park. As a result, waiting times might be imprecise since many users are needed to make the system reliable.

One solution to ensure that all users are participants in the system is to provide them with traceable objects. These devices guarantee the proper functioning of the system. In order to achieve this, two solutions will be deeply analysed. The first is RFID, a well-known technology in the IoT and tracking sector. The second one, Bluetooth Low Energy, has been taking off for a few years and brings good advantages.

Option 1: RFID Deployment

RFID stands for Radio Frequency IDentification. It is one of the oldest and most widely used technologies in the IoT field. It has been broadly deployed in the logistics industry for asset tracking. For this case study, this technology will be used for counting people.

Three components comprise every RFID system: a scanning antenna, a transceiver and a transponder. An RFID reader or interrogator is used when the scanning antenna and transceiver are integrated. The RFID reader is a network-connected gadget that can be portable or fixed to a surface. It sends signals that turn on the tag using radio waves. After being turned on, the tag returns a wave to the antenna, which is converted into data. The transponder corresponds to the RFID tag. The read range of RFID tags varies depending on several elements, such as the type of tag, type of reader, frequency, and interference from the environment or other RFID tags and readers [65].

There are mainly two types of tags:

- **Active tags** have their own power source, including a battery. They are more reliable and easy to track over large distances. However, it has a lower estimated lifetime and a bigger size.
- **Passive tags** do not have a battery since the energy is received from the reading antenna, inducing a current in the tag antenna. These tags are extremely cheap and embedded into a tiny size.

Depending on the frequency, the measurement range will vary considerably [66]:

- **Low-frequencyy (LF)** RFID systems range goes from 125 kHz to 134.2 kHz. Reader-write distance is short, usually 10 cm. Some of its features are energy-saving, little external interference, slow data transmission rate and only one tag can be read at a time. It is suitable for short-distance applications with low transmission rates and small amounts of data, such as access control and electronic wallet.

- **High Frequency (HF)** RFID systems range has a predefined value of 13.56 MHz. This frequency value is used for NFC (Near-Field Communication). The reading distance is less than 1 metre. It is defined in standards such as ISO 14443A/B and ISO 15693. Encryption is widely used within this protocol to protect personal data. Applications such as card payments or identity cards use this system.
- **Ultra-High Frequency (UHF)** RFID systems range goes from 860 MHz to 960 MHz, but the standard in the European Union is 865 MHz - 868 MHz. It allows long-distance reading (about 5 metres in passive RFID tags), fast transmission data and over 100 tags reading simultaneously. It is widely used in supply chain management, production line automation, and warehouse management.

The solution

Attractions usually have a well-differentiated entrance and exit. This condition must be met to ensure the system's proper functioning, avoiding multiple entrances and exits or diffuse spaces. In order to count the number of people, it is only necessary to take measurements at the entrance and exit of the attraction. The entrance and exit usually have a width of between 1 and 4 metres. The goal is for people to enter continuously without punching in a short-range RFID reader. Therefore, a UHF RFID system will be deployed, similar to the ones set up for tracking assets in warehouse management [67]. Therefore, an antenna, reader and tags must be chosen:

1. **Antenna**

   Several parameters must be considered when choosing the antenna. The first one is the frequency range. As this is an ultra-high frequency system, the antenna's range must be between 865 - 868 MHz. The second one is polarisation, which is the direction in which the electric field of a radio wave is propagated through a medium. As it is impossible to know the RFID tag's orientation when scanned, the optimal solution is to choose a circular position antenna, which allows tag reading in any orientation. The third one is angle covering. The antenna is intended to read tags over a narrow range, acting like a light beam, to avoid detecting people closer to the entrance but not accessing the ride. For that reason, an angle covering less than 70º will be chosen. The last parameter is gain, a value of how far the antenna can detect tags. A gain value over 5 dB will be enough for this project since there will be no obstacles between the antenna and the tag. Besides these parameters, the maximum antenna power cannot exceed 2 watts, as the European regulation specifies. The chosen antenna for the system is the model AN480 Wide-Band RFID Antenna from Zebra [68]. This brand is one of the top leaders in the market for RFID infrastructures. Cheapest antennas are found in the market, but this solution provides durability and reliability. The main specifications for the antenna are:

   - Gain: 6.0 dB

- Angle covering: 65º in both planes
- Frequency range: 865 - 956 MHz
- Polarisation: circular
- IP sealing: IP54

2. **Reader**

   Antennas are connected to the reader, which is in charge of powering the Antenna and sending the radio wave to the tag. A reader can support several antennas. Depending on the distance between the entrance or the ride's exit, one reader with two antennas or two readers with one antenna each will be selected. The reader can control the power sent to the antenna, allowing the adjustment of the measuring range to the established limits. The chosen reader for the system is the model RFID UHF fixed FX9600 from Zebra [68]. It is a versatile option with a built-in WiFi connection over IPV4 and IPV6 and Bluetooth, so it is unnecessary to deploy a wired connection to the controller. Nevertheless, it is possible to use an Ethernet connection as well.

3. **Cable**

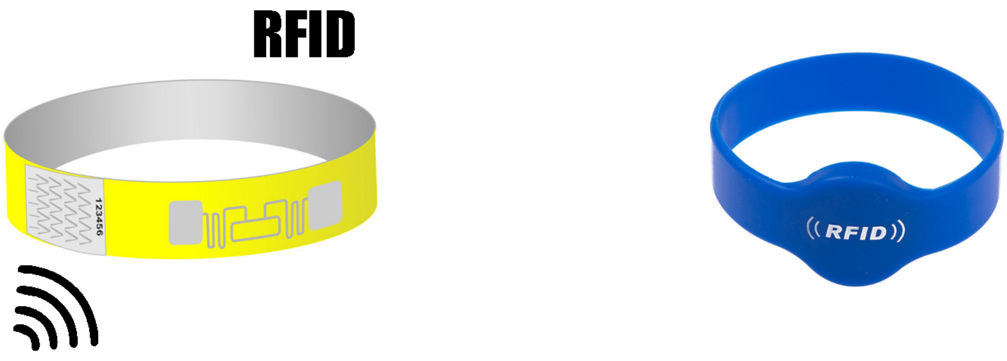
   UHF antennas must be connected through a coaxial cable to the RFID reader. This cable is usually between 2 and 6 metres long because the signal gets attenuated over a distance. The cable's length depends on the reader's power, the antenna's gain and the type of cable, defined by the losses (dB) for each 100 m. These losses are specific for each cable, and the lower the losses, the longer the signal can be transmitted. Although it is recommended to choose short-distance cables to improve operability, it is possible to get about 20 metre-long cables or longer if losses remain low [69].

   For rides with a reader at both the entrance and the exit, the antenna will be installed next to the reader, so just a short cable will be needed. However, if it is possible to use the same reader for both sites, then a study regarding distance and losses must be carried out depending on each situation. Although money is saved as one less reader is used, wire installation might be complex.

4. **Tag**

   UHF RFID tags are made of four components: the RFID chip, an antenna, an inlay and a carrier. The chip is an integrated circuit with attributes such as operating frequency, memory type and capacity, data transmission and power. The antenna collects the radio waves to power the circuit and sends this data back to the reader. The antenna and the integrated circuit comprise the inlay. All these elements are usually stored in the carrier, which can vary in shape and material, taking the form of wristbands, cards, fobs, sticks and almost any imaginable object.

For this project, the model Global Tag UHF 4630 will be used [70]. It has a size of 46x30mm and is designed to be read regardless of the position angle. These tags are printed on paper or PP/PET. They can be fit into a disposable PET waterproof paper wristband for customers or embedded into a silicone wristband, as figure 3.5 illustrates. This design is very suitable for theme parks. It can be customizable with the park logo, and a barcode or serial number can be printed on the wristband for external identification.



(a) RFID paper wristband

(b) RFID silicone wristband

Fig. 3.5. RFID wristbands models [38]

The following schema shows the perception layer architecture for the RFID solution

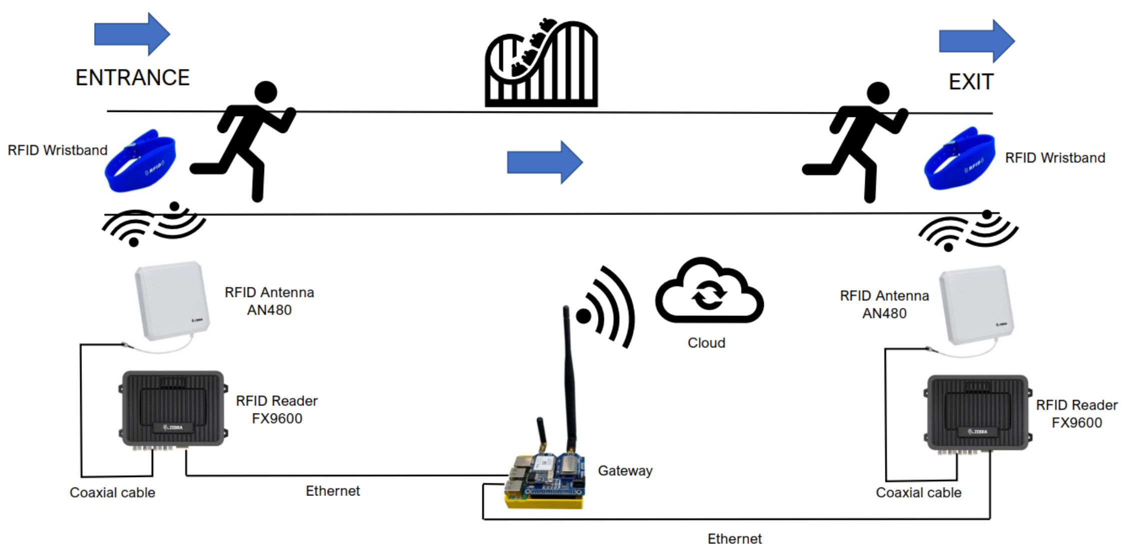


Fig. 3.6. RFID solution architecture

Option 2: BLE Deployment

BLE stands for Bluetooth Low energy, and it can briefly be defined as the IoT version of Bluetooth. It is a wireless, low-power personal area network that operates in the 2.4 GHz ISM band, the same band where classic Bluetooth operates. Its goal is to connect devices over a relatively short range. This technology is ideal for small data package transfer using low power consumption. Table 3.3 shows the main differences between classic Bluetooth and BLE [71]:

	Bluetooth Classic	**Bluetooth Low Energy**
Communication	Continuous, bidirectional	Short data transfers in one direction
Range	100 m	10-40 m
Energy consumption	1 W	0.01 - 0.050 W
Data rate	1-3 Mbit/s	125 kbit/s - 2 Mbit/s
Latency	100 ms	6 ms

Table 3.3. Bluetooth classic vs Bluetooth Low Energy

BLE technology relies on special devices called beacons [72]. They are small radio transmitters powered by batteries. Beacons are similar to a lighthouse as they constantly look for devices to scan. These devices locate beacons emitting BLE (Bluetooth Low Energy) signals. Beacons have three main parts: a small ARM computer, a Bluetooth smart connectivity module and the batteries for powering the device. The ARM CPU has an antenna responsible for sending electromagnetic signals adjustable in frequency and length. The transmission power (Tx) parameter measures how far a signal can travel. It is measured in dBm and can vary from -30 dBm to +4 dBm. This way, the signal can range from 0m to 300m. The advertising interval determines how often the beacon is broadcasting packets.

There exist two protocols to connect beacons with devices. The first one, called iBeacon, was developed by Apple, and it is the first beacon patented protocol. Beacons were developed, indeed, by Apple. It enables mobile apps to look for beacon signals within a specific range and show the content if found. The second most extended protocol is Eddystone, developed by Google. It is an open communication standard where services on Android smartphones look for Eddystone URLs and show any content broadcast via a Bluetooth beacon, whether or not they have an app installed.

Initially, BLE beacon technology was designed to interface with mobile phones. Each beacon has a Universally Unique Identifier (UUID) and constantly emits a signal. When a Bluetooth-enabled mobile device comes into range of the signal, it receives this unique identifier from the beacon. This identifier is sent to the cloud, and the server returns the corresponding action associated with the identifier to the device, usually a notification or message. For this reason, this use has spread within the retail sector to launch promotions and messages to users when they enter stores.

However, BLE beacon technology has many other applications, such as asset tracking location. For this use case, fixed BLE receivers and roaming asset beacons are used. This way, the beacon's usage is inverted concerning the previous application: the beacon goes from being in a fixed position to being mobile and associated with the tracked object. Instead of mobile phones, fixed BLE receivers are now in charge of detecting the signal that the beacon continuously emits. When a tagged item is closed, the BLE receiver communicates this information to a cloud service over a network protocol. As the goal is to ensure that all users are tracked, the fixed receiver and mobile beacon tags are the chosen approach to design the solution.

The solution

A location asset tracking system will be used to develop this solution. This system is designed to locate objects in a fenced space and know their exact position with an accuracy of less than one metre. However, the design of the solution will follow the same pattern as that designed for RFID technology: counting people at the entrance and exit. Since it is not necessary to know the users' exact position along the entire queue, the entrance and exit zone will simply be monitored. Therefore, this BLE system will be used for detection instead of position. This approach is known as Focus Detection RTLS.

Users will carry a small beacon embedded in a wristband. This bracelet will emit BLE signals in packets every so often (a frequency of one second is sufficient). A fixed BLE receiver will be placed at the entrance of the attraction. When a user passes near it, it will detect their UUID and be sent to the cloud through the integrated gateway, telling that the user has just entered the attraction. In the same way, we will proceed to the exit, where another fixed BLE receiver will be installed. It is important to note that the receivers must also have unique identifiers that associate them with each attraction.

In order to carry out this development, the technology developed by Quuppa will be used. Quuppa Intelligent Location System is a powerful one-size-fits-all Real Time Location System (RTLS) technology platform for location-based services and applications [73]. The Q17 locator model will be used as a BLE receiver. It is a compact and elegant model that uses Ethernet connectivity to transfer the information to the server. For the beacon or tag, the QT1-1 model will be used. It is small in size, waterproof and has 3-year-long battery life. This tag can be embedded into a wristband, which is more comfortable for the user.

The following schema shows the perception layer architecture for the BLE solution:

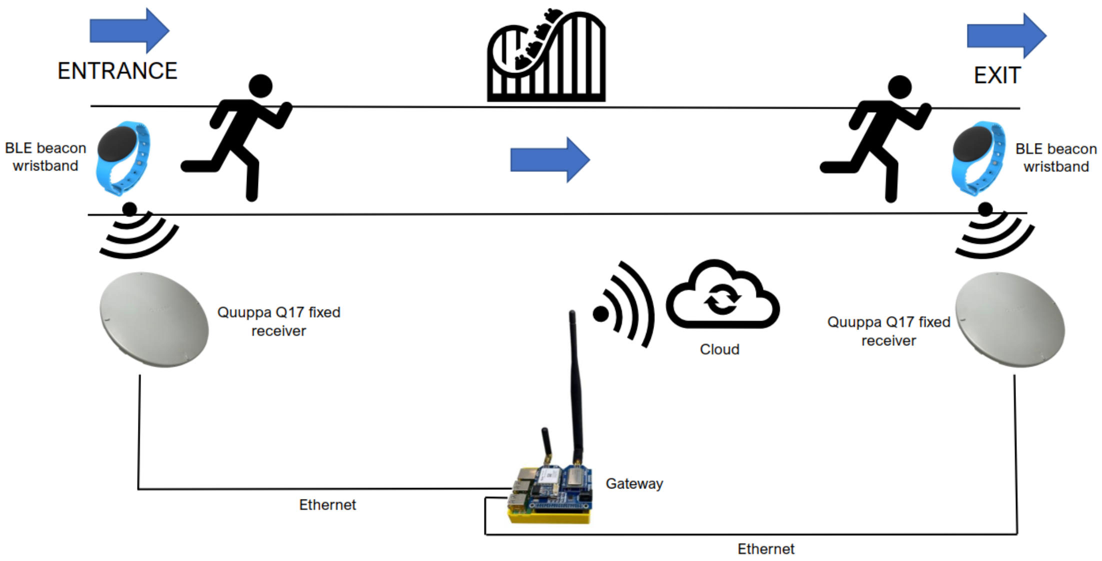


Fig. 3.7. BLE solution architecture

RFID vs BLE

The main differences between the two approaches are exposed in the bullet list below:

- RFID is a much older technology than Bluetooth Low Energy. It is, therefore, a technology with much greater baggage. There are many more devices and a more studied and widespread technology.
- RFID solution uses passive tags, so they do not require a battery. The BLE solution uses active tags that need a battery, although this can last for a few years.
- RFID wristbands are priced at less than 50 cents, while BLE beacons, although not expensive, are priced around 15-25 euros per unit.
- The fixed infrastructure required to deploy an RFID system is much more expensive than that required for a BLE system.
- BLE systems are much easier and faster to install than RFID systems.
- The passive RFID system works through checkpoints; that is, it detects the passage of the tracked asset through a specific point. The BLE system works best for locating people as it is designed as a real-time location system (RTLS).
- BLE systems are more secure than RFID regarding data protection and integrity.

Finally, table 3.4 shows the economic cost of developing each solution

	RFID	BLE
Reader/Fixed receiver cost	1000 € (2 units needed)	100 € (2 units needed)
Antenna cost	200 € (2 units needed)	-
Fixed infrastructure cost per ride	2.400 €	200 €
Total fixed infrastructure cost	103.200 €	8.600 €
Wristband cost	0.50 € (35.000 units needed)	10 € (35.000 units needed)
Wristbands total cost	17.500 €	350.000 €
Total system cost	120.700 €	358.600 €

Table 3.4. Cost estimation for BLE and RFID deployments

The financial result is striking. From the first moment, it was stated that BLE infrastructure is considerably cheaper than RFID technology as far as the fixed elements of the structure are concerned. However, the importance of wearables had been left aside in that first economic perception. Fixed infrastructure must be installed in a limited number of attractions, 43 in the case of Port Aventura Park. However, the number of wearables must be equal to the park's maximum capacity, estimated at 35,000 visitors, which means that any small extra cost in the wearables is considerably increased in the final result.

Regarding RFID, the infrastructure accounts for 85% of the total cost compared to 15% of the cost of the wearables. For the BLE system, the opposite occurs: the cost of the infrastructure is only 3% compared to the 97% represented by the wearables.

Once the initial investment is made, it is easier and cheaper to scale up the BLE solution. However, it involves a higher initial outlay. Choosing one solution or another will depend on the interests of the park. If the aim is to count people at entrances and exists, then the problem is perfectly covered with the RFID solution. However, if managers want to perform real-time user geolocation, using the BLE solution would be more appropriate, with the additional cost of installing more BLE receivers to carry out this real-time location system all over the park.

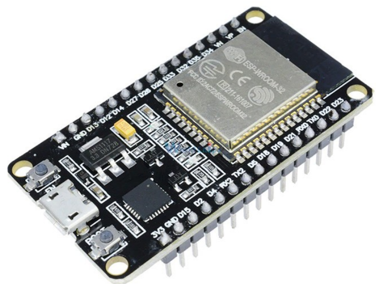
3.2.2. Connectivity layer

In order to transfer the data captured by the sensors to the cloud, it is necessary to add a gateway to the system that acts as an API between the sensor and the cloud. A gateway allows the connection between two networks with different technologies, such as different types of connectivity, interfaces or protocols. Gateways allow for wired and wireless connections, making them helpful in transmitting wired sensor data wirelessly via LoRa, WiFi, or cellular, for example. In addition, they reinforce system security, manage inbound and outbound traffic between IoT devices and the cloud, and improve the energy efficiency of connected devices.

Gateways are often used to pre-process information. This action is known as edge computing. Pre-processing is usually done when data needs to be processed close to the devices to ensure real-time action during critical situations, such as autonomous driving. Concerning this project, the data processing will be done in the cloud, as data does not have to be updated and processed in a brief period of time. The gateway will establish the connections between the reader/receiver and the cloud, switch from a wired connection protocol to a wireless one, and use the specified data protocol.

There are many models of gateways on the market. The LEC-6041, certified for Industrial IoT, is a model for the industrial field. However, tiny microcontrollers such as the ESP32 or any model of RaspberryPi are also often used for IoT applications.

(a) LEC 6041 Industrial controller



(b) ESP32 microcontroller

Fig. 3.8. RFID wristbands models [38]

The next step is to choose both the network and data protocol to transfer the data.

3.2.2.1. Network Protocol

Ideally, the best way to send the data from the gateway to the cloud is through the local network installed in the park. These enclosures usually have a WiFi network for clients or to communicate internally between employees and managers. If no network is deployed, a simple solution would be to provide the park with a WiFi network that serves both to transmit data and so that users can connect and view the information from the park app. The messages of each user have an approximate size of 128 bits; since only text is transmitted and there are no images or videos. Assuming that a user enters every second in each attraction, which is a considerable overestimation of the system, the amount of information transferred per second is

$$128 \text{ bits x } 3{,}600 \text{ users x } 43 \text{ attractions} = 19.81 \text{ Mbit/hour} = 5.5 \text{ Kbps}.$$

Currently, the latest WiFi protocol, 802.11ax (Wifi 6), has a maximum speed of 2.4 Gbps [74]. Therefore, there is enough bandwidth to transmit the data and to be able to scale the system without any problem.

LPWAN networks (Low Power Wide Area Networks), such as LoRa or NB-IoT, are designed for IoT applications. However, this devices are not designed to send many messages simultaneously, so they are not a good option for this project.

3.2.2.2. Data Protocol

MQTT protocol will be used to send messages as it is the most widespread within the field of IoT. The publish/subscribe structure works great for this scenario, where the sensors of each attraction will send the information to a specific topic whose name will be the same as that of the attraction. That way, there will be as many topics as there are attractions, as shown in figure 3.9 . This approach will later facilitate the storage and management of the data.

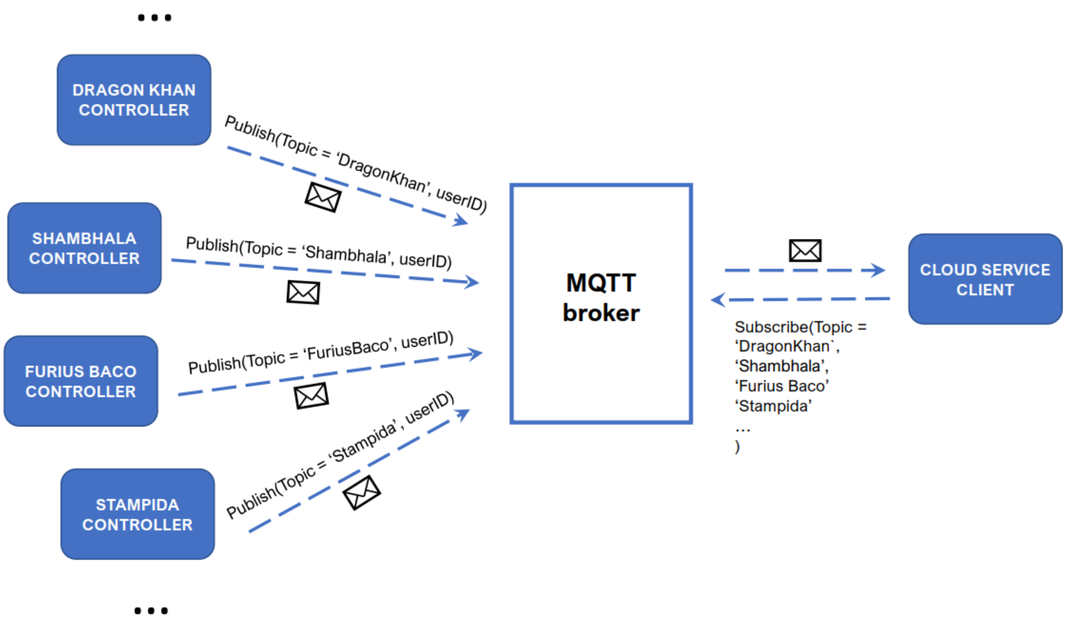


Fig. 3.9. MQTT architecture

3.2.3. Processing layer

The best option for this project is to use the services offered by the Cloud. Building on-premises servers entail an additional cost that is not initially justified. The safest option is to contract the services of a Cloud platform as it allows testing the system and guarantees that it works without making a significant investment. There are many IoT platforms on the market today. Many of them are part of Cloud platforms that have been expanding their services to offer solutions within the IoT world.

An IoT platform acts as a liaison between the domain of tangible items and the domain of valuable insights acquired from data. Internet of Things platforms combine various tools and features to develop distinctive hardware and software products for gathering, storing, analysing, and managing the vast amount of data generated by connected assets and devices [75].

The following list represents the top IoT platforms on the market in 2022:

- Google Cloud IoT
- Cisco IoT Cloud Connect
- Salesforce IoT Cloud
- IRI Voracity
- Particle
- IBM Watson IoT
- ThingWorx
- Amazon AWS IoT Core
- Microsoft Azure IoT Hub
- Oracle IoT

IoT cloud platforms typically incorporate functions like app development, device administration, connectivity management, data collecting and storage, and data analysis and visualisation into end-to-end solutions. They usually have a core module for IoT, which is the brain of the IoT platform. Then, information can flow to other modules such as storage, databases, analysis and data visualisation. Functionalities between IoT platforms are pretty similar; hence any of these platforms is an excellent solution for this project.

Databases are an essential part of cloud services. Designing the database is a critical part of the system to ensure data is consistent and avoid duplicate values. For this project, a relational database will be the selected option. Thanks to the structured table format and the relation between different tables, it is easy to connect the information from the different rides and users.

The database design works as follows. First, two tables store information about the users and the rides. It is not difficult to get valuable features from the users such as age, gender, or whether they come alone, in family, with friends or as a couple. This information is precious for the park in order to get statistics. In the second table, rides are associated with a specific code. The idea behind this table is to add more information about the ride if needed in the future. Figure 3.10 shows what this table might look like.

user_id	age	gender	companion
1a2b3c4d	25	male	friends
3f5g4e9t	32	other	family
2p9o9i7y	65	female	alone
4g6y5r8e	20	female	couple

(a) Table 1: User information

attraction_id	attraction_name	attraction_state
1	Shambhala	open
2	Dragon Khan	refurbishment
3	Furius Baco	closed

(b) Table 2: Ride information

Fig. 3.10. Users and ride information tables

Then, the main tables are created. The first one is the historical data table. It will be used to store all the entrance and exit records for every user. Therefore, users will appear in this table as often as they go into the ride. The second table, called “temporary table”, will be different for every ride. It will be used to count the number of people in order to control the queuing system, as it only stores the IDs of users waiting in line. It uses the concept of “primary key”. A primary key is a unique value for each record within a database. It might be a driver’s license, telephone, or vehicle identification number. Within a table, there must be just one primary key. The primary key for this database will be either the ID of every RFID tag or the UUID from every BLE beacon. Users can only be registered once in just one temporary table at a time since they cannot be on two rides simultaneously. They are stored on the temporary table in the last position as soon as they enter a ride. When a user leaves the ride, their row is deleted from the table, and all position values go one step forward. These tables can be seen in figures 3.11 and 3.12.

user_id	ride_id	action	year	month	day	time
1a2b3c4d	15	enter	2022	9	26	12:00:34
3f5g4e9t	43	exit	2022	9	26	12:00:35
2p9o9i7y	32	exit	2022	9	26	12:13:45
1a2b3c4d	15	exit	2022	9	26	12:15:01

Fig. 3.11. Historical data table

SHAMBHALA	
position	user_id
1	1a2b3c4d
2	3f5g4e9t
3	2p9o9i7y
4	1a2b3c4d

(a) Table 4.1: Shambhala

DRAGON KHAN	
position	user_id
1	3e4r5t6y
2	9p8i7u6y
3	5t6y5t6y
4	6t5y8u7i

(b) Table 4.2: Dragon Khan

Fig. 3.12. Attractions' temporary tables

Finally, the last table will store the waiting time and the number of people at every ride every minute. The diagram shown in figure 3.13 illustrates the logic of the system.

ride_id	number of people	waiting time	year	month	day	time
15	150	10 min	2022	9	26	12:00:00
43	300	30 min	2022	9	26	12:00:00
32	25	5 min	2022	9	26	12:00:00
15	1650	95 min	2022	9	26	12:00:00

Fig. 3.13. Waiting time table

The relational database has a logic behind to store the values in the tables. Every time the system reads a new id, the system must fulfill the following rules:

1. Two "user_id" cannot appear simultaneously in two temporary tables of two different attractions. If this happens because some input or output value has not been read correctly, the new read value prevails. The old record is deleted from its corresponding table.

2. If the "user_id" is not registered in the temporary table of that attraction, the ID is saved at the end of the table. Then, the "user_id" is recorded in table 3, indicating "enter" in the "action" field. A user might not always leave the ride through the exit, i.e. the user regrets going on the ride when already queuing. Thanks to this system, there is no physical entrance or exit. The user is entering or leaving the ride depending on whether the system identifies the user was there before or not.

3. If the "user_id" is registered in the temporary table of the attraction, this record is deleted from that table, and the "user_id" is saved in table 3, selecting "exit" in the "action" field.

Figure 3.14 shows the schema following the logic of these rules mentioned before:

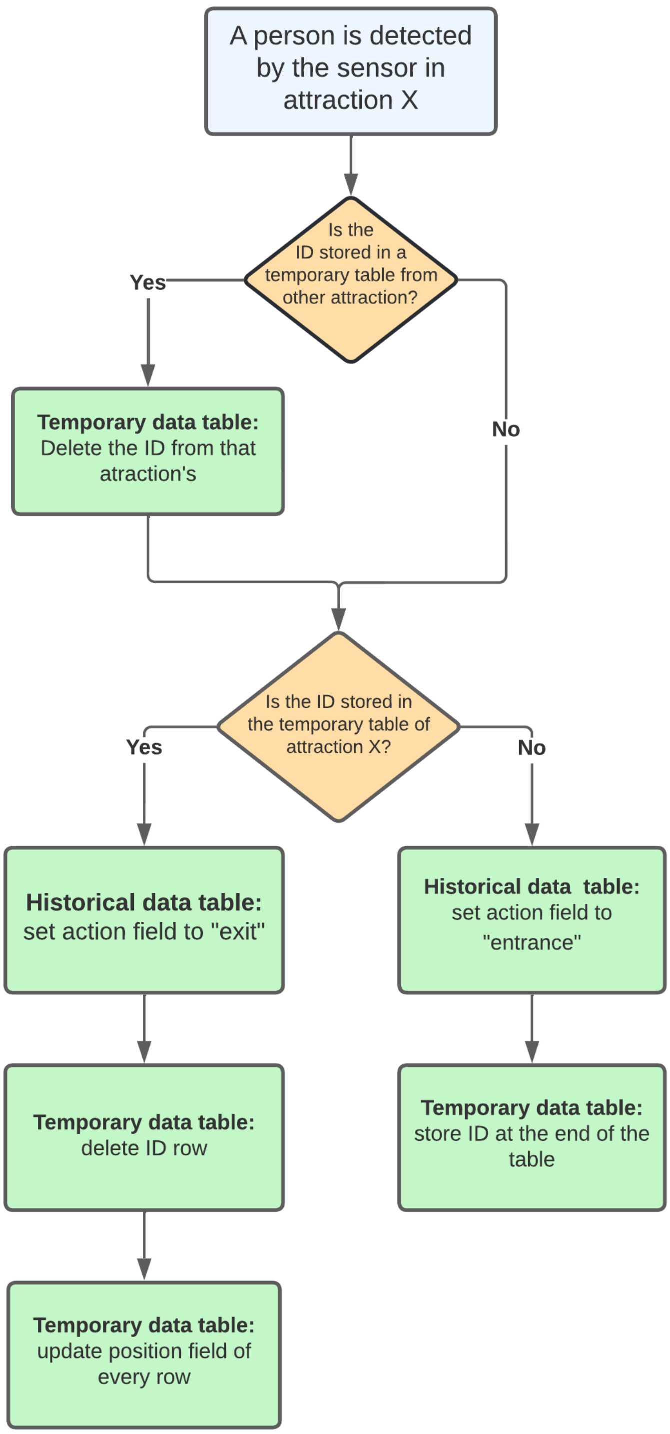


Fig. 3.14. Relational database system's logic

3.2.4. Application layer

The application layer represents the physical interface where data is visualised and analysed. Theme park managers can access the data and get helpful information such as the most congested areas, most popular rides or which ones are not so popular. Clients can visualise this information through the park's mobile application. Waiting times for each ride are displayed, along with the park's map, attractions, restaurants or shows. The waiting time information is also shown in digital panels at the ride's entrance or on screens around the park, so user's can check the waiting time without using their mobile phones.

3.3. Designed solution

After deep research, the schema of the whole integrated IoT infrastructure for measuring waiting times in attractions is synthesised in figure 3.15:

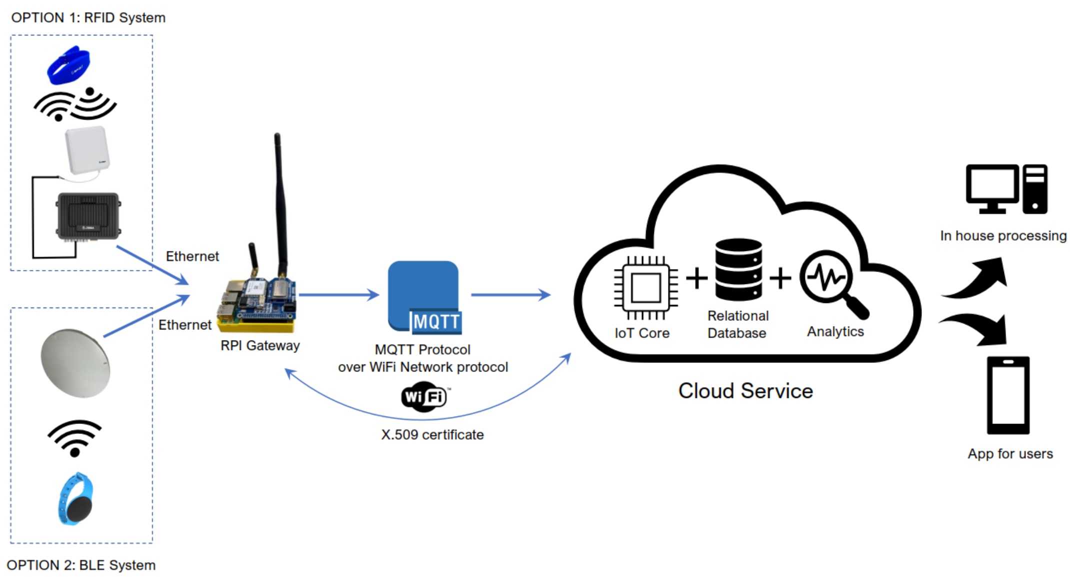


Fig. 3.15. IoT architecture for monitoring waiting time in real-time

4. DEVELOPMENT OF A PROOF OF CONCEPT

In this chapter, a small Proof of Concept (PoC) is carried out to test the technology within the real-time waiting time monitoring system. For this proof of concept, the following components are used:

- RC522 RFID Module
- Raspberry Pi 3 Model B V1.2
- RFID cards and fobs
- Wires and protoboard
- WiFi connection
- Amazon Web Service

The solution with an RFID sensor will be tested for this proof of concept (PoC). The objective is to analyse how the gateway (raspberry pi) is configured to send the device data to the cloud using the MQTT protocol through WiFi. In addition, a data pipeline is carried out between the different Amazon Web Service modules, from data collection in IoT Core until it is displayed in QuickSight.

Raspberry Pi is a single-board computer developed by the Raspberry Pi foundation. The installed operating system is called Raspberry Pi OS and is based on a GNU/Linux distribution, specifically Debian. It was formerly known as Raspbian [76]. The RFID reader used is the RC522 module, which is used both to read and write RFID tags. It uses a 13.56 MHz modulation and demodulation system, a spectrum encompassed in High Frequency (HF). This module is not UHF, therefore, tags must be closer than 4 cm to be able to read them. Two RFID cards and fobs will be used as “user’s wearables”. Image 4.1 shows the physical assembly of the system.

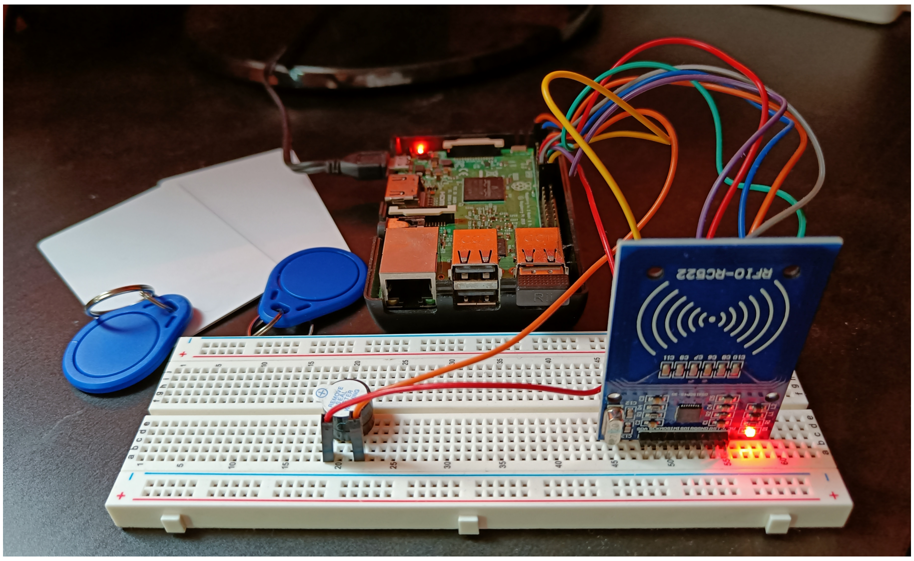


Fig. 4.1. PoC assembly with Raspberry Pi Model 3B and RC522 RFID module

Amazon Web Services has been chosen as the cloud platform to send, store and visualise the data. It is an easy-to-manage platform with very versatile and zero-cost modules for the tasks developed. Figure 4.2 illustrates the physical assembly plus the data pipeline through AWS configured for this PoC.

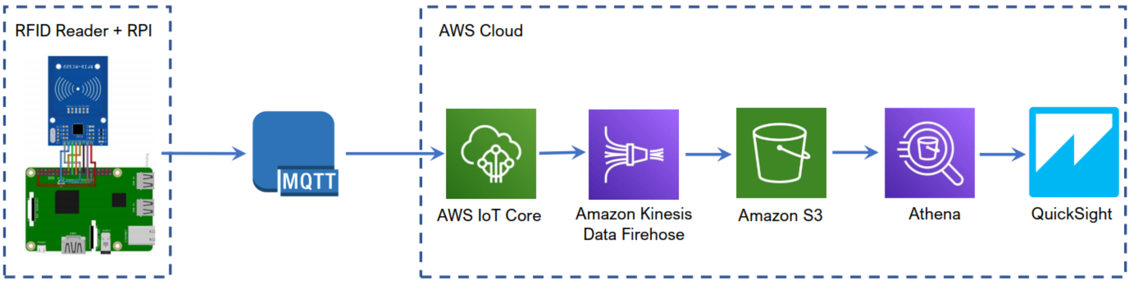


Fig. 4.2. Data pipeline

The steps taken to configure the RPI and connect it with AWS through MQTT to send the messages are detailed below:

1. First, the physical assembly must be done. The RFID reader pins are connected to the corresponding GPIO of the RPI. First, the physical assembly must be done. The RFID reader pins are connected to the corresponding GPIO of the RPI.

2. The latest operating system version is installed on the Raspberry Pi along with the newest version of the Python module.

3. Directories are created to store the different programs and certificates.

4. A small program is made to change the original name of the RFID cards and associate specific names: User1, User2, User3 and User4.

```
import RPi.GPIO as GPIO
from mfrc522 import SimpleMFRC522

reader = SimpleMFRC522()

try:
        text = input('New data:')
        print("Now place your tag to write")
        reader.write(text)
        print("Written")

finally:
        GPIO.cleanup()
```

Fig. 4.3. Program for writing in tags

5. The AWS Software Development Kit is installed. It includes the necessary libraries to make the MQTT connection.

6. The client certificates (X.509 model) required by Amazon to make the connection are installed in the RPI. The amazon Certification Authority (CA) is installed on the device, and a public/private key pair is generated and stored on the device as well. Everything is ready to create the Python program that allows the connection establishment.

7. Required libraries are imported.

```
#Import Libraries
from awscrt import io, mqtt, auth, http
from awsiot import mqtt_connection_builder
import time as t
from datetime import datetime
import json
from mfrc522 import SimpleMFRC522
import RPi.GPIO as GPIO
from gpiozero import Buzzer
```

Fig. 4.4. Python libraries

8. The name of the topic and the paths of the certificates are specified.

```
# Define ENDPOINT, CLIENT_ID, PATH_TO_CERTIFICATE, PATH_TO_PRIVATE_KE
ENDPOINT = "a1xeuniv275mfo-ats.iot.eu-west-2.amazonaws.com"
CLIENT_ID = "testDevice"
PATH_TO_CERTIFICATE = "certificates/iotaws-certificate.pem.crt"
PATH_TO_PRIVATE_KEY = "certificates/iotaws-private.pem.key"
PATH_TO_AMAZON_ROOT_CA_1 = "certificates/root.pem"
reader = SimpleMFRC522()
TOPIC = "Ride1/WaitingTime"
buzzer = Buzzer(23)
```

Fig. 4.5. Path to certificates

9. MQTT connection to AWS is made

```
# Spin up resources
event_loop_group = io.EventLoopGroup(1)
host_resolver = io.DefaultHostResolver(event_loop_group)
client_bootstrap = io.ClientBootstrap(event_loop_group, host_resolver)
mqtt_connection = mqtt_connection_builder.mtls_from_path(
            endpoint=ENDPOINT,
            cert_filepath=PATH_TO_CERTIFICATE,
            pri_key_filepath=PATH_TO_PRIVATE_KEY,
            client_bootstrap=client_bootstrap,
            ca_filepath=PATH_TO_AMAZON_ROOT_CA_1,
            client_id=CLIENT_ID,
            clean_session=False,
            keep_alive_secs=6
            )
print("Connecting to {} with client ID '{}'...".format(
        ENDPOINT, CLIENT_ID))
# Make the connect() call
connect_future = mqtt_connection.connect()
# Future.result() waits until a result is available
connect_future.result()
print("Connected!")
# Publish message to server desired number of times.
print('Begin Reading & publishing')
print('Press ctrl+c to stop reading')
```

Fig. 4.6. Connecting to AWS through MQTT

10. A loop is programmed so that it continuously reads the messages. Each message includes the attraction's ID, the attraction's name, the user's id, the user's name and the reading timestamp. Messages are sent in JSON format.

```
#Infinite Reading Loop
while True:
        id, text = reader.read()
        CurrentDate = datetime.now()
        json_date = json.dumps(CurrentDate, default=str)
        message = {}
        message['rfid_name'] = text.strip()
        message['rfid_id'] = id
        message['entry_time'] = json_date
        message['attraction_id'] = 15
        message['attraction_name'] = "Shambhala"
        messageJson = json.dumps(message)
        mqtt_connection.publish(TOPIC, messageJson, qos=mqtt.QoS.AT_LEAST_ONCE)
        print('Published to the topic: ' + TOPIC)
        buzzer.on()
        t.sleep(0.5)
        buzzer.off()
        t.sleep(2)
```

Fig. 4.7. Coding the reading of RFID tags

Once all these steps have been completed, it must be verified that data is being sent to AWS each time a card is passed through the RFID reader. In order to check it, the MQTT test tool of the IoT core module is accessed. As can be seen in figure 4.8, the data is received correctly.

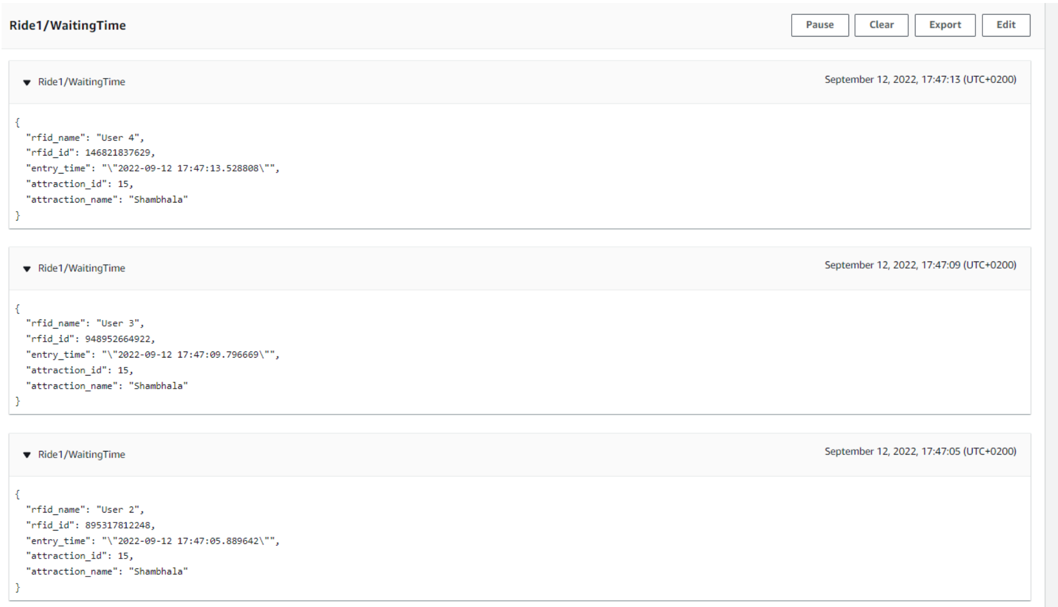


Fig. 4.8. Testing MQTT connection between RPI and AWS

The data is currently inside AWS, but now it is necessary to create the data pipeline that transforms and stores this data to be displayed by a dashboard. The first module in the chain is IoT Core [77]. It is the brain of the IoT platform and the one in charge of connecting with the other AWS modules. It is the backbone of IoT deployments. The first step is to store the data in the database, called S3. An intermediate step is used through the Amazon Kinesis Data Firehose module. This module is used when there is a large data intake. Instead of sending each message as a file, messages are grouped within the same file, sent from time to time or when the file exceeds a specific size. For this PoC, the sending time is one minute. Hence, the waiting time will be updated every minute for each attraction. Through this module, and using a specific rule created in IoT core, it is specified which topic to subscribe to and the bucket where the data is stored in Amazon S3. A bucket is roughly a folder where the data related to an attraction is stored. There can be as many buckets as needed.

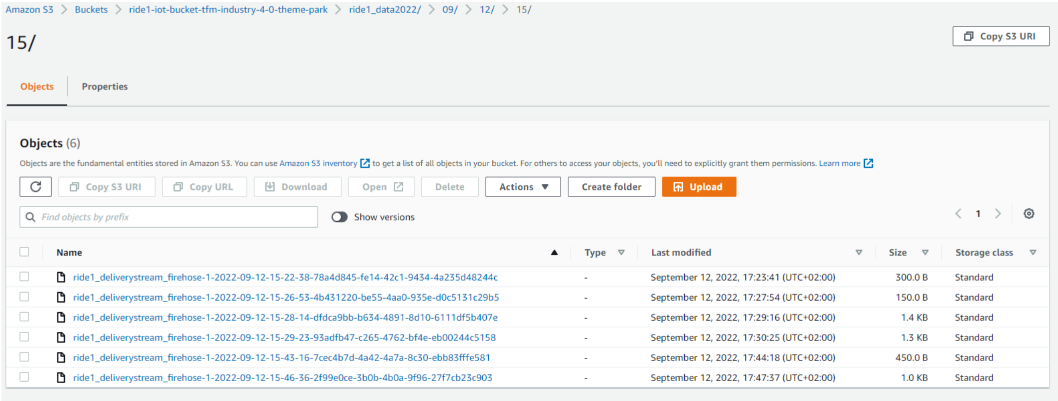


Fig. 4.9. Buckets in S3

Once the data is stored in S3 and organised by date folders, the files are sent to QuickSight. It is necessary to adapt the data to the correct format. The Athena module converts the data from JSON to a table format with columns and rows.

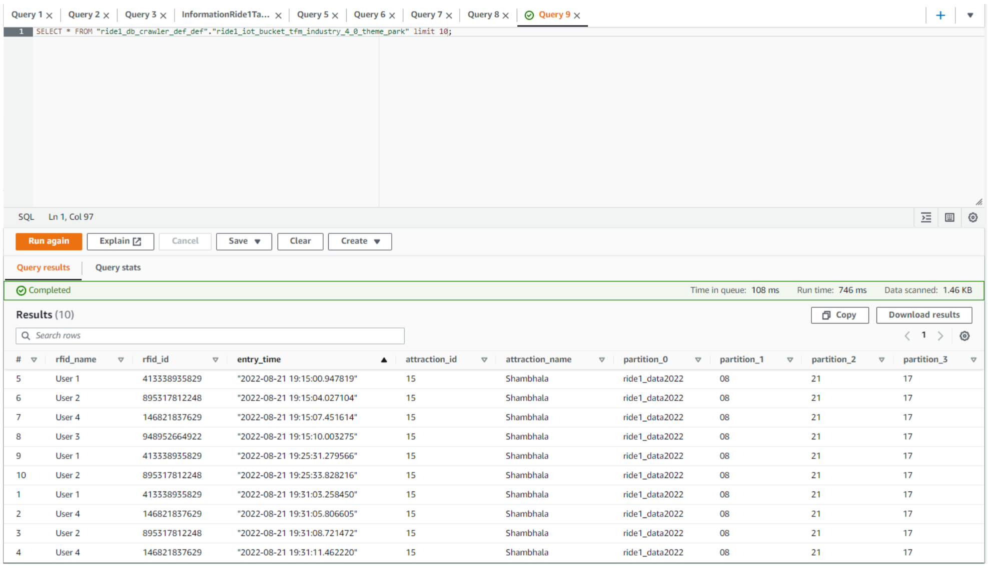


Fig. 4.10. Athena module

The last stage is to connect to Amazon QuickSight. This module allows data visualisation and making comparisons through dashboards.

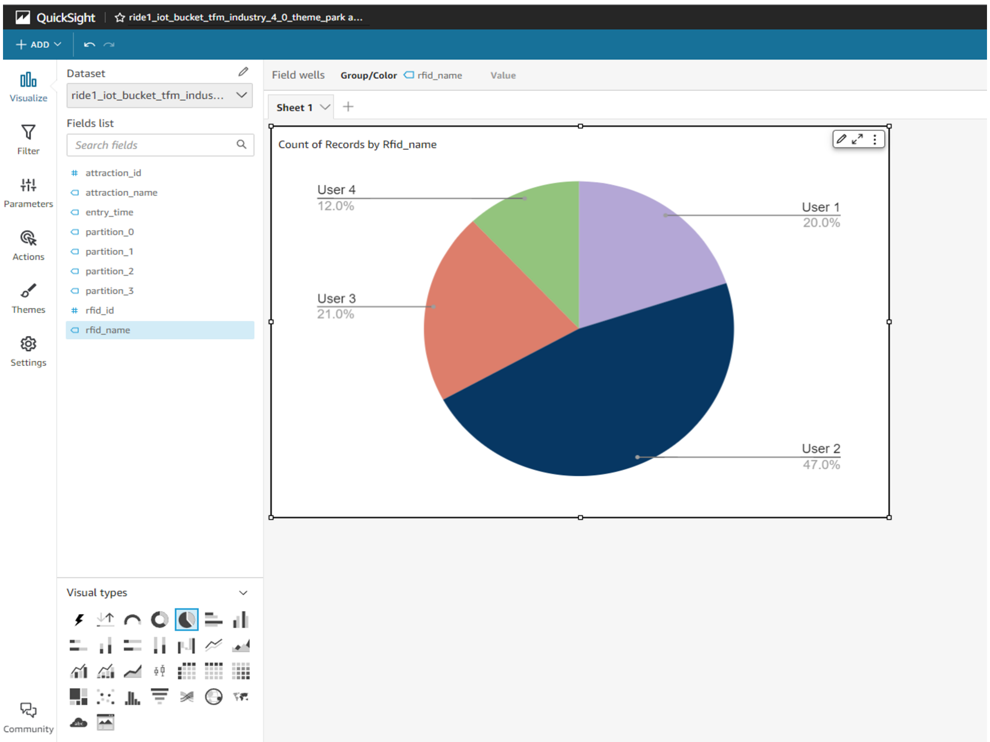


Fig. 4.11. Data visualisation

This step concludes the development of this proof of concept. Thanks to this deployment, it has been possible to understand how the MQTT protocol works and the connection between a gateway and a cloud service to transmit data from an IoT device.

5. FUTURE IMPROVEMENTS AND CONCLUSIONS

5.1. Future improvements

5.1.1. System deployment

This section describes how the system deployment will be carried out. First, the system must be tested just on a few attractions, not to make a significant investment. This stage is essential to check the proper functioning of the solution. The optimal situation would be to test both RFID and BLE in situ to check which offers better performance.

The system must be calibrated to adjust the antennas' measurement ranges to cover the input and output zone range without exceeding these thresholds. In some cases, it may be necessary to adapt the entry and exit areas to delimit the access areas to the attractions and avoid multiple entry points. Once it is verified that the system is optimal and works for the installed attractions, it can be extended to the rest of the attractions and added to the IoT platform.

5.1.2. Connected park

The connected park concept proposes a continuous and monitored connection between clients, workers, and the park itself. Currently, the system has been designed to count the waiting time in the attractions since they are those places in the park where queues usually form. However, it is important to remark that the solution is, after all, a people counter that transforms this value into waiting time.

It is proposed to transfer this solution to other points in the park in future work. If this solution is added to restaurants, shops, toilets, entertainment venues or entrances to some regions of the park, it would be fully monitored and there would be a real-time record of the number of people in each place in the park. In addition, it is possible to know where the client has been prior to and after a specific place and the time spent on that site.

Moreover, the wristbands worn by users can offer many other possibilities. These bracelets can, in turn, be used to cover a series of services:

- Electronically save the park entrance ticket
- Store services purchased within the park, such as FastPass, restaurant reservations, and VIP experiences.
- Save personal payment data through the park app to make purchases without using a mobile or card.

- Use it as a key for lockers.
- It can be used as a room key for hotels within the theme park resort.

In order to carry out these services, wearables must be modified. In the case of RFID wristbands, which have a UHF tag, it is necessary to attach another tag to carry out these transactions within a short distance. It must be remembered that wristbands are designed to be read within a range of 5 meters, which is unusable in the case of payment with a dataphone or ticket reader. These actions require a small distance to be reliable. In addition, the card issuance frequency would not match these devices, which makes them incompatible. Therefore, it is necessary to incorporate a 13.56 MHz (HF) tag inside the bracelet, the one NFC technology uses. This technology is used in the contactless sector thanks to the bi-directionality of data and the security protocols it implements. In the case of BLE bracelets, the same would be done.

These wristbands already exist on the market, combining UHF and NFC tags in the case of RFID wristbands and BLE beacon and NFC tags for BLE wristbands. Both systems coexist together without incompatibilities because the emission frequency is different.

The Walt Disney Company and Universal Studios are already investing money in this technology. They are starting to implement this service in their parks to ensure customers have everything they need in a single bracelet. Volcano Bay water park at Universal Studios Florida has already implemented a similar system, with the wristband being mandatory for customers as part of the experience. This solution is advantageous in water parks since people do not usually carry their mobile phones or credit cards, making purchasing items in the park easier with the wristband. In addition, there are interactive elements throughout the park, such as water jets and mechanisms that are activated by bringing the bracelets closer to the indicated points; as well as automatic photographic points that take pictures of the clients when they bring their wristbands closer to the spot [78].

5.1.3. Virtual queuing

A virtual queuing system is proposed as a complement to this solution. These systems are increasingly being adopted in theme parks to improve the user experience. People can wait virtual in other places in the park without waiting in line. This system works well when implemented in the attractions with the longest queues, so the user can virtually queue at one or more attractions while physically queuing on other rides.

There are many ways to implement virtual queuing systems. One way is through mobile applications, where the user can select the attraction they want, sign up for the virtual queue, and a QR code is generated to be scanned at the attraction's entrance. Another solution is through machines spread throughout the park where users perform this process without needing mobile devices. Finally, and taking advantage of the tracking wristbands solution, users sign up for virtual queues using machines located at each attraction's entrance that record the wristbands' ID by approaching a reader. When it is time to go to the attraction, the bracelet vibrates. The bracelet is identified at the entrance of the attraction to verify that it is in the correct access strip. Volcano Bay has also implemented this system at Universal Studios [78].

5.2. Conclusions

5.2.1. Solution discussion

This project aimed to analyse what benefits Industry 4.0 can bring to solve problems within the theme park sector. Hence, deep research has been carried out about the current situation of both sectors, which technologies have allowed the development of Industry 4.0 and how some of them are used today in cutting-edge attractions to offer users immersive experiences.

As for the problems that most concern users, there are attractions out of service, sudden stops for technical reasons, queue management, and long waiting times. Many theme parks have waiting times warning systems, but these are often inaccurate based on estimates or insufficient data collection. For this reason, it was proposed to use the advantages offered by industry 4.0 to design a real-time waiting time monitoring system for attractions by implementing an infrastructure combining IoT, cloud computing and databases.

Theme park managers are increasingly interested in knowing data about the actions and movement of their clients in the park. They can use this information to obtain statistics that allow them to optimise resources and improve facilities based on their users' preferences. This is the reason why the system to be implemented must provide a solution to both data gathering and real-time waiting times. The so-called "tracking technologies" are chosen as a solution. Thanks to RFID or BLE systems along with personal wristbands, waiting times can be obtained by counting people at the entrance and exit; as well as precious information for managers:

- Most popular and least popular attractions
- Heat map with busiest times of the day.
- Attractions in which users re-ride the most.
- Attractions with the longest waiting times.

The possibilities are endless if this system is extended to all park services, as detailed in the future improvement section. It can be used to optimise plenty of resources. For instance, determine which toilets are used the most and restructure cleaning shifts to increase the cleaning frequency in those ones. A cleaning threshold can also be determined, that is, toilets must be cleaned every 1000 users, for example.

This system also helps to redeploy employees to support those attractions with the highest demand, making decisions such as increasing or reducing the number of trains at an attraction based on its flow. Attraction hours can be adjusted using this information. If it is determined that no one gets on the water attractions after 9:00 p.m., the closing time can be brought forward with the energy savings that this entails.

One of the main drawbacks of the system is having to provide all users with an extra element, such as wearables, to make this system work. From the user's point of view, carrying an additional element must be justified. If the user suddenly has to carry a device that offers no extra advantage compared to previous visits, the customer will remain baffled. Consequently, a good solution is change the regular paper ticket for paper RFID wristbands, which are single-use and many parks use them as a purchase identification. However, if extra features want to be added such as storing the park entrance ticket and extra services, conduct payments, interaction with elements of the park or keeping the hotel room key, then non-disposable solution such as silicone bracelets is the most suitable solution. These bracelets would be delivered by the park at the beginning of the day and returned at the end. They would be a way of unifying all the park services in a single device, as mentioned in the future improvements section. This way, users understand that wristbands enhance their experience and must be worn, thus guaranteeing the proper functioning of the queue system. At the end of the day, the information stored in these bracelets is reset so that other clients can use them again.

Finally, it should be noted that knowing the exact waiting time at the attractions does not eliminate the queue; it only provides the user with reliable information thus they can take decisions. As queues in theme parks are not going to disappear, the best park managers can do is to work on improving operations in the attractions: use the maximum number of vehicles available, agility when loading and unloading people, create pre-loading areas to speed up this process, and above all, create waiting areas that are visually beautiful and entertaining for the user. Queuing areas can also be part of the attraction, as they gradually introduce the user to the adventure they are about to live, hence it is a way of extending the attraction itself so that the experience is longer. Some theme parks, like Disney, invest a lot of efforts in designing breathtaking queues for customers enjoyment. Rise of the resistance is one of Disney's latest attractions and queue is so immersive that it is considered part of the ride itself, fading the line between riding and queuing [79].

5.2.2. General Data Protection Regulation

It is essential to consider the European regulatory framework regarding data privacy policy. The General Data Protection Regulation (GDPR) (Regulation 2016/679) is a regulation by which the European Parliament, the Council of the European Union and the European Commission intend to strengthen and unify data protection for all individuals within the European Union (EU) [80]. The main objective of the GDPR is to give citizens and residents control over their personal data and to simplify the regulatory environment for international business by unifying regulations within the EU.

For this solution, data related to the behaviour of people inside the park is stored: places visited, length of stay, and attraction's order of visit. Data such as age or gender may also be stored for statistical purposes. However, data is not associated with customer's personal profile at any time. Data is linked to a fictitious profile created to store users' behaviour information. Therefore, personal data such as name, phone number or address is stored. In addition, data collection takes place in a physical space the user voluntarily accesses and accepts its rules of operation when buying the ticket. The only personal information that might be stored is bank account details in the NFC chip, just in the case user wants to use this service. This data is always deleted at the end of the visit when wristbands are given back. Therefore, this system fully complies with the GDPR in terms of data protection.

5.2.3. Economic discussion

From an economic point of view, it is important to analyse the economic profitability of the system. The RFID system is more profitable than the BLE one when there are few readers installed, since the main cost lies in the price of the fixed infrastructure. In the BLE system, the opposite occurs; it begins to be more profitable compared to RFID one when the receivers are increased. Both systems tend to equal their cost when 150 infrastructures are used, which is the approximate number of venues PortAventura has considering attractions, restaurants, shops, shows, toilets and hotels. The system is a long-term investment where the implementation cost lies in the initial investment, around 400,000 euros if it is installed for all the venues. The only additional costs will be derived from maintenance issues and the replacement of damaged wearables.

It is difficult to know the economic profitability of the system without knowing which is the park annual investment and its benefits in the short and long term. It would be necessary to study to what extent this system helps to optimise resources and improve operations and investment strategies. Port Aventura expects to exceed 103 million euros in EBITDA and the 241 million euros invoiced before the COVID-19 crisis this year, achieving their best result ever.

Although it is difficult to estimate in what percentage this solution benefits the park, the truth is that companies using data to define their strategies optimise resources and obtain more benefits. According to a study by Capgemini, companies driven by data obtain 22% more profits. It also highlights that companies that can be considered data experts enjoy between 30% and 90% competitive advantages in different metrics related to customer participation, gross income, operational efficiency and cost savings. [81]. In a sector as competitive as leisure, it is important to understand customer preferences and behaviour to offer solutions that suit their tastes. This solution is then a great investment since it is possible to understand customers behaviour and take profitable decisions based on this information.

5.2.4. Industry 4.0 and theme parks

To conclude, a brief overview about the benefits that industry 4.0 can bring to the theme park sector is made. Industry 4.0 is mainly focused on the industrial field. However, over the years, it has spread to many sectors, such as health and agriculture. After all, the philosophy behind industry 4.0 is to create more efficient, sustainable and safe systems using intelligent tools that allow resources to be optimised and more profit to be obtained, improving operability. This philosophy is, therefore, adaptable to any sector of society. Theme parks are companies, and as such, they intend to maximise their profits and offer quality services to increase the rate of return.

During this work, it has been shown how industry 4.0 is present in theme parks, directly or indirectly, and how integrated solutions that merge technologies help improve park operations. For instance, it is possible to:

- Create better maintenance models for attractions and increase safety thanks to data analysis and IoT infrastructures.
- Collect data to understand customer behaviour through the use of data analytics.
- Use industry 4.0 technology such as robotics, AR/VR, autonomous mobile robots and emulation in theme park attractions.
- Control and optimise park resources through management programs, such as ERPs.

Industry 4.0 offers such broad solutions that there will always be some branch that can benefit theme parks, creating a synergy between both sectors where both customers and managers can benefit.

BIBLIOGRAPHY

[1] L. Bassi, 'Industry 4.0: Hope, hype or revolution?' In *2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI)*, 2017, pp. 1–6. DOI: 10.1109/RTSI.2017.8065927.

[2] B. Bajic, A. Rikalovic, N. Suzic, and V. Piuri, 'Industry 4.0 implementation challenges and opportunities: A managerial perspective,' *IEEE Systems Journal*, vol. 15, no. 1, pp. 546–559, 2021. DOI: 10.1109/JSYST.2020.3023041.

[3] 'La industria 4.0 es la clave para el crecimiento del pib.' (), [Online]. Available: https://www.expansion.com/economia-digital/. (accessed: 22.08.2022).

[4] 'El potencial de la cuarta revolución industrial.' (), [Online]. Available: https://www2.deloitte.com/es/es/pages/manufacturing/articles/potencial-cuarta-revolucion-industrial.html. (accessed: 14.09.2022).

[5] 'The worlds oldest amusement park.' (), [Online]. Available: https://www.bakken.dk/english/. (accessed: 25.08.2022).

[6] B. Richard, K. Kaak, and M. Orlowski, *Theme Park Tourism. [Encyclopedia Entry]*. Jan. 2016.

[7] *Europe Theme Park Market Size, Share & Trends Analysis Report By Revenue Source (Tickets, Food & Beverages, Merchandize, Hotels & Resorts), And Segment Forecasts, 2020 - 2027*. Dec. 2020, p. 110.

[8] 'Theme park tourism market outlook (2022-2032).' (), [Online]. Available: https://www.futuremarketinsights.com/reports/theme-park-tourism-market. (accessed: 25.08.2022).

[9] C. Klingenberg, 'Industry 4.0: What makes it a revolution?,' Jul. 2017.

[10] 'The fourth industrial revolution.' (), [Online]. Available: https://www.cadm.com/the-fourth-industrial-revolution/. (accessed: 10.09.2022).

[11] B. Bajic, A. Rikalovic, N. Suzic, and V. Piuri, 'Industry 4.0 implementation challenges and opportunities: A managerial perspective,' *IEEE Systems Journal*, vol. 15, no. 1, pp. 546–559, 2021. DOI: 10.1109/JSYST.2020.3023041.

[12] 'What are autonomous robots?' (), [Online]. Available: https://www.robots.com/articles/what-are-autonomous-robots. (accessed: 9.09.2022).

[13] 'Cloud computing.' (), [Online]. Available: https://www.salesforce.com/mx/cloud-computing/. (accessed: 9.09.2022).

[14] '¿qué es la realidad aumentada?' (), [Online]. Available: https://www.innovae.eu/la-realidad-aumentada/. (accessed: 9.09.2022).

[15] 'Difference between simulation and emulation.' (), [Online]. Available: https://www.stechies.com/difference-between-simulation-emulation/. (accessed: 9.09.2022).

[16] 'What is additive manufacturing?' (), [Online]. Available: https://www.ge.com/additive/additive-manufacturing. (accessed: 9.09.2022).

[17] 'What is cybersecurity?' (), [Online]. Available: https://www.ibm.com/topics/cybersecurity. (accessed: 9.09.2022).

[18] 'What is industrial automation? types of industrial automation systems.' (), [Online]. Available: https://www.electricaltechnology.org/2015/09/what-is-industrial-automation.html. (accessed: 31.08.2022).

[19] 'Industrial automation.' (), [Online]. Available: https://instrumentationtools.com/five-levels-in-industrial-automation/. (accessed: 31.08.2022).

[20] 'Sistemas de control industrial.' (), [Online]. Available: https://www.copadata.com/es/productos/platform-editorial-content/sistemas-de-control-industrial/. (accessed: 31.08.2022).

[21] A. R. Penin, *Sistemas Scada*. Marcombo, 2011.

[22] 'Automation pyramid and network in the production.' (), [Online]. Available: https://www.researchgate.net/figure/Automation-pyramid-and-network-in-the-production-23-24_fig1_350871174. (accessed: 10.09.2022).

[23] 'Roller coaster block sections: Explained.' (), [Online]. Available: https://www.youtube.com/watch?v=gDS_ht-0b5M. (accessed: 02.09.2022).

[24] 'What is the importance of scan cycle in plc?' (), [Online]. Available: https://www.quora.com/What-is-the-importance-of-scan-cycle-in-PLC. (accessed: 10.09.2022).

[25] 'Tiempo de reacción plc.' (), [Online]. Available: https://programacionsiemens.com/tiempos-de-reaccion-de-un-plc-siemens/. (accessed: 31.08.2022).

[26] K. Rástočn and J. Ždánsky, 'Specificities of safety plc based implementation of the safety functions,' in *2012 International Conference on Applied Electronics*, IEEE, 2012, pp. 229–232.

[27] '¿qué es un plc de seguridad?' (), [Online]. Available: https://plcdesign.xyz/que-es-un-plc-de-seguridad/. (accessed: 10.09.2022).

[28] 'System and method for autonomous navigation in a ride vehicle.' (), [Online]. Available: https://patents.google.com/patent/US7739006B2/en?oq=US7739006B2. (accessed: 31.08.2022).

[29] '[4k] pooh's trackless hunny hunt ride - amazing trackless ride - tokyo disneyland 2016.' (), [Online]. Available: https://www.youtube.com/watch?v=SEyEI6WELDo. (accessed: 10.09.2022).

[30] 'Millennium falcon: Smuggler's run.' (), [Online]. Available: https://starwars.fandom.com/wiki/Millennium_Falcon:_Smuggler%5C%27s_Run. (accessed: 31.08.2022).

[31] ''star wars' soars in real time: Behind 'millennium falcon'.' (), [Online]. Available: https://blog.siggraph.org/2020/08/star-wars-soars-in-real-time-behind-millennium-falcon.html/. (accessed: 31.08.2022).

[32] 'How it works: Patent behind disney's millennium falcon: Smugglers run ride.' (), [Online]. Available: https://www.bizjournals.com/orlando/news/2019/10/04/how-it-works-patent-behind-disneys-millennium.html. (accessed: 10.09.2022).

[33] 'Universal files patent for augmented reality glasses to be used in mario kart ride.' (), [Online]. Available: https://themeparkuniversity.com/universal/universal-files-patent-augmented-reality-glasses-used-mario-kart-ride/. (accessed: 10.09.2022).

[34] 'Academia toscani.' (), [Online]. Available: https://toscaniautomazione.wixsite.com/toscaniacademy. (accessed: 31.08.2022).

[35] 'Simworx.' (), [Online]. Available: https://www.simworx.co.uk/. (accessed: 31.08.2022).

[36] 'This avatar figure is the most advanced animatronic ever.' (), [Online]. Available: https://www.inverse.com/article/31974-disney-s-na-vi-shaman-is-the-most-advanced-animatronic-ever. (accessed: 10.09.2022).

[37] R. K. Mobley, *An Introduction to Predictive Maintenance*. Elsevier Science, 2002.

[38] O. Merkt, 'On the use of predictive models for improving the quality of industrial maintenance: An analytical literature review of maintenance strategies,' in *2019 Federated Conference on Computer Science and Information Systems (FedCSIS)*, 2019, pp. 693–704. DOI: 10.15439/2019F101.

[39] 'Predictive maintenance & asset management with advanced data analytics.' (), [Online]. Available: https://www.gslab.com/blogs/predictive-maintenance. (accessed: 1.09.2022).

[40] M. Berno *et al.*, 'A machine learning-based approach for advanced monitoring of automated equipment for the entertainment industry,' in *2021 IEEE International Workshop on Metrology for Industry 4.0 & IoT (MetroInd4.0&IoT)*, 2021, pp. 386–391. DOI: 10.1109/MetroInd4.0IoT51437.2021.9488481.

[41] J. F. Shortle, J. M. Thompson, D. Gross, and C. M. Harris, *Fundamentals of queueing theory*. John Wiley & Sons, 2018, vol. 399.

[42] 'Richard larson.' (), [Online]. Available: https://idss.mit.edu/staff/richard-larson/. (accessed: 10.09.2022).

[43] V. Vukadinovic, F. Dreier, and S. Mangold, 'A simple framework to simulate the mobility and activity of theme park visitors,' in *Proceedings of the 2011 Winter Simulation Conference (WSC)*, 2011, pp. 3248–3260. DOI: 10.1109/WSC.2011.6148022.

[44] W. L. Li, 'Impact of waiting time on tourists satisfaction in a theme park: An empirical investigation,' in *2010 IEEE International Conference on Industrial Engineering and Engineering Management*, 2010, pp. 434–437. DOI: 10.1109/IEEM.2010.5674481.

[45] S. T. Somayya Madakam R. Ramaswamy, 'Internet of Things (IoT): A Literature Review.,' *Journal of Computer and Communications*, no. 03, pp. 164–173, 2015. DOI: 10.4236/jcc.2015.35021.

[46] 'The internet of things: Oppotunities and challenges.' (), [Online]. Available: https://www.europarl.europa.eu/RegData/etudes/BRIE/2015/557012/EPRS_BRI(2015)557012_EN.pdf. (accessed: 3.09.2022).

[47] 'Internet of things global standards initiative.' (), [Online]. Available: https://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx. (accessed: 24.07.2022).

[48] A. El Hakim, 'Internet of things (iot) system architecture and technologies, white paper.,' Mar. 2018. DOI: 10.13140/RG.2.2.17046.19521.

[49] 'Iot infrastructure guide.' (), [Online]. Available: https://www.macrometa.com/iot-infrastructure. (accessed: 4.09.2022).

[50] 'Iot architecture: The pathway from physical signals to business decisions.' (), [Online]. Available: https://www.altexsoft.com/blog/iot-architecture-layers-components/. (accessed: 4.09.2022).

[51] 'What is edge computing? everything you need to know.' (), [Online]. Available: https://www.techtarget.com/searchdatacenter/definition/edge-computing. (accessed: 3.09.2022).

[52] 'What is cloud computing?' (), [Online]. Available: https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing/. (accessed: 4.09.2022).

[53] 'Edge computing vs cloud computing.' (), [Online]. Available: https://www.macrometa.com/topics/edge-computing-vs-cloud-computing. (accessed: 4.09.2022).

[54] 'Iiot vs. iot.' (), [Online]. Available: https://www.macrometa.com/iot-infrastructure/iiot-vs-iot. (accessed: 4.09.2022).

[55] 'Ieee 802.3 ethernet working group.' (), [Online]. Available: https://www.ieee802.org/3/. (accessed: 4.09.2022).

[56] J. Tosi, F. Taffoni, M. Santacatterina, R. Sannino, and D. Formica, 'Performance evaluation of bluetooth low energy: A systematic review,' *Sensors*, vol. 17, no. 12, 2017. DOI: 10.3390/s17122898. [Online]. Available: https://www.mdpi.com/1424-8220/17/12/2898.

[57] 'Ieee standard for low-rate wireless networks.' (), [Online]. Available: https://standards.ieee.org/ieee/802.15.4/7029/. (accessed: 4.09.2022).

[58] 'Amqp vs. mqtt.' (), [Online]. Available: https://www.macrometa.com/iot-infrastructure/amqp-vs-mqtt. (accessed: 4.09.2022).

[59] 'Introduccion al protocolo coap.' (), [Online]. Available: https://www.gotoiot.com/pages/articles/coap_intro/index.html. (accessed: 4.09.2022).

[60] '¿qué es una base de datos relacional (sistema de gestión de bases de datos relacionales)?' (), [Online]. Available: https://www.oracle.com/es/database/what-is-a-relational-database/. (accessed: 7.09.2022).

[61] '¿qué son las bases de datos nosql?' (), [Online]. Available: https://aws.amazon.com/es/nosql/. (accessed: 7.09.2022).

[62] 'Turnstile.' (), [Online]. Available: https://www.offgridenergyindependence.com/articles/2649/energy-harvesting-turnstile. (accessed: 10.09.2022).

[63] '3d people counter.' (), [Online]. Available: https://megacount.io/stereo. (accessed: 10.09.2022).

[64] 'Vector 4d people counter.' (), [Online]. Available: https://www.irisys.net/products/vector4d-people-counter. (accessed: 10.09.2022).

[65] 'Rfid.' (), [Online]. Available: https://www.techtarget.com/iotagenda/definition/RFID-radio-frequency-identification. (accessed: 5.09.2022).

[66] 'What are the different types of rfid tags.' (), [Online]. Available: https://www.asiarfid.com/different-types-of-rfid-tags.html. (accessed: 5.09.2022).

[67] S. G. Kumar, S. Prince, and B. M. Shankar, 'Smart tracking and monitoring in supply chain systems using rfid and ble,' in *2021 3rd International Conference on Signal Processing and Communication (ICPSC)*, 2021, pp. 757–760. DOI: 10.1109/ICSPC51351.2021.9451700.

[68] 'Rfid zebra.' (), [Online]. Available: https://www.zebra.com/es/es/products/rfid.html. (accessed: 10.09.2022).

[69] 'Longitud de los cables uhf y máxima potencia permitida.' (), [Online]. Available: https://www.fqingenieria.com/es/conocimiento/longitud-de-los-cables-uhf-y-maxima-potencia-permitida-67. (accessed: 10.09.2022).

[70] 'Etiquetas rfid (hf, nfc, uhf) – smart labels.' (), [Online]. Available: https://www.global-tag.com/es/portfolio/etiquetas-rfid-hf-nfc-uhf/. (accessed: 10.09.2022).

[71] 'Everyone is using bluetooth low energy – should you?' (), [Online]. Available: https://www.avsystem.com/blog/bluetooth-low-energy-ble/. (accessed: 7.09.2022).

[72] 'What is a beacon?' (), [Online]. Available: https://www.beaconstac.com/what-is-a-bluetooth-beacon. (accessed: 10.09.2022).

[73] 'Quuppa rtls technology overview.' (), [Online]. Available: https://www.quuppa.com/overview/. (accessed: 10.09.2022).

[74] 'Diferentes protocolos de wi-fi y velocidades de datos.' (), [Online]. Available: https://www.intel.es/content/www/es/es/support/articles/000005725/wireless/legacy-intel-wireless-products.html. (accessed: 7.09.2022).

[75] '10 best iot platforms for 2022.' (), [Online]. Available: https://www.sam-solutions.com/blog/top-iot-platforms/. (accessed: 7.09.2022).

[76] 'What is a raspberry pi?' (), [Online]. Available: https://opensource.com/resources/raspberry-pi. (accessed: 22.08.2022).

[77] 'Aws documentation.' (), [Online]. Available: https://docs.aws.amazon.com/. (accessed: 22.08.2022).

[78] 'Parque acuático temático universal's volcano bay.' (), [Online]. Available: https://www.universalorlando.com/web/es/us/theme-parks/volcano-bay. (accessed: 13.09.2022).

[79] 'The best and worst lines to be stuck in at disney world.' (), [Online]. Available: https://www.disneyfoodblog.com/2021/08/02/the-best-and-worst-lines-to-be-stuck-in-at-disney-world/. (accessed: 14.09.2022).

[80] 'General data protection regulation.' (), [Online]. Available: https://gdpr-info.eu/art-24-gdpr/. (accessed: 14.09.2022).

[81] 'Las empresas impulsadas por datos obtienen mejores resultados.' (), [Online]. Available: https://almacenamientoit.ituser.es/noticias-y-actualidad/2020/11/las-empresas-impulsadas-por-datos-obtienen-mejores-resultados. (accessed: 14.09.2022).

Official Master Degree in Connected Industry 4.0
Universidad Carlos III de Madrid

Thesis Abstract

The main target of this project is to explore how industry 4.0 can benefit the theme park sector, focusing on the design of a system that monitors waiting times in attractions using industry 4.0 technology.