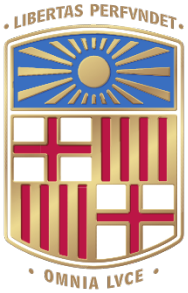

UNIVERSITAT DE BARCELONA

Final Degree Project

Biomedical Engineering Degree

Transforming Hospital Clínic de Barcelona Logistics through RFID:

An In-Depth Study of Implementation, Validation and Economic Assessment

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Abstract

Efficient supply chain management plays a critical role in intrahospital logistics. Radiofrequency identification (RFID) technology has emerged as a powerful tool to optimize the supply chain across multiple industries, including healthcare. Its application in hospitals is rapidly expanding due to its ability to automate inventory tracking, reduce human error, and improve data accuracy.

This final degree project is framed within the context of the RFID implementation project at Hospital Clínic de Barcelona (HCB), where the technology has been deployed in surgical and interventional areas. The system includes RFID tagging of high-value consumables, prostheses, and medical devices; with fixed RFID readers installed throughout operating rooms, storage areas, and waste disposal zones, and corridors.

Implementing RFID in a complex hospital environment like HCB presents considerable logistical and technical challenges. As part of this thesis, I actively contributed to the implementation process. One of the main contributions was the successful validation of the shielding paint in adjacent rooms, which effectively eliminated signal interference. Moreover, a material compatibility study identified specific packaging types that interfered with radiofrequency signal propagation, allowing for corrective measures.

Although the system is still in the final phase of implementation, early results are promising. The integrated RFID solution has demonstrated robust performance, significantly reducing non-value time spent by clinical staff on logistical tasks. An economic analysis conducted in one of the pilot sites showed a favourable return on investment (ROI), further supporting the system's viability and potential scalability across the hospital.

Key words: RFID, Intrahospital logistics, Inventory tracking, Automation, Economic analysis, System validation.

Resum

La tecnologia d'identificació per radiofreqüència (RFID) ha sorgit com una eina potent per optimitzar la gestió eficient de la cadena de subministrament. La seva aplicació als hospitals està en expansió gràcies a la capacitat per automatitzar el seguiment d'inventari, reduir els errors humans i millorar la precisió de les dades.

Aquest treball de final de grau s'emmarca en el projecte d'implementació de tecnologia RFID a l'Hospital Clínic de Barcelona (HCB), on s'ha desplegat en àrees quirúrgiques i d'intervencionisme. El sistema inclou l'etiquetatge mitjançant RFID del material fungible d'alt valor, les pròtesis i els dispositius mèdics mòbils, amb lectors RFID fixos instal·lats en quiròfans, magatzems, zones de residus i passadissos.

L'HCB és un entorn complex i presenta reptes logístics i tècnics considerables. En el marc d'aquest projecte, he contribuït activament al procés d'implementació. Una de les aportacions principals ha estat la validació exitosa de la pintura aïllant en sales adjacents, eliminant de manera efectiva les interferències de senyal. A més, un estudi de compatibilitat de materials va identificar tipus d'embalatges que dificultaven la propagació del senyal, permetent aplicar mesures correctores.

El sistema encara es troba en la fase final d'implementació, però els resultats preliminars són prometedors. La solució RFID integrada ha demostrat un alt rendiment , reduint significativament el temps que el personal clínic dedica a tasques logístiques. Una anàlisi econòmica realitzada en un dels centres pilot va mostrar un retorn positiu de la inversió (ROI), reforçant la viabilitat del sistema i la seva escalabilitat potencial dins l'hospital.

Paraules clau: RFID, Logística intrahospitalària, Seguiment d'inventari, Automatització, Anàlisi econòmica, Validació del sistema.

Resumen

La tecnología de identificación por radiofrecuencia (RFID) ha demostrado ser altamente eficiente en la optimización de los modelos logísticos. Su introducción en el sector hospitalario está creciendo y permite la automatización de los inventarios, la reducción de errores y tiempos y la precisión de los datos.

Este trabajo de final de grado se enmarca en el proyecto de implementación de tecnología RFID en el Hospital Clínic de Barcelona (HCB), con su implantación en áreas quirúrgicas y de intervencionismo. El sistema incluye el etiquetado mediante RFID del material fungible de alto valor, las prótesis y los dispositivos médicos móviles, con lectores RFID fijos instalados en quirófanos, almacenes, zonas de residuos y pasillos.

El HCB es un entorno complejo y presenta retos logísticos y técnicos considerables. He contribuido activamente en el proceso de implementación de este proyecto. Una de las aportaciones principales ha sido la validación exitosa de la pintura aislante en salas adyacentes, eliminando de manera efectiva las interferencias de señal. Además, un estudio de compatibilidad de materiales identificó tipos de embalajes que dificultaban la propagación de la señal, permitiendo aplicar medidas correctoras.

A pesar de que el sistema se encuentra aún en la fase final de implementación, los resultados preliminares son prometedores. La solución RFID integrada ha demostrado grandes cambios, reduciendo significativamente el tiempo que el personal clínico dedica a tareas logísticas. Un análisis económico realizado en uno de los centros piloto mostró un retorno positivo de la inversión (ROI), reforzando la viabilidad del sistema y su escalabilidad potencial dentro del hospital.

Palabras clave: RFID, Logística intrahospitalaria, Seguimiento de inventario, Automatización, Análisis económico, Validación del sistema.

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1 Introduction

1.1 Motivation and aim of the project

The world is constantly experiencing technological evolution, transforming the way we live and work. A proof of that is the Internet of Things (IoT), a concept referring to the connection of physical objects to the internet, enabling them to be searched, tracked, and interacted with [1] to make industries smarter and our lives more efficient. Innovations in different fields have vastly improved the efficiency of processes across industries. Those advancements, indeed, are driven by the identification of challenges or weak points and the development of strategies to address them.

One of the areas where efficiency plays an important role is logistics and inventory management. Ensuring that the right items are available in the right place at the right time is fundamental for operational success, although it is also complex. Poor inventory visibility, misplacement of items, overstocking, or delays in restocking can result in significant financial losses, supply shortages or excess inventory, as well as reduced service quality.

In the healthcare context, these risks are particularly critical. Hospitals are inherently complex due to the constant movement of patients, healthcare professionals, consumables, and medical equipment. Therefore, efficient tracking and coordination are essential, especially in areas like surgical and interventional units, where workflows must be optimized to ensure quality care and resource availability.

Over time, significant advancements to improve inventory management and logistic procedures have been seen in the industrial sector, but the healthcare field has lagged behind. Radio Frequency Identification (RFID) is a technology capable of greatly improving supply chain efficiency and inventory control. It consists of a wireless automatic identification system that uses radiofrequency (RF) waves to detect and track tagged objects, people, and animals. This technology allows simultaneous reading of multiple tags at a distance without direct line of sight, enabling real-time monitoring and automated data collection. Given its advantages, it has been widely adopted across numerous industries such as retail, automotive, construction, warehousing, and farming [2]. In healthcare, RFID is also present, although it is more commonly applied in specific areas such as medication tracking or patient identification, rather than being fully integrated into hospital-wide logistics systems. Many hospitals still rely on manual processes, which are highly time-consuming and prone to human errors and delays. This often leads to inaccurate tracking of medical supplies in real time, irregular execution of inventory, and increased operational costs, compromising both efficiency and patient safety.

The Hospital Clínic de Barcelona (HCB) is a tertiary public university hospital with more than a century of history, composed of fifteen institutes and specialized areas. It operates across three main campuses: Villarroel, Maternitat, and Plató. Altogether, HCB has over 40 operating rooms, 800 inpatient rooms, and 4500 professionals, supporting a high volume of clinical procedures daily. To manage this complexity, the

hospital uses SAP, an enterprise resource planning system that centralizes hospital data and provides access to workflows, inventory, and logistics operations.

In an effort to modernize its internal logistics model, HCB has recently developed a large-scale project to implement RFID technology in its surgical and interventional areas. The project focuses on automating the management and control of high-tracking consumables, implants, and medical equipment using RFID. Its goal is to create a fully traceable supply chain, from suppliers, through the central warehouse in Cornellà, to hospital centres and ultimately patient care. As a result, this initiative aims to improve inventory accuracy and consumption tracking, enable real-time asset localization, and reduce the time nursing staff spend on administrative tasks.

The motivation for this thesis arose from the opportunity to be involved in this transformative process. As a biomedical engineering student, I strongly believe in the importance of using new technologies to develop smart solutions that improve our daily lives, especially in fields that directly affect people's well-being, such as healthcare. Being a student at the University of Barcelona, which is associated with Hospital Clínic de Barcelona, gave me the opportunity to become familiar with the hospital's structure, workflows, and needs.

Through this work, I aim to highlight some practical challenges and solutions involved in adopting RFID in healthcare logistics, as well as analysing the profitability of the implantation. Therefore, providing a practical case study that may serve as a reference for future applications in similar contexts.

I took part in the project in a multidisciplinary role, collaborating with both the Infrastructure and Biomedical Engineering, and the Strategy and Planning Directorate departments. My contributions ranged from technical validations and material compatibility tests to supporting the definition of tasks in the implementation of the project and conducting an economic analysis.

1.2 Objectives

The main objective of this project was to support and analyse the implementation of an RFID system at HCB to improve the intra-logistics model, enhancing operational efficiency for healthcare staff and ensuring better care for patients. The specific objectives included:

- To validate the RFID technology on-site
- To identify RFID-incompatible envelope materials
- To validate the shielding paint
- To perform an organised structure of tasks required to carry out an RFID implementation in a hospital setting
- To conduct an economic analysis of implanting the RFID system

1.3 Limitations

The nature of the hospital environment and the specific context of this project presented several limitations.

In the first place, this project was developed within a seven-month undergraduate thesis, which restricted the possibility of conducting extended validation cycles or long-term monitoring of the RFID system's performance after its full deployment.

Moreover, my involvement took place during the final stages of the pilot implementation at Plató and the initial phases at the Villarroel centre. Consequently, some conclusions are based on preliminary tests, observations, and documentation, rather than on complete operational data after deployment.

In addition, given the large scale of the RFID implementation and the time constraints of this thesis, it was only possible to perform the technical validation of the RFID technology in one interventional area at the Villarroel site. However, the validation method is consistent across all hospital areas.

Finally, since this thesis concluded before the RFID system was fully deployed throughout the hospital, post-implementation data regarding time savings, logistic improvements, or efficiency gains are only available from the pilot site.

Despite these limitations, this work contributes meaningfully to both the technical validation and organizational readiness required for a large-scale RFID system implementation in a complex hospital setting.

1.4 Scope

I joined the hospital's project when the pilot stage was concluded and the deployment at the central headquarters was beginning, which allowed me to be directly involved in both technical and organizational aspects of the system's implementation. The completion of this thesis coincided with the final phases of the HCB's project, when the implemented RFID system was entering its validation phase.

To address the defined objectives, the scope of this project was divided into two main locations, corresponding to the pilot site and the central hospital headquarters.

Plató (Pilot Site)

At Plató, where the system was already installed during a pilot phase, my work focused on testing and validating specific technical aspects that emerged during post-implementation evaluations, as well as performing an economic analysis based on real operational scenarios. This included:

- Assessment of RFID-incompatible packaging materials: I identified envelope materials stored in the surgical storage room that interfere with RFID readability. I evaluated their impact on system performance and documented potential alternatives, although these alternatives were not implemented as part of this project.

- Validation of electromagnetic shielding paint: I verified the effectiveness of the shielding paint applied between a waste disposal zone and an adjacent surgical area. This included reviewing the paint's components and evaluating its role in preventing cross-readings between the two rooms.
- Economic analysis: I performed a cost-benefit analysis of the pilot implementation, using staff time savings provided by the hospital's Directorate of Strategy and Planning.

Villarroel (Central Headquarters)

At the Villarroel site, where the RFID system was in its implementation phase, my contributions centered on understanding the real hospital environment, supporting task coordination, and assessing the technical validation of the technology. This included:

- Field observation: I participated in visits to those hospital areas where RFID was being implemented to observe how the system integrates with existing infrastructure and adapts to real clinical workflows.
- Organizational task structuring: based on a predefined list of tasks, I contributed by organizing them into structured, clear blocks.
- Technical validation of the system: I conducted a complete validation of the RFID system within the DIVAS unit of the hospital, covering four interventional rooms and their storage area. This included testing tag detection across different zones and confirming correct tag consumption through RFID waste bins.

2 Background and Theoretical Framework

2.1 Hospital logistics

Supply chain management (SCM) refers to the coordinated planning and execution of activities involved in delivering the right products, in the right quantity, at the right time. This includes every step of the supply chain, from raw material acquisition to the distribution of finished goods to end users [3]. A large number of participants are involved in this process, including suppliers, manufacturers, distributors, providers, and customers [3].

Within this context, hospital logistics focuses on the internal management of all activities regarding medical resources within a healthcare facility. This is hugely delicate due to the critical nature of its operations and the high cost of medical supplies and equipment. Maintaining the balance between minimizing expenses and ensuring continuous product availability for patient care is a challenge.

Many hospitals still rely on manual processes to manage inventory, physically counting items in storage areas and placing orders when stock levels fall below a predefined threshold. These methods are not only prone to human error but also highly time consuming. In fact, logistics activities represent over 30% of a hospital's total costs [4].

The healthcare sector has lagged behind in adopting advanced technologies and optimization strategies to improve supply chain management compared to other industries [4,5]. This is due to its operational sensitivity, where even minor mistakes can result in serious clinical consequences, along with regulatory issues [5] and a lack of hospital engagement management in the past, as these activities have often been viewed as secondary to patient care [4]. Consequently, logistics and materials management have traditionally received little attention in healthcare planning, despite their significant financial and operational impact.

However, in recent years, growing awareness of these challenges has led to research of new strategies to improve operational efficiency and reduce waste. Some of the approaches to enhance supply chain efficiency include surplus planning, forecasting with optimization algorithms, and the implementation of technologies such as RFID [5]. This technology is gaining huge attention in hospital logistics to keep better track of inventory, reduce human errors, and obtain real-time data.

2.2 Conceptual basis: RFID technology

Radiofrequency identification (RFID) is an automatic wireless technology designed for efficient product identification. It employs radio waves to detect targets, read their data and store the associated information, enabling the identification of objects, animals, and people [6,7]. This system offers significant advantages over traditional identification bar code systems. In the first place, RFID enables the identification of product labels from a distance, eliminating the need for a direct line of sight and enhancing the operational efficiency [8]. Furthermore, this capability facilitates the simultaneous identification of thousands of products, hugely decreasing the time required for the process and making it highly effective. Unlike

barcodes, which store more limited information and require human intervention for scanning, RFID tags are specific for each item and offer greater accuracy and automation [9].

RFID systems consist of a tag, an antenna and a reader, connected to a software that manages the identified data and a database that stores it. The information related to an item is contained within the tag. The RFID reader emits a radio frequency signal, which is amplified by the antenna over a specified coverage area. Upon receiving this signal, the tag transmits its stored information back to the reader, enabling data to be captured and sent directly to the associated software for processing [10,11].

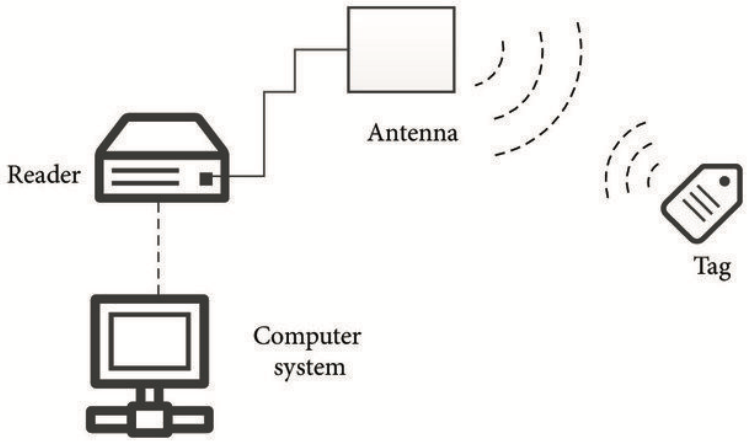

Figure 1: RFID system functionality [12].

2.2.1 Operating frequency

This technology can operate at different frequency bands, which refer to the specific radio frequency ranges used to receive and transmit data. The three mains used include low frequency (LF), high frequency (HF), and ultra-high frequency (UHF) [6]. Each of them offers specific characteristics that make them more suitable for certain application depending on factors such as reading range, data transmission rate, and environmental conditions.

LF operates between 125 and 134 kHz, with a close-range reading range typically within 10 cm and less than 1 meter. It uses near-field coupling, which is generally based on data exchanges between magnetic fields, making the system function in the presence of metals and liquids. Although data is stored at a small amount and transmitted at a slow rate, it has strong penetrating ability and little interference from the outside world [6]. Applications include animal tracking, ticketing or access control systems [7].

HF systems operate at 13.56 MHz, also working with near-field coupling and reaching read distances of up to 1 meter [6]. They are commonly found in

applications like small item management, library book tracking, and contactless payment systems.

UHF band criteria changes depending on the continent and some countries, ranging from 860 MHz ~ 960 MHz. In Europe, it operates at a range of 865 MHz to 868 MHz. These systems generally use far-field electromagnetic coupling, specifically the backscattering principle, which allows them to achieve longer reading distances, typically ranging from 2 to 12 meters or more [6]. It enables faster data transmission and reading multiple tags simultaneously, making it well suited for supply chain, large item management, and vehicle identification. However, UHF tags are more sensitive to interference caused by metals and liquids.

2.2.2 System components

RFID tags

RFID tags are attached to target objects for its identification and have a unique identification number. They store associated data which is transmitted to the RFID reader during communication. RFID tags are composed of two fundamental components:

- A chip or integrated circuit (IC), which is a microprocessor that manages important functions such as decoding, decrypting, and error checking. It contains a memory unit which stores the information associated with the tagged object, as well as the Electronic Product Code (EPC), a unique identifier that distinguishes each physical item. Depending on the application, RFID chips can have different types of memory: Read-Only, programmed during manufacturing and cannot be altered; Write-Once, Read-Many (WORM), which allows data to be written once and read multiple times; and Read/Write, which permits data to be modified multiple times [13].
- An antenna made of a conductive material which allows the tag to receive and transmit signals, acting as the transceiver. It is connected to the chip and its design determines the frequency at which it operates.

They are both contained in a substrate, which is typically made of a flexible material, such as plastic or polymer, designed to resist several environmental conditions.

Based on its power source, these tags can be classified into active, semi-active and passive [6,14].

Passive tags do not contain an internal power source, they rely on the radio wave emitted by an RFID reader which powers the chip [15]. When the reader emits the signal, the antenna in the tag captures its energy momentarily to power the chip. Then, the integrated circuit sends back the stored data to the reader. These tags have small dimensions and weight, as well as low cost and long life since they do not use batteries. However, their reading range is shorter and depends on the strength of the reader's signal. Passive tags are usually the most affordable option, with prices ranging from a few cents to around one euro, depending on the size and features.

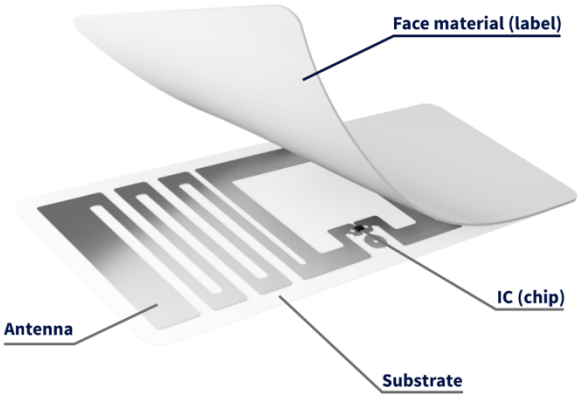

Figure 2: Components of an RFID tag [16].

Active tags, on the other hand, have their own power supply, usually in the form of a battery, allowing them to interact continuously and autonomously with their environment so that their signal can be captured by a reader. These tags offer a longer reading range and can store more information than passive tags. Nevertheless, the power supply shortens the lifespan of active tags, as their batteries eventually require replacement. It also results in larger tag sizes, and generally, they are more expensive than passive tags.

Semi-active tags include a battery which only powers the chip and not the signal transmission, requiring RFID readers to emit electromagnetic waves in order to establish communication. Since the battery is not in continuous use and only activates when a signal is received, it remains inactive most of the time, causing the tag lifespan to be longer compared to active ones. They offer greater range and data capacity than passive tags but are cheaper and smaller than active ones. Furthermore, some of them can integrate sensors.

RFID tags are available in a wide variety of shapes and sizes, having different functionalities and making them suitable for multiple applications.

RFID readers

RFID readers enable the identification of tags, and the execution of data read and write operations. These devices not only determine the operating frequency of the entire RFID system but also serve as the power source for passive RFID tags [17]. Consequently, the output power of the reader is essential for defining the effective communication range between the tags and the reader. The main components of an RFID reader include the control unit and the radiofrequency interface [18].

On the one hand, the control unit is typically managed by a microprocessor, which handles command processing, communication protocols, data encryption, and signal coding and decoding. It also includes anti-collision ability to read several tags simultaneously, and user interface control [17]. On the other hand, the reader generates radiofrequency signals to power and activate the tag, and demodulates its received signal [18]. For effective communication, both the reader and the tag must operate within the same frequency band [17].

RFID readers can be fixed and handheld.

Fixed readers are generally larger, stationary, and more powerful. These are often installed in settings in which continuous, automated scanning is necessary, such as medical logistics and retail security gates. In the UHF band, fixed readers can achieve reading distances between 15 and 20 meters, while in the HF one, their range is limited up to 1 meter.

Figure 3: Fixed RFID reader [19].

Handheld readers are smaller, wireless, and portable, typically powered with a battery. These offer greater flexibility, allowing the user to move freely and scan tags in different locations. However, their reading range is shorter than fixed readers. Approximately, the UHF band achieves up to 5 – 7 meters, and the HF band up to 1 meter.

Figure 4: Handheld RFID reader [20].

RFID antennas

In RFID systems, antennas are always linked to a reader. They are very important components that make communication with passive tags possible. Depending on the reader, the antenna can be integrated or external. The second option is widely used in large-scale scenarios, offering the possibility of placing multiple antennas throughout a target area and connected to the same reader. RFID antennas act as bridges between the tag and the reader, enabling two-way data transmission. When

a tag enters the reader's detection zone, impedance changes between the tag's chip and its own antenna occur due to the interaction of the incoming RF signal, influencing how the signal is transmitted back to the reader [21]. The antenna captures this reflected signal and sends it to the reader for interpretation.

Three key design characteristics determine the effectiveness of the RFID antenna: operating frequency band, gain, and polarization.

In the first place, antennas are optimized for specific frequency bands, which must match the operating frequency of the RFID system to ensure reliable communication. Common configurations include stacked structures, dipole-type designs, and microstrip antennas. Another critical parameter is the gain, as it directly impacts the reading range and the accuracy of tag detection. By maximizing gain, antennas can achieve broader coverage with lower power consumption, making them highly efficient. Finally, since tags are often placed without orientation control and are usually linearly polarized, RFID antennas typically employ circular polarization. This ensures consistent communication regardless tag orientation. This type of polarization is achieved by generating two electromagnetic waves with equal strength and a phase difference of 90º [18].

Figure 5: RFID antenna.

Middleware

From a computing perspective, middleware refers to any software that facilitates communication and data exchange between different computer systems [22]. In RFID systems, the middleware is the software that connects the hardware to enterprise applications [23], ensuring that the collected data integrates with the existing IT infrastructure. It plays a crucial role in system management by processing the large volume of information received from RFID tags. Through programmed logics, the middleware filters, aggregates and stores this data for its further use in specific business applications [23]. It transforms raw tag readings into structured, meaningful information for decision-making or business operations.

2.2.3 Applications

Given its advantages, RFID technology has been adopted across multiple industries for different applications, such as libraries, retail, agriculture, and healthcare. In the healthcare sector, RFID offers a wide range of applications.

- Patient tracking: By assigning RFID wristbands, healthcare professionals can identify patients during their stay, making it possible to locate them instantly in case of an emergency, as well as ensuring the right patient receives the right treatment at the right time. This is of special importance for patients who are disoriented, unconscious, or have movement restrictions.
- Medical record management: RFID can also be integrated into both physical files and digital platforms for medical record management. This enables fast retrieval of sensitive information and ensures that patient data is handled efficiently.
- Sample identification: Biological samples, such as blood bags, or biopsy specimens, can be tagged with RFID to ensure accurate identification and prevent mix-ups. It improves workflow in laboratories and guarantees samples are correctly matched with patient records, reducing diagnostic errors.
- Supply chain management: one of the most important applications in terms of time savings within the hospital is inventory and supply chain management. Hospitals rely on a great number of consumables which can be automatically tracked using RFID. This improves stock control, prevents shortages, and helps reduce waste by enabling better forecasting and expiration date monitoring.

2.3 RFID limitations in the hospital setting

Despite all the improvements that RFID can bring to hospitals, there are also downsides that need to be taken into account. One of the most significant barriers to the adoption of this technology is the financial cost [24]. The required initial investment includes purchasing hardware and software, making infrastructure modifications in some cases, covering maintenance, and undergoing organizational changes. Although costs have decreased over the years, it can still represent a significant investment, especially for small healthcare facilities.

Moreover, signal interferences and RFID tag misreadings may occur when placed too close to conductive materials such as metal objects and liquids [25], as these surfaces reflect electromagnetic waves and disrupt tag performance [26].

Another important consideration is data privacy and security, particularly regarding the risk of unauthorized access to sensitive health information. Is essential to ensure encrypted communication between tags, reader, and systems to prevent data misuse and violation of regulations [27].

Furthermore, RFID system interoperability with the hospital's preexisting IT infrastructure can also be a barrier. They were not originally designed to support integration with tracking technologies, which makes interoperability difficult and increases complexity [28].

2.4 State of art

Over the past decade, RFID technology has been increasingly adopted in healthcare supply chains. One of the key reasons behind this growing adoption is the versatility of modern RFID tags, which are available in multiple shapes, sizes, and materials, enabling them to be attached to a wide range of objects.

Technological advancements have increased the reliability of RFID systems. One notable improvement addresses the interference issue caused by metallic surfaces. Metallic materials reflect electromagnetic signals, which can affect the communication between readers and tags. New on-metal RFID tags incorporate insulating materials and redesigned structures that allow

Recent advancements have expanded the capabilities of RFID tags. Metallic surfaces interfere with RFID signal transmission by reflecting electromagnetic waves, which can reduce performance. To overcome this, new designs incorporate insulated layers and redesigned structures that allow for efficient operation even when placed directly on metal objects [29].

In parallel, chipless RFID tags are a promising alternative to traditional systems. Unlike conventional RFID tags, which contain integrated microchips, chipless versions rely on materials such as conductive polymers or specially engineered surfaces that reflect specific radio wave patterns [30]. These tags encode information in the physical properties of the material itself, eliminating the need for costly microelectronics. Their main advantage is their manufacturing simplicity and cheaper price, making them suitable for large scale inventory tracking, consumables, and real-time monitoring applications [31].

Another important achievement in RFID systems is the development of RFID tags with integrated sensors. They not only identify and locate objects but also monitor environmental or physical conditions- Many of these sensors can operate passively, without a battery, capturing energy directly from the signal of the RFID reader. This allows for continuous tracking of parameters such as temperature, pH, humidity, pressure, and material stress [32]. In the context of hospital logistics, this is highly beneficial, for example, ensuring that medications which are sensitive to temperature are stored correctly, or detecting micro damages in high-value medical equipment.

At the software level, RFID middleware platforms have become more sophisticated over time. They now support advanced logic to interpret data according to specific hospital workflows and can integrate in real-time with hospital information systems (HIS) and enterprise resource planning (ERP) platforms. Importantly, to ensure data security, the connection between the RFID middleware and the hospital systems is designed to be on-directional, meaning the RFID software does not access sensitive patient information.

In recent years, there has also been notable progress in combining RFID with artificial intelligence, especially through deep neural networks. Research initiatives are exploring how AI algorithms can progress large volumes of RFID data to identify patterns, predict stock shortages, optimize item placement, and detect anomalies in

movement or usage. Early results suggest that this integration enhances operational intelligence and decision-making capabilities in hospital logistics [33].

Numerous pilot projects in hospitals around the world are currently exploring the use of RFID to streamline supply chain operations. These initiatives focus on tracking critical assets, reducing inventory errors, and preventing equipment loss. While some institutions remain cautious due to uncertainties around return on investment (ROI), early results have been highly promising. In fact, a growing number of hospitals are moving beyond pilot stages and fully integrating RFID systems into their daily logistics operations, reporting increased efficiency and cost savings.

2.5 State of the situation: HCB

2.5.1 System

Before the introduction of RFID technology, inventory management at HCB relied heavily on manual processes and departments. This involved counting inventory items one by one, manually registering used products as consumed, placing orders by hand, and other similar tasks, most of which were carried out by nursing staff, taking time away from clinical or patient care activities.

With the implementation of UHF RFID, HCB has remodeled its internal logistics system, enabling real-time stock visibility, automatic consumption tracking, reduced workload related to administrative tasks, and standardization of materials per surgical procedure. The hospital's project focuses on high-tracking consumables, prostheses, and medical equipment, particularly within operating rooms and interventional areas.

The RFID technology at HCB was provided by Dipole RFID and it includes a complete system, from physical tag placement to data processing and integration with the hospital's management and information systems.

Hardware

RFID readers are installed to detect the location of tagged items in real time. Each reader (Impinj R700) can connect up to four antennas via a certified UTP LAN network with Power over Ethernet (PoE), allowing data and power transmission through a single line.

In addition to fixed readers, handheld RFID readers are also used for on-site tasks such as inventory control or tests. These portable devices consist of three components: an RFD40 UHF sled, a TC21 touchscreen mobile, and a charging base, all manufactured by Zebra Technologies.

The antennas used at the hospital are Laird circularly polarized models, offering volumetric coverage to capture signals from multiple directions. Optimal antenna placement is crucial to guarantee accurate tracking and the overall effectiveness of the RFID system. Each location is chosen based on workflows, infrastructure, and layout of the area:

- Operating and interventional rooms: in most operating rooms and interventional areas, four antennas are strategically located to track material and asset flow (entry, usage, and exit). Their placement accounts for elements such as the patient bed, robotic arms, and doorways to optimize signal coverage and minimize interference with other areas. In these rooms, antennas are placed inside protective casings made of medically approved materials, not only to maintain hygiene and safety in the operating room but also to protect the hardware from environmental factors.
- Storage rooms: antennas are positioned at entrances and exits. In larger storage rooms, additional antennas are installed within the space to track internal movement and enhance tracking accuracy.
- Waste disposal areas: an antenna is installed in these zones to ensure accurate detection of discarded items. Selecting proper locations is critical to avoid erroneous readings from nearby zones and to ensure waste products are correctly registered as consumed.
- Hallways and in-outs: antennas in hallways track asset movement between rooms and help determine if a device has exited or entered a unit, along with the time and date. This is especially important for mobile medical equipment.

RFID printers are used to generate RFID tags with encrypted data. Most medical products are labeled at the external warehouse; however, the hospital uses these printers to label all untagged items arriving to the medical units untagged.

All RFID tags used follow the UHF Gen2 ISO 18000-63 standard and are categorized based on their application:

- Type 1 tags: used for high-tracking consumables and feature a permanent adhesive.
- Type 2 tags: specifically designed for electromedical devices, compatible with metal surfaces.
- Type 3 tags: used for prostheses and come with a removable adhesive.

In addition to the generally applied hardware, two components were also installed at HCB due to its specific needs:

- Desk reader for prostheses: a desktop reader with a circular antenna is placed under the nursing table in each operating room. It allows medical staff to scan prostheses immediately after use and register all data from the product as these are high-cost and regulated medical products. Apart from the specifications of the item, this reader ensures accurate recording of time, date, and OR location. Once data is received by the hospital's IT system, it is automatically associated with the corresponding patient.
- RFID-enabled waste bins: in operating and interventional rooms without separate exits for waste disposal, RFID-equipped waste bins facilitate effective tracking and management of discarded items. These bins help prevent errors in consumption registrations that may occur when unused supplies and waste share the same entry and exit routes.

Software

Each reader uses an embedded software to filter and preprocess data, minimizing the volume of information transmitted. The software operates in three layers:

i. Dipole Connect: Each reader first runs a Linux-based system to apply basic logic to clean up duplicate or incorrect readings. This data is then sent through the local network to the Control Service.
ii. Control Service: This layer ensures all readings are properly delivered to the central system and verifies there are no information losses.
iii. Logic Service: The last service processes all data by applying logic rules which are specific for each area or workflow within the hospital. Validated data is then sent to the middleware, which serves as a bridge between the RFID system and the hospital's information systems (ERP-SAP).

HCB information system

ERP-SAP manages critical information such as patient records, surgical planning, and inventory. Received data from the middleware is integrated so that the system can take automated actions based on the hospital's needs. For instance, to generate automatic replenishment orders through the MRP (Material Requirements Planning) tool when stock levels fall below a predefined threshold.

2.5.1 Implementation phases

The RFID at HCB was implemented progressively in phases across different sites. Initial pilot deployments were carried out at the two smaller facilities, Maternitat, which includes 7 operating rooms, and Plató, equipped with 10 interventional and surgical rooms. These pilots aimed to assess the feasibility, performance, and integration of RFID technology within real hospital workflows.

Following this successful testing phase, the project was scaled up to Villarroel, the major hospital campus, where the system has been deployed across different departments. Currently, the project is at its final stage, the technology has been installed in the majority of the targeted clinical areas and is undergoing final validation processes prior to its complete operational initiation.

3 Market analysis

3.1 Market evolution

RFID first emerged during World War II, militaries used a radiofrequency identification system to detect from a distance whether a plane was “Friend or Foe” [34]. Afterwards, research about this technology was done and in 1973 Mario W. Cardullo received the first patent for an active tag. Nevertheless, it was not until 1983 when Charles Walton officially patented the term RFID [35]. Since then, radiofrequency identification has seen rapid growth across many industries, transforming processes to improve efficiency and safety. In the early 2000s RFID started to get attention from the healthcare sector. Hospitals started implementing RFID pilot plans for patient tracking, drug identification, inventory management, and infection control [36].

An important milestone in the advancement of RFID technology was the creation of a global standard that allowed for consistent item identification across industries. The Auto-ID Center started this initiative by developing standardized frameworks for RFID components (hardware and software), which began operating in 2003 after being transferred to EPCglobal [37]. The result was the establishment of Electronic Product Code (EPC), a unique identifier used to distinguish individual products rather than just categories. These standards have been widely adopted across industries since then, including the healthcare sector, where the integration of RFID technology has been gradual. However, over the years, it has been implemented across various areas and applications. According to the IDTechEx report “RFID in Healthcare 2006-2026”, global expenses on RFID in the healthcare sector increased significantly, from $90 million in 2006 to $2.1 billion in 2026 [38].

Nowadays, RFID is used in numerous healthcare settings, not only in hospitals, but also in pharmaceutical companies, biotechnology firms, clinical laboratories, and specialized centers such as blood banks and oncology units. These institutions adopted RFID to track medical equipment, monitor biological samples, identify patients, manage inventory control, and ensure proper drug administration, among many others. The growing presence of RFID in the healthcare market is driven by its numerous benefits, primarily centered on improving patient safety, real-time tracking, optimized workflows, operational cost savings, and reduced human error.

Recent technological advancements, including more durable and sensitive RFID tags, improved accuracy, and integration of artificial intelligence, have further expanded its possible cases of use. Although many healthcare facilities still rely on paper-based processes and traditional methods, an increasing number of centers are recognizing the benefits of moving toward digitally integrated systems, where RFID plays a growing role in enabling safer, more efficient, and cheaper healthcare delivery.

According to Precedence Research [39] and InsightAce Analytic [40], the global RFID market in the healthcare sector was valued at approximately USD 7 billion in 2024. It is expected to grow at a compound annual growth rate (CAGR) of around

17% between 2025 and 2034, reflecting the increasing adoption of this technology in the healthcare system worldwide.

In Spain, the healthcare sector is rapidly embracing RFID technology to enhance efficiency, patient safety, and digital transformation. The market is expected to grow significantly, driven by hospital needs inventory control, equipment tracking, and medication management. As adoption expands across Spanish hospitals and other healthcare facilities, RFID is becoming an innovative tool for reducing errors, optimizing workflows, and modernizing Spanish healthcare. The market is projected to grow at a CAGR of approximately 9% between 2025 and 2035 [41].

3.2 Main players

The RFID market is supported by a large number of specialized providers offering hardware, software, and integrated solutions tailored for different industries, including healthcare. Zebra Technologies [42] is one of the most prominent companies in the field, with over 50 years of experience. In 2008 they launched the industry's first mobile RFID printer-encoder, marking a milestone in portable identification and tracking. The enterprise provides a wide range of RFID solutions used in hospitals for patient identification, asset tracking, and inventory control.

Impinj [43], another U.S. based company, is a leading member of the RAIN RFID alliance, an industry group that promotes the adoption of UHF passive RFID on the EPC Gen2 standard. They enable fast, long-range, and battery-free identification of items. The company has significantly contributed to the scalability and efficiency of RFID deployments in complex environments such as healthcare facilities.

Avery Dennison [44] is a materials science and digital identification solutions company operating globally. In the RFID healthcare field is known for its expertise in developing specialized applications such as medical wearables, wound care, and pharmaceuticals. They support item-level traceability and improve patient safety by ensuring precise and timely access to medical products.

Alien Technology [45], recognized as one of the 50 most promising IoT solution providers in 2016, is a pioneer in UHF RFID solutions. They offer a broad range of RFID chips, tags, inlays, and readers, as well as professional services for multiple industries. Its technologies are particularly valuable in healthcare applications such as inventory management, patient tracking, and asset logistics.

In the European market, NXP Semiconductors is a key global player in secure RFID technologies headquartered in the Netherlands. The company develops integrated solutions for various healthcare applications, including tracking tools and treatments, verifying patient identity, and keeping tabs on blood and tissue products [46].

Dipole [47], a Spanish company with more than 20 years of experience, offers customized RFID solutions for different types of industries including healthcare. It provides a wide range of RFID tags, readers, antennas, and its software platform Dipole Connect, which simplifies system deployment and real-time traceability.

Together, these key players along with many other specialized providers, are developing innovative RFID solutions to address the specific needs of the healthcare sector.

3.3 Global Trends and Real-World Applications

Among all types of healthcare institutions, hospitals account for the largest share of the RFID market. This is mainly due to their high volume of patients and the need to release healthcare professionals from non-clinical tasks. In terms of product types, RFID tags represent the most significant component of the market. Their versatility, low cost, and ability to be attached to a wide range of products make them essential to healthcare applications.

Globally, North America holds the leading position in the RFID healthcare market, with the United States representing the dominant force. This is supported by strong investments in healthcare technology, a powerful digital infrastructure, and early adoption by the sector. However, the Asia Pacific region has been and is expected to continue experiencing the fastest growth in the RFID healthcare market. Countries such as China, India, and South Korea are rapidly incorporating this solution to modernize their healthcare facilities [39].

3.4 Real-World cases

The following cases are examples of hospitals which are currently using the RFID technology in some point of their supply chain with the aim of improving their logistics model.

Hull University Teaching Hospitals NHS Trust (UK)

In the intensive care unit, there were persistent challenges locating medical equipment as patients were transferred between departments. This caused delays in procedures and inefficient use of staff time. To address this issue, the hospital launched a pilot by the side of Zebra Technologies to adopt RFID technology that allowed them to continuously monitor the location of vital equipment. Positive results made the hospital to extend the solution to its two main clinical campuses, Hull Royal Infirmary and Castle Hill Hospital, where it estimates an annual saving of 87,500 hours of clinical staff time. [48]

University of Tennessee Medical Center (USA)

UT Medical Center identified inefficiencies in its surgical supply chain. Staff often left the operating room during interventions for nearly 11 minutes per case on average to get necessary supplies, causing workflows interruptions and increasing the risk of infections in the surgical room. Additionally, the hospital needed better tools to track stock levels, consumptions and physician preference cards. The solution was to deploy an Impinj RAIN RFID system to tag each surgical item. When

discarded in a specific bin, those tagged products are automatically captured by near field antennas and registered to information systems of the hospital to proceed with billing and inventory. The hospital obtained significant improvements with the adoption of this technology, reducing the time of medical personnel managing supplies and increasing operational efficiency. [49]

Hospital General Universitario Gregorio Marañón (Spain)

The hospital identified a need to reduce the burden of logistical and administrative tasks on clinical staff. They aimed to improve the efficiency of supply chain processes, while ensuring all necessary medical materials were available at the location and time needed for patient care. To address this, the hospital deployed a pilot program in 2022 using RFID technology in its Hemodynamic Unit. Given positive outcomes, the hospital is planning to progressively expand the RFID system to other departments and surgical areas. [50]

Hospital Universitario Torrecárdenas (Spain)

This Andalusian hospital sought to improve the traceability and management of surgical items, ensuring full control from reception to consumption. An important challenge was achieving secure and bidirectional integration between hospital systems and automate inventory control for critical medical supplies. For this reason, in 2025, the hospital installed 18 RFID smart cabinets capable of tracking all movements (entries, withdrawals, and returns) and registering time, date, and person responsible for each action. This implementation led to improved operational efficiency, real-time traceability of surgical implants, reduced administrative errors, and regulatory compliance, ultimately enhancing patient safety. [51]

Hospital Clínic de Barcelona (Spain)

HCB had previously explored RFID technology through tests involving the use of RFID wristbands for patient identification and RFID cabinets for managing medical supplies. This year, HCB has become one of the first hospitals in Spain to implement a complete RFID system across its entire infrastructure, including its two external centers, Maternitat and Plató, which served as pilot sites. The new system enables automated management and control of consumables, prosthetics, and hospital assets using radiofrequency identification. Early results have been highly positive, with initial estimates indicating a 63.3% weekly time saving under the new logistics model.

4 Concept Engineering

This section presents the different approaches considered for carrying out the tasks of this work. Each option is described and compared in terms of efficiency and suitability within the hospital context, helping identify the most appropriate method for each activity.

4.1 Identification of RFID-incompatible envelopes

In the implementation of the RFID system, a tag is placed on the surface of the packaging for all consumable materials and prosthetic devices. However, certain envelope materials are made out of metallic components, which, as explained in the theoretical framework, are not compatible with RFID technology since radiofrequency waves cannot propagate through them. Since Type 1 tags, used for consumables, and Type 3, for prostheses, are not protected nor designed to be used on these critical envelopes, RFID readers cannot detect those items correctly. This leads to misreading issues and, consequently, inaccurate inventory management.

To address this problem, it is necessary to conduct tests and identify which envelopes cause problems. Different approaches are described below:

i. Material-based screening

The first method involves gathering a complete list of the materials used in the packaging of all consumable materials and prostheses. Once this information is obtained, a preliminary analysis is conducted to identify materials that are potentially problematic for radio waves transmission based on literature. This step serves as an initial screening to narrow down the number of items requiring further testing. After identifying the critical materials, physical measurements are performed on the selected envelopes to confirm whether they block RFID signal propagation. The main drawback of this approach is the time it requires not only to collect information about envelope materials from different suppliers, but also to analyse each of them and select those that might be problematic.

ii. Visual inspection

The second approach consists in directly examining the physical packaging rather than relying on manufacturer-supplier material data in the first place. It begins with a thorough visual inspection of all existing envelopes to identify those that are likely to cause RFID interference. Once these potentially critical packages are selected, tests are performed to measure their impact on signal transmission and confirm those envelopes that weaken or obstruct RFID signals. This method offers an efficient and quicker way to identify problematic packaging while only requiring material specifications for the selected problematic envelopes, rather than for all items from suppliers. However, there is a risk of overlooking some problematic envelopes, which could lead to future reading failures due to envelope blocking and the need to repeat the tests.

iii. Inventory mismatches

The third option focuses on detecting problematic packaging by analysing inconsistencies between the hospital's digital inventory provided by the middleware and real stock levels. If certain items consistently fail to appear in the system despite being physically present, it could indicate that their envelope is interfering with RFID signal transmission. To confirm this, a manual inventory count is performed to check that the software records match with the actual stock. Once discrepancies are identified, only the problematic packaging materials need to be analysed, requesting material details from suppliers only for confirmed cases. This method is slightly more accurate than the previous one due to the increased objectivity in problematic envelope selection, although it requires more time to identify them.

From a time efficiency perspective, the first method is the most time consuming and impractical, especially in a hospital setting with a large and diverse inventory. In contrast, the second approach consisting in visual inspection offers much more time efficiency. By performing a direct examination of the packaging and conducting targeted measurement tests only on potentially problematic items, time is optimized. Although there is a risk that some critical envelopes could be overlooked in the initial inspection, this approach allows for rapid identification and resolution of most misreading issues without great delays. The third approach falls somewhere in between in terms of time efficiency. Even though it does not require contacting suppliers, it does involve manually counting inventory to identify mismatches, which can still be time consuming. Moreover, this method does not proactively detect problematic envelopes but reacts to errors in the inventory after they have already occurred.

Given these considerations, and taking into account that hospitals require practical, timely solutions that minimize operational disruptions, the visual inspection method was selected as the most efficient approach for identifying RFID-incompatible packaging.

After identifying the problematic envelopes, it is essential to perform measurements and verify that these materials are indeed incompatible with RFID technology.

i. On-site tests

A straightforward approach involves conducting manual, physical measurements using a handheld RFID reader. By adjusting the appropriate parameters of the reader and performing several tests from different positions and distances, this method provides rapid and accurate results resembling real world conditions. However, one downside is that results may vary depending on the environmental conditions and the operator's consistency, which may introduce some variability and limit repeatability.

ii. Simulation program tests

Another option is to use a simulation software, which requires detailed information about the composition and physical properties of the potentially problematic envelopes, as well as finding a suitable simulation program capable of incorporating this data. Nevertheless, such information might be difficult to obtain, and simulations do not fully reflect real world conditions.

Considering the possibility to get quick and real-world results, the on-site test method was the one chosen. Even though it may have some variability, it is still the most straightforward and effective way to confirm if the packaging interferes with RFID signals.

Once the critical envelopes have been identified, it is necessary to implement a solution to resolve the issue of signal blockage. Several alternatives were considered:

i. Relocation of tags to non-critical areas of the envelope

One option is to place the RFID tag in an area of the packaging that does not interfere with signal transmission. For instance, placing the tag on the side or top of the envelope, or in an area less affected by the material's properties, can improve tag readability. Nonetheless, in some cases, the entire envelope may be composed of a material that blocks the signal, making this solution ineffective and requiring other alternatives.

ii. Work with suppliers to change the envelope material

Another approach is to contact the suppliers and request a change in the material for the envelopes. The objective is to substitute them with RFID-compatible materials, allowing the signal to pass through without interference and ensuring the tag can be read adequately. While this solution can be effective, it may take time and effort to renegotiate with suppliers, and in some situations, the envelope material may not be replaceable owing to the specific protective requirements of the product inside. A thorough economic analysis would also be necessary.

iii. Use tags with protective shielding

A third solution is to replace the current RFID tags with ones that are specifically designed to withstand misreadings from the packaging material. These tags are typically equipped with a protective shield that prevents the envelope from blocking the radio signals, ensuring the tag can still be read even when placed on a problematic envelope. However, these types of tags are more expensive, so it would be important to assess their cost-effectiveness before implementation.

After evaluating all solutions, it was decided to use tags with protective shielding to mitigate the risk of signal interference caused by metallic packaging. This option offered a reliable solution without requiring changes to existing packaging or supply chains, making it the most practical and scalable choice in the context of the project.

4.2 Validation of shielding paint

During the implantation process, one of the technical challenges encountered was unintended tag readings in adjacent rooms due to electromagnetic interference. RFID signals can propagate through walls and other non-metallic barriers, potentially resulting in cross-readings. This affects the accuracy of the location data and the overall reliability of the system.

This issue was observed at Plató after the pilot deployment, specifically in a storage area and an operating room located adjacent to the waste disposal room. The wall separating these rooms was susceptible to causing cross-reading between areas. If an item was mistakenly detected in the waste disposal area, it would be automatically registered as consumed in the hospital's information system. Conversely, if an item was incorrectly detected in the storage room while it was actually in the waste disposal area, inventory discrepancies would arise, leading to supply chain inefficiencies. Although only few cross-readings had been detected in this location, it is crucial to minimize system malfunctions. Given the importance of maintaining accurate stock levels in a hospital environment, ensuring RFID signal isolation in this zone was very important.

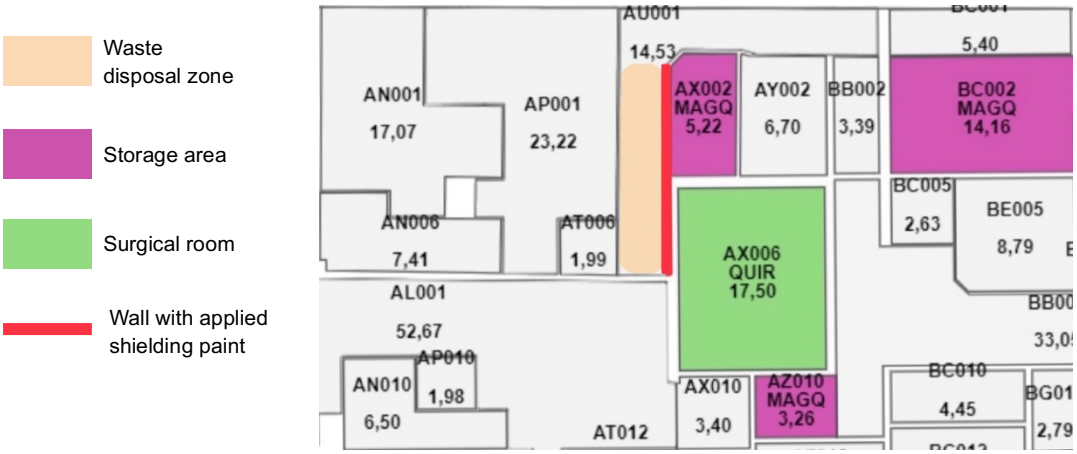

Figure 6: Infrastructure layout showing shielding paint coverage.

To mitigate this risk, shielding paint was applied to the separating wall identified as susceptible to signal interference. This solution aimed to prevent cross-readings between critical adjacent spaces and ensure reliable tag localization within each defined zone. However, before extending this solution to the more complex environment of the Villarroel facility, a validation process was required. To confirm

the actual attenuation capacity of the shielding paint, three different approaches were considered:

i. On-site validation

This method involves using a portable RFID reader to scan across the rooms affected by interference. The idea is to place a tag in different locations near the separating wall and observe if it is detected in the adjacent room. This option provides immediate, real-world feedback on the effectiveness of the shielding paint and it is the fastest way to solve cross reading issues. However, if an operating tag is used in the test, it could be mistakenly recorded by the system as consumed when detected by the antenna located at the waste holding area, requiring manual correction in the database. This issue can be avoided by using test tags, not linked to any real inventory item.

ii. Computerized simulation modelling

A second option is to create a virtual model of the actual infrastructure using a simulation software capable of calculating RFID signal propagation. This approach requires specific technical information such as room dimensions, wall materials, and the physical properties of the shielding paint, such as conductivity and attenuation parameters. The main advantage of this method is the possibility of performing an unlimited number of tests without interfering with hospital operations. Nevertheless, simulation may not perfectly reflect real-world behaviour, and the set-up of the model can be time consuming.

iii. Ongoing monitoring through system data analysis

A third approach involves continuously monitoring the RFID system by analysing inventory data daily. This means tracking the reported movements and consumption of products to verify that they correspond with the actual stock levels, helping to identify any items mistakenly marked as consumed due to cross-readings. Although this method is the most accurate in confirming the long term performance of the system, it is also the slowest and most challenging to execute, as it requires manual inspections and consistent tracking over an extended period.

The chosen approach was the first option, involving real-world analysis of the paint's signal attenuation capacity by performing measurements across the affected areas. This decision was driven by the need for accurate and practical data that reflect real-world conditions within the hospital environment. While computational simulations and ongoing system monitoring offer valuable insights, they either rely on assumptions or require extended time frames to assess the paint's performance. Direct on-site measurements allow for immediate results and more reliable evaluation of the shielding paint effectiveness, making it the most suitable method in this context.

4.3 RFID technology validation

The main objective of this task was to validate the performance and integration of the RFID technology being implemented at the central site of HCB. The validation aimed to assess whether the system accurately detects, locates, and registers the use of tagged medical products within a clinical environment. This process was essential to ensure the reliability of the technology. To achieve this goal, several approaches were considered:

i. Validation during ongoing clinical activity

This method consists of performing the validation in a fully operational setting, during real clinical activities. The validation involves comparing the actual location and consumption of materials during interventions with the information recorded in the RFID middleware. Its main advantages include providing the most accurate representation of system performance under real-world conditions, as well as allowing direct observation of how staff interact with the new system. However, this method is time-consuming, as it requires waiting for actual clinical interventions to occur in order to verify consumable usage and item tracking. Additionally, the variability of daily workflows during the validation period makes it difficult to replicate tests consistently.

ii. Validation in a real environment without clinical activity

The validation is performed without interfering with real clinical activities, but within the actual hospital infrastructure. This method involves recreating real-world conditions by placing test RFID tags in those areas where consumables, implants, and medical devices are typically stored or used in practice. This validation enables accurate assessment of RFID system behaviour in a real hospital setting and is repeatable across hospital units. Nonetheless, it may not capture dynamic and real clinical usage patterns.

iii. Long-term comparative workflow analysis (pre-RFID vs post-RFID)

It involves performing a prolonged comparison of logistics and inventory management workflows with and without RFID technology. It requires maintaining parallel records, manual (pre-RFID) and automatic (post-RFID), for a certain period and analysing consistency between the two. This approach offers a comprehensive understanding of the long-term impact of RFID technology. Nevertheless, it requires a significant amount of time to obtain meaningful results and involves duplicated effort: in addition to performing all logistical tasks using the traditional method, it is also necessary to compare every consumed item, inventory count, and movement manually recorded with the data collected by the RFID system. Furthermore, if discrepancies arise, it is difficult to determine whether they are due to human error in the manual process or a malfunction in the RFID technology, making its evaluation complex.

The third method involves excessive duration and resource demands, especially when taking into account that the RFID system must eventually be validated across all hospital units. The need to perform all tasks using both systems contradicts the primary goals of RFID implementation of streamline processes and reduce manual workload. Therefore, this option was ultimately discarded. Approaches 1 and 2 differ mainly in whether validation is performed during actual clinical activity or in a controlled and inactive environment. Both methods offer highly realism in terms of infrastructure, detection zones, and system logic. However, given that the aim of this validation was to confirm the proper functioning of the RFID technology, ensuring all components worked as expected, the second approach was selected to reduce the time performing validation tests and avoid disruption to clinical staff during clinical procedures.

4.4 Task compilation and structuring

Coordinating a project of such magnitude as the implementation of RFID technology across an entire hospital is a complex task. This complexity arises not only from the scale of the implementation but also from the diversity of professionals involved, comprising multiple sectors such as logistics, infrastructure, maintenance, medical, procurement, and informatic systems. In this context, it is crucial to have a very well-defined and structured list of tasks. Each of these tasks must be clearly described and assigned. The lack of proper task definition and assignment may lead to miscommunication, inefficiencies, and delays in the overall project timeline. Different approaches for the collection and organization of task-related information were explored and are discussed below.

In the first place, the task list can be compiled through active **in-situ participation** in all phases of the project, observing tasks while being carried out according to the specified requirements. This approach involves being present during the different stages of the implementation process, observing the workflow, and directly documenting each task. Furthermore, it allows the real-time identification of responsibilities, dependencies between tasks, timelines, and unforeseen challenges. This method can be beneficial for the list documentation phase as it enables the inclusion of additional tasks that might not have been initially foreseen, refining procedures and addressing key aspects. Additionally, it provides a deeper understanding of the dynamics and interconnections between different departments. However, the main drawback of this approach is the lack of a clear and accessible task list of the entire project from the start. Without a view of the overall timeline, it may become difficult to understand task dependencies, which can reduce the team's sense of urgency.

In the second place, the required information can be directly **provided by the project coordination team**, composed of experienced professionals with a comprehensive understanding of the project scope, timeline, and responsibilities. This approach essentially involves establishing contact with a specific department to gather all the necessary information. Although this approach might be the quickest and most straightforward, it might later become necessary to modify the structure or certain elements of the task list. To reduce this risk, the coordination team should have consulted departments beforehand to make sure no discrepancies arise regarding task timelines or workload distribution.

In the third place, **insights from other hospitals** that have already implemented the RFID technology can be gathered through bibliographic reviews, case studies, published reports, or professional consultations. This external knowledge can help identify standard workflows, common challenges, and best practices. Nevertheless, the main downside of this approach lies in the fact that each institution operates under unique conditions, infrastructure, and organizational cultures, which may limit the direct applicability of external insights.

After evaluating the three approaches, a hybrid method was selected that combined direct field involvement through on-site visits with continuous collaboration with the hospital's Strategy and Planning Directorate, ensuring the reliability and completeness of the task list.

Once all project tasks are identified and compiled, they must be structured and sorted in an optimal and understandable manner. The structure may vary depending on the project's needs, the available tools, and the communication between different teams. Some approaches that were initially considered for task grouping or sequencing include the following:

i. By timeline

Structuration of tasks based on their chronological order, arranging them according to their respective deadlines. This approach emphasizes the sequential order of tasks, reducing the risk of delays in critical project phases and ensuring that milestones are met on time. However, if unforeseen events arise during the project development, the entire timeline may require restructuring.

ii. By work packages

Each set of tasks is assigned to a specific team or department responsible for their execution. This method simplifies the tracking process within each workpackage, as each of them focuses on its assigned responsibilities without being overly concerned about the tasks other teams are performing. Despite the advantages, this method may lead to a lack of synchronization between departments which can affect the overall workflow.

iii. By project phases

Grouping tasks into major project stages (e.g. initial contact, space revision, hardware installation, software configuration, etc.). This approach facilitates continuous monitoring since the completion of each milestone or phase can serve as a checkpoint to assess the project progress. Nonetheless, task dependencies across different phases may not always be obvious.

iv. By type of component installed

Separation of tasks based on the specific components being implemented (e.g. tasks involved in the installation of an RFID antenna might include selecting the installation location, ensuring the availability of PoE ports, scheduling the installation, validating its functionality, etc.). This approach ensures that each device receives the necessary attention, reducing the risk of errors during the installation process. However, it might not always align accurately with the overall project timeline, as it focuses on individual components rather than larger project objectives.

Ultimately, tasks were structured by project phases, as this method provided a clear and intuitive overview of progress while aligning with the implementation process. It allows for easier milestone tracking and coordination across teams. Despite minor interphase dependencies, this approach is the most practical and scalable.

Apart from compiling the tasks, they must be documented and written down in a format which is accessible, intuitive, and easy to update for all members involved in the project. The tool or software chosen would be likely to allow task assignment, deadline management, track real-time updates to comprehend a collaborative workspace and task consulting. Some convenient programs are discussed below.

i. Microsoft Planner

This platform allows users to create plans, assign tasks, set start dates and deadlines, and visualise project phases in different formats like Gantt charts, boards, calendars, among others. As part of Microsoft 365, it is tightly integrated with other Microsoft tools, such as Teams, Outlook and Loop. The main downside is the subscription cost. The available features and functionalities increase with the price.

ii. Asana

This software shares some similarities with the one mentioned above in terms of format and task organisation, and it also offers multiple views, such as list, board, calendar, and Gantt chants. However, a notable difference is the wide range of

integrations with other tools, including Google Workspace, Microsoft 365, Canva, Notion, Dropbox, GitHub, and many others.

iii. Excel

Although this program is not specifically designed for project management, it can still be used as a basic tool to track progress. Its main advantage is that most people are already familiar with it, which makes adoption easier. However, there is a higher risk of errors due to manual input and the lack of project management features. Therefore, this tool would be useful for small projects that do not require complex planning.

Microsoft Planner was chosen as the tool for task organisation and management owing to its compatibility with the digital environment of the hospital, as all employees already use Microsoft 365. This ensured easy integration with Microsoft accounts across all departments and provided a familiar and intuitive interface that made adoption easier.

4.5 Economic Analysis

The implementation of a new technological system in a hospital setting not only requires technical feasibility but also economic justification. Conducting an economic analysis is essential to quantitatively assess the improvement that the RFID system brought to the hospital in terms of efficiency, cost reduction, and resource optimization. Furthermore, it provides valuable insights that can serve as a reference for other hospitals considering similar implementations.

Given the context of the HCB and the early stage of the implementation in most units, different approaches were considered to define the scope and structure of the economic evaluation.

i. Global economic analysis covering the entire HCB

This option involves conducting a comprehensive financial assessment across all hospital units where the RFID system is being implemented. It requires gathering capital investment, maintenance, and operational cost from all hospital units included in the RFID implementation. In addition, estimating the expected time savings, resource efficiency, and tag consumption rates at each site is also necessary. This method provides a complete economic view of the system's implementation at the institutional level. However, the deployment is still in progress, and not all units have fully adopted the technology. As a result, this approach would involve significant assumptions and financial projections, mostly regarding efficiency outcomes.

ii. Specific economic analysis on a single pilot site

In this second method, the scope of the financial evaluation is limited to one hospital unit, where the RFID system is already fully implemented and has been operating for a sufficient period to collect performance data. Although this

approach does not provide results for the entire hospital, it does offer valuable insights into how the system has performed in one area, based on real operational information.

At the time of the analysis, the pilot site was the only unit with complete data on time savings and the benefits of the technology deployment after a period of functioning. By working with real data from a real environment, a more precise and reliable economic analysis can be performed. In contrast, it is not yet possible to accurately measure the overall impact of the system across the entire HCB, even though some pricing information is already available. This is because the project is still undergoing validation in most units, and the RFID infrastructure is not yet fully operational. Since a global cost-benefit analysis would be fully based on assumptions, the second option was selected to provide more reliable results on economic indicators.

5 Detail engineering

In this section, the method selected for each task in the Concept Engineering section is described, detailing how it was implemented.

5.1 Identification of RFID-incompatible envelopes

The identification of incompatible envelopes was performed at Plató centre, specifically, in one of the surgical storage areas. I began the study by conducting a systematic visual inspection of all stored products. Envelopes were examined and selected as possibly problematic based on their apparent material composition, looking for those containing metallic layers, foil-like surfaces, or laminated materials with reflected finishes, all of which are known to attenuate or block RFID signals. Plastic and paper-based envelopes without metallic-like composition at first sight were excluded from testing, unless they presented atypical characteristics that raised concerns.

Although this method did not guarantee the identification of all problematic materials, it provided a fast and efficient way to filter out the likely RFID-incompatible candidates for further validation. As a result of this screening, I selected five products and conducted RFID reading tests to confirm whether signal degradation or total reading failure occurred when tags were placed on their packaging. Additionally, I included a control envelope with no apparent issues, to serve as a reference for comparison. All tested tags in the surgical storage room were Type 1 (high-tracking consumables).

The experimental validations were performed using the Zebra Technologies RFD40 UHF standard sled, connected via Bluetooth to a compatible Zebra mobile device. I tested each selected product by placing it inside a surgical room to mimic its typical operational environment and evaluated the readability of the tag under different distances and angles. I took distance measurements using a measuring tape, with the reader positioned at different distances ranging from 0 cm to 200 cm from the tag.

Moreover, I introduced angular variation in some cases to consider practical scenarios where the tag might not always face the antenna directly. This angular positioning was defined with respect to the plane of the envelope where the RFID tag was attached:

- 0º angle corresponded to a frontal reading, where the reader was directly facing the tag.
- 90º angle represented a lateral reading, where the reader was positioned perpendicular to the plane of the tag.

For each combination of distance and angle, I pressed the reader's trigger button, and the screen displayed a list of all RFID tags detected during that reading. For each tag, three key parameters were shown: the unique identifier, the read count (indicating the number of times the tag was detected during the scan), and the RSSI (Received Signal Strength Indicator). For the purpose of this study, RSSI was the main parameter considered. This value measures the power present in a received

radio signal and is expressed in negative dBm values, where less negative values indicate stronger signals. Based on the RSSI, I classified the envelopes into the following categories:

a. Fully readable (RSSI > -65 dBm): tag consistently detected under all distance and angle conditions.
b. Partially readable (-90 dBm < RSSI < -65 dBm): tag detected under most distance and angle combinations, but with weaker signal strength.
c. Unreadable (RSSI < -90 dBm): tag could not be accurately detected under the tested conditions.

After classifying the envelopes, the only two were marked as fully readable, one of which was the control item. The remaining four, three partially readable and one unreadable, were considered incompatible due to poor readability. Detailed validation results can be found in Annex A.

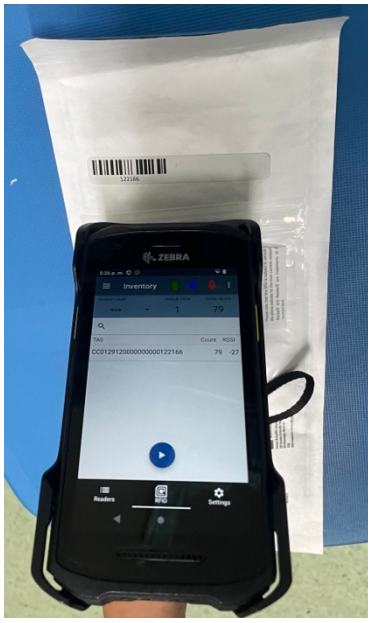

Figure 7: Handheld RFID reader scanning a tag.

The chosen solution for the incompatible ones was to replace their RFID tags with other models that include protective shielding. This shielding isolates the tag from the metallic surface or other interfering materials, thereby improving signal readability and preventing detection issues. These tags are not applied to all products from the start due to their higher cost compared to standard RFID tags.

This identification provided insights into how some materials affect RFID technology performance and helped determine whether alternative tagging strategies were necessary to accomplish an adequate integration with the RFID system.

5.2 Validation of shielding paint

As mentioned in the *Concept Engineering* section, the RFID shielding paint was applied at Plató to mitigate the risk of unintended cross-readings across adjacent rooms. I conducted its validation through on-site testing to ensure the effectiveness of this solution before considering its application in other hospital areas.

The materials and equipment I employed for this test included:

- A handheld RFID reader, specifically the Zebra Technologies RFD40 UHF standard sled, connected via Bluetooth to a compatible Zebra mobile device.
- A real hospital consumable item labelled with a passive UHF Class 1 RFID tag attached to its envelope, which is the standard type used for most RFID tagged products in the hospital.
- A measuring tape to assess distances.
- A tablet to record the detected results during the test.

The validation protocol was designed not only to evaluate the signal blocking capability of the shielding paint but to confirm that it had been correctly and uniformly applied along the entire wall surface. It was divided into two phases, involving intra and cross-room reading examinations.

1. Intra-room validation

Firstly, I placed the tagged item at several fixed locations inside each of the three areas (waste disposal zone, surgical storage room and operating room). In each location, the handheld RFID reader remained stationary and close to the area's fixed antenna. I tested the tag at multiple distances, ranging from 0.5 to 2 meters, and varied its orientation to simulate realistic tag positioning. These measurements aimed to verify whether the tag could still be correctly detected within their respective rooms, confirming that the shielding paint did not affect detection inside zones.

2. Cross-room validation

Secondly, I evaluated whether tags placed in one room could be detected across the painted wall. To do this, I alternated between placing the tagged item in the storage room or surgical room and positioning myself with the handheld reader in the waste disposal area, and vice versa. I performed scans at multiple locations within each room, testing different tag orientations to identify any signal leakage or blind spots along the painted wall. This cross-reading test helped determine the effectiveness of the shielding paint in preventing RFID signals from passing through the wall.

For each scan, I pressed the reader's trigger button, which provided the tag's unique identifier, the read count, and the RSSI. Inside each area, tag readings were considered acceptable if the RSSI value was above -90 dBm. Moreover, the shielding paint was considered effective if the tag placed in adjacent rooms was not detected during the cross-reading tests, regardless of its orientation or distance. Therefore, indicating that the paint successfully blocked unintended propagation of UHF RFID signals across the wall.

Results showed that the shielding paint was properly applied and functions effectively to block RFID signals from crossing the wall. On the one hand, the intra-room tests showed successful tag detection within each room, with RSSI values between -29 and -44 dBm. On the other hand, the cross-room tests confirmed the paint's effectiveness, as no tags were detected from one room to the other, even when the reader was brought close to and pointed directly at the painted wall.

5.3 RFID technology validation

Owing to the timeline of this project and the large scale of the RFID implementation at HCB, I performed the validation of the technology in one of the interventional areas of the Villaroel site, specifically in the DIVAS (Digital Vascular Angio Subtraction) unit. This department is dedicated to radioangiography procedures and includes four interventional rooms (D1, D2, D3, and D4), as well as an internal storage area.

To simulate real hospital products, the three types of tags used in the hospital were printed and associated with test tags. Each type represented a different object category:

- 41 Type 1 tags for consumables
- 4 Type 2 tags for medical devices or assets
- 41 Type 3 tags for implants

The validation consisted of two main phases:

1. Technology performance validation

The first phase focused on verifying that the RFID antennas installed throughout the unit accurately detected and located all tagged items. To replicate real scenarios, I randomly distributed the tags throughout the DIVAS unit according to typical storage and usage patterns.

- Type 1 tags (consumables) were placed in storage areas within the internal warehouse and the interventional rooms, zones where such materials are commonly kept and used.

- Type 2 tags (medical devices) were placed in hallways and inside procedure rooms.

- Type 3 tags (implants) were positioned inside interventional and storage rooms.

Before initiating the testing, tag codes were noted down along with their exact location. After waiting five minutes, enough time for the middleware to register the tag positions, I accessed the software, which is responsible for processing the RFID reader data. Then, I verified whether the system correctly recorded the tag placements. In addition, for the Type 2 tags, I performed in-out detection tests by moving them across the entry and exit boundaries of the unit. This allowed me to confirm that the entrance and exit readers correctly registered the movement of assets in and out of the interventional facility.

Out of the 86 tags tested, all of them were accurately detected and located by the system. The in-out detection tests also returned successful results, with the middleware correctly registering both entries and exits of the 4 tags.

2. Consumption validation

The second phase aimed to verify that the system correctly registered consumed items once they are discarded in the RFID waste bins. A total of 68 test tags, representing consumables and implants, were thrown away to the RFID bins across all four interventional rooms. The middleware was then monitored to verify that each item was recorded as consumed in the correct location. This is an important validation, as the actual hospital workflow relies on this automatic registration of consumed items, eliminating the need for manual counting and documentation, as well as improving traceability.

All 68 tags were successfully registered as consumed by the middleware, confirming the proper functioning of the RFID antennas and readers in the waste bins and the middleware logic responsible for updating usage of supplies in real time.

Figure 8: Screenshot of RFID middleware showing test tag consumption.

5.4 Task compilation and structuring

The strategy I followed for task compilation combined **on-site visits** for direct field involvement with **continuous collaboration from the management team**. This approach allowed me to collect detailed and reliable information about the hospital's internal dynamics and real operational needs.

On the one hand, the on-site visits involved staff from various departments, including nursing, cleaning, infrastructure, logistics, and representatives from the RFID installation company. These visits were crucial to gain first-hand insight into the actual infrastructure, daily workflow, and practical procedures in the surgical block where the system was meant to be implemented. This approach helped identify specific tasks that needed to be incorporated into the project plan. For example, during the visits, it was noted that some surgical rooms lacked PoE ports needed to connect the Keonn desktop RFID readers. As a result, an additional task was created to install these network ports before the RFID devices could be set up. These types

of needs, which emerged during the visit, would have been difficult to identify through documentation alone.

On the other hand, I worked closely with the Strategy and Planning Directorate team who, given their experience managing other activities within the institution, provided essential information to complete task gathering. Their understanding of internal proceedings and departmental roles, together with the on-site visit enabled the definition of the task list.

Once the initial list of tasks was compiled, I grouped them into project phases or blocks to simplify their management and improve understandability. These groups were defined based on similarities between tasks, and each block was assigned a clear purpose to help structure the workflow effectively:

1. Initial contact and information gathering: this first block focuses on the initial phase of the RFID implementation project. An overview of the new system is explained to all participants involved, reference personnel are identified, and important documentation and information is collected. The objective is to collect all requirements, establish initial responsibilities, and prepare for the following phases.

2. Revision of spaces: in this phase, the physical spaces are visited on-site to obtain a practical understanding of where the hardware and equipment will be installed. This step allows the team to confirm the spatial arrangements, verify technical feasibility, and identify any potential technical or logistical issues. It also ensures that spaces meet all requirements for the installation.

3. Planning and foresights: this block deals with resource and time planning. Tasks within this phase include estimating necessary resources, defining timelines, and forecasting logistical needs.

4. Definition of the intra-hospital logistics model: tasks in this section focus on establishing a clear logistics framework for RFID implementation, including inventory management, systems integration and configuring logistics workflows.

5. Physical works and modifications: this phase addresses the physical modifications required for the implantation of the technology. Not only does it include infrastructure changes but also electrical adjustments. Furthermore, the hardware installation is contained in this phase.

6. Middleware parametrization: focuses on configuring and validating the middleware, which serves as the intermediary between RFID hardware and hospital systems. The responsible for the completion of this block is the RFID supplier company.

7. User formation and middleware validation: this section includes training hospital staff and validating the middleware functionality, ensuring all logics were correctly defined in the previous block.

8. SAP parametrization: this phase involves configuring the hospital's SAP system to ensure compatibility with the RFID infrastructure. It is essential to prepare

the system environment to process and interpret the high amount of data transmitted from the middleware.

9. System deployment and launch: the final block covers the deployment of the RFID system across the implementation area. It aims to ensure a seamless integration between the RFID components, middleware, and SAP, while also validating the system performance.

Within each of these blocks, I organized tasks chronologically, based on their initiation time. This ensured a clear understanding of task dependencies and critical milestones.

When task structuring was done, I manually entered all defined tasks into the Microsoft Planer program, specifying their respective start and end dates and the assigned person responsible for adequate completion of each task. Additionally, dependencies between major task blocks were established to make structure and sequencing clearer.

5.5 Economic Analysis

The economic analysis of implementing the RFID system for the management and control of healthcare products focuses on a single institute, Plató, which has been the site of the previous validations and is currently fully operational.

Investment

The capital investment considers the overall cost of implementing the RFID system across the HCB, as well as the specific components required for the effective operation of the system at Plató. This includes all expenses ranging from project management costs to the hardware and software installed at Plató.

On the one hand, general costs are common across the 20 locations where the HCB has deployed the technology. This accounts for the project management and the integration with the client's system, whose total price has been divided into 20. On the other hand, costs at the unit level include all hardware and software installed in Plató, as well as the labour costs for installation.

Component	Units	Unitary price (€/unit)	Total price
Hardware			
Ceiling reader	18	2,207.5	39,735.07
Waste disposal area reader	2	2,207.5	4,415.01
Handheld reader	2	1,473.81	2,947.62
Desktop reader	8	810.13	6,481.06
RFID-enabled bin	2	2,850	5,700
RFID tag printer	1	2,200	2,200
Software			
Dipole connect	20	277	5,540
Integration with client's system	-	325	325
Configuration and installation services			
Physical installation of readers and antennas	20	720	14,400
System configuration and startup	20	290	5,800
Network cabling installation	20	314.44	6,288.8
Project management	-	475	475
TOTAL (€)			**94,307.56**

Table 1: Capital investment at Plató.

Expenses

Expenses are divided into fixed and variable depending on whether they remain constant regardless of usage levels or vary with the volume of operations.

Fixed costs refer to maintenance, which in this project refers to post-warranty services. This includes all technical support provided after the expiration of the supplier's warranty period, which is 2 years from implementation.

Conversely, variable costs correspond to the RFID tags expected to be consumed each year at the Plató site. The tags are differentiated by type and price: RFID tags for consumable items and RFID tags for medical equipment with metallic surfaces, since each newly acquired device receives a tag. It is important to note that cost variations over time are not considered in this analysis since factors like number of surgeries, which influence variable costs, depend on external conditions and cannot be accurately predicted.

Component	**Price**	**Periods (years)**				
		1	2	3	4	5
Fixed costs						
Maintenance	7% implantation	3,898	3,898	6,601	6,601	6,601
Variable costs						
Type 1 and Type 3 tags	0.11 €/unit	1,554	1,554	1,554	1,554	1,554
Type 2 tags	0.58 €/unit	49	0	0	0	0
TOTAL (€)		**5,501**	**5,452**	**8,155**	**8,155**	**8,155**

Table 2: Fixed and variable costs.

Income

The most significant benefit of implementing the new RFID system is the optimization of staff time. Automation of processes such as registration, material counting, and order placement significantly reduces the manual workload, thereby improving efficiency. A detailed time analysis of the processes before and after implementation shows that staff now save a total of 1040 minutes per week. Table 3 shows the tasks where time is saved with the new technology, who is responsible for each task, and how much time is saved per week.

Pre-implementation	
Total time spent on non-value tasks	1,642 minutes/week
Post-implementation	
Reduction of time for order placement	696 minutes/week
Reduction of time for register	264 minutes/week
Reduction of time for product counting	80 minutes/week
Total reduction of time	**1,040 minutes/week**
New total time spent on non-value tasks	602 minutes/week
% Saved time	**63.3%**

Table 3: Time reduction on non-clinical tasks.

The above-mentioned activities are carried out by different types of hospital staff: order placement is conducted by nurses and administrative personnel, product registration is done by nurses, and product counting is typically performed by the head nurse.

Using this information along with the HCB employment agreement, the time savings have been translated into monetary value, in Euros, based on the hourly wage associated with each job category. This includes the employer's gross salary plus the contributions HCB pays to Spanish Social Security. These contributions cover common contingencies, unemployment, vocational training, FOGASA, and work-related accident insurance, corresponding to 33.4% of the employee's gross salary.

Job category	Hourly wage (€)	Annual labour cost savings (€)
Head nurse	34.81	13,579
Nurse	27.89	11,254
Administrative	26.51	4,664
TOTAL (€)		**29,497**

Table 4: Annual labour cost savings per job category.

This amount represents an indirect economic benefit derived from a better allocation of personnel time, allowing them to focus on higher value tasks for the facility.

Financial Evaluation

For the financial evaluation, the concept of fund flow is introduced. This refers to the difference between revenues and costs of the project over a given period, which in this analysis is 5 years. Cash flow is updated with a 2% annual interest rate.

Concept (€)	Periods (years)					
	0	**1**	**2**	**3**	**4**	**5**
Investment	94,308					
Fixed costs		3,898	3,898	6,601	6,601	6,601
Variable costs		1,603	1,554	1,554	1,554	1,554
Income		29,497	29,497	29,497	29,497	29,497
Cash flow	- 94,308	23,996	24,045	21,342	21,342	21,342
Cumulative cash flow	- 94,308	- 70,312	- 46,267	- 24,925	- 3,583	17,759
Updated (2%)	- 94,308	23,525	23,064	22,612	22,169	21,734

Table 5: Final financial evaluation.

Finally, financial indicators are computed to economically justify the implementation of the new system:

Net Present Value (NPV)

This financial indicator is used to assess the profitability of an investment while accounting for the value of money over time. It is applied when cash flows occur over multiple years, as is the case in this analysis.

$$\text{NPV} = -I_0 + \sum_{t=1}^{T} \frac{CF_n}{(1+r)^t} \tag{1}$$

$$\text{NPV} = \mathbf{11,486.7}€$$

Internal Rate of Return (IRR)

It measures the percentage return of an investment, representing the discount rate at which NPV equals to zero.

$$0 = \text{NPV} = -I_0 + \sum_{t=1}^{T} \frac{CF_n}{(1+IRR)^t} \tag{2}$$

$$\text{IRR} = \mathbf{6.3}\%$$

Return On Investment (ROI)

Is used to evaluate how profitable an investment is by comparing the net gain or loss it produces to the amount of money invested. In simpler terms, it shows how much profit the user earns for every euro invested.

$$\text{ROI} = \frac{\text{Income/Cash inflow} - \text{Investment}}{\text{Investment}} \tag{3}$$

$$\text{ROI} = \mathbf{18.8}\%$$

Payback period

Indicates the investment recovery period, which refers to the number of years required to recover the invested amount. It is calculated by adding the annual cash flows until they equal or exceed the initial investment.

$$\text{Payback} = \begin{bmatrix}\text{Last period with negative}\\ \text{comulative cash flow}\end{bmatrix} + \frac{\begin{bmatrix}\text{Absolute value of last}\\ \text{negative cumulative cash flow}\end{bmatrix}}{\begin{bmatrix}\text{Cash flow value}\\ \text{in the next period}\end{bmatrix}} \tag{4}$$

$$\text{Payback} = \mathbf{4.17\ years}$$

6 Execution schedule

Proper planning is crucial for the success of any project. This section presents the project execution timeline, which ensures efficient coordination of activities and compliance with established deadlines.

First, the Work Breakdown Structure (WBS) diagram is presented, organized hierarchically and visually structured to allow easy identification of this project's tasks.

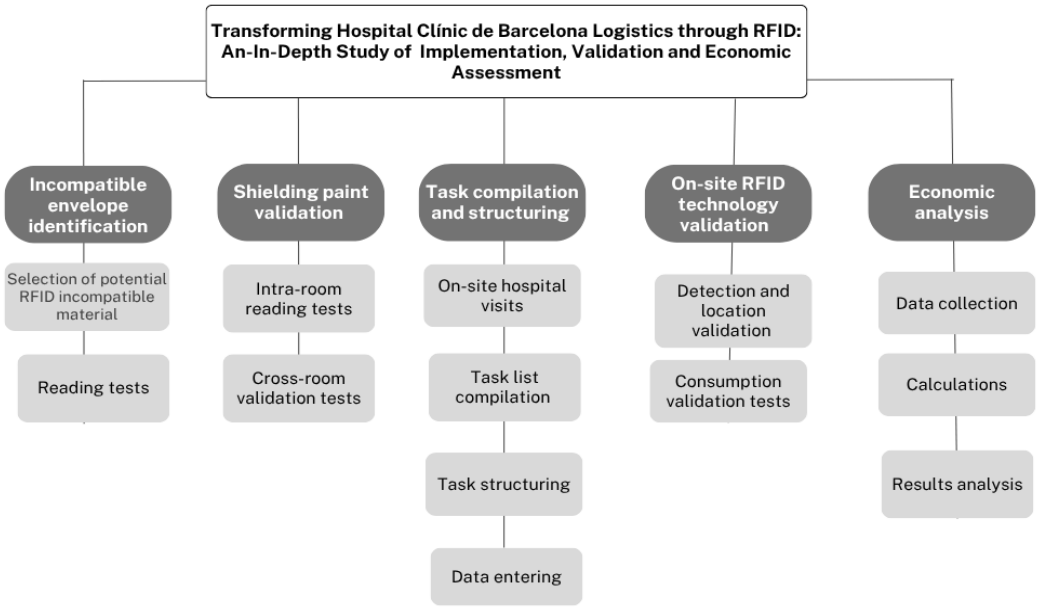

Figure 9: Work Breakdown Structure (WBS) diagram.

Secondly, the GANTT chart allows visualization of all defined tasks over a timeline, from the project's start to its completion.

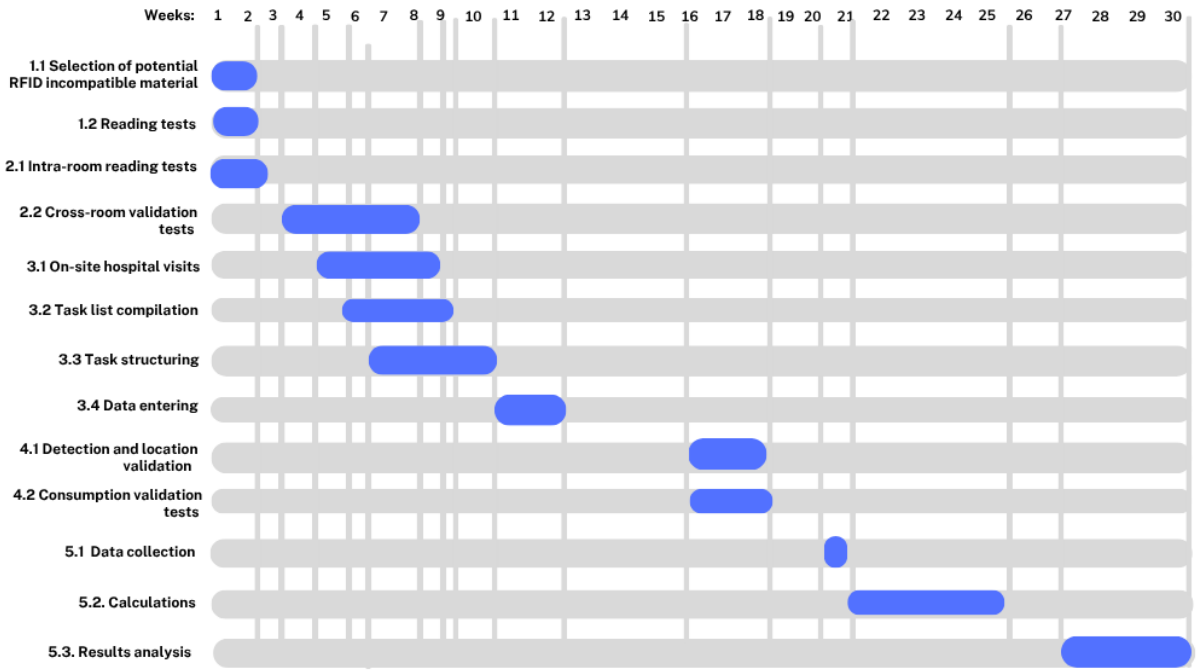

Figure 10: GANTT chart.

7 Technical feasibility

To assess the technical feasibility of this thesis, a SWOT analysis was carried out. This allows the identification of factors that may influence the success of the project by evaluating its strengths, weaknesses, opportunities, and threats.

Strengths

The work carried out during at the pilot site has demonstrated the technical feasibility and potential economic viability of the RFID system. the positive results obtained, including successful validation and cost-efficiency indicators, provided clear evidence for scaling the system to the main Villarroel site.

Weaknesses

Due to the complexity and size the HCB, the implementation process still requires several months of continuous monitoring and adjustment of existing procedures. In addition, a complete evaluation of the system has still to be conducted once the entire deployment is operational. This temporarily limits the ability to measure its overall performance and integration.

Opportunities

This project presents a great opportunity to develop and document a complete technical and organisational analysis of an RFID implementation in a hospital setting. The experience gained and lessons learned throughout this process can be useful for future projects in similar environments.

Threats

Given the large scale of the hospital's project, which involves the coordination of multiple departments, time management has been a challenge. Several delays have occurred during the implementation process, affecting the originally planned timeline and requiring rescheduling of certain validations performed in this work.

8 Economic viability

Analysing the budget and associated costs of this thesis is essential for effective management and future works. Table 6 shows the detailed breakdown of the total project costs based on the tasks outlined earlier in the execution schedule.

Concept	Spent time (h)	Cost (€)
Investigation	90	1,800
Analysis	140	2,800
Hospital visits	7	140
Validation tests	8	160
Writing	200	4,000
TOTAL (€)		**8,900**

Table 6: Economic viability of this thesis.

Equipment that was already available, such as a computer used for the study and the handheld RFID reader used for validations, has not been included in the cost calculation, as it is considered a depreciable asset.

9 Regulations and legal aspects

The implementation of RFID technology in the healthcare sector must comply with several international and national standards to ensure interoperability, safety, and legal compliance.

At the international level, organizations such as the International Standards Organization (ISO), GS1, World Trade Organization (WTO), and EPCglobal work together to define global RFID protocols. **ISO 18000-63** [52] standard together with **EPC Gen2** [53] protocol define the physical and logical requirements for passive UHF RFID systems operating in the 860 – 960 MHz frequency band.

In Spain, the National Telecommunications and Technologies General Authority liberalized the 865 – 868 MHz frequency band (permitted UHF in Europe) in 2007, allowing RFID use without prior approval of the public Administration [54]. To operate within this frequency band, RFID devices must comply with the technical requirements outlined in the regulated radioelectric interface **IR-96**, published in *Boletín Oficial del Estado (BOE)* in 2008 [55]. Additionally, all equipment is required to undergo telecommunications conformity evaluation as established in the ***Real Decreto* 1890/2016 [55]**.

Regarding privacy and data protection, the European Union has developed a strong legal framework that includes the General Data Protection Regulation (GDPR) and the ePRivacy Directive [56]. These laws ensure that any system collecting or processing personal data respects fundamental rights. Data security, transparency, and informed consent must be guaranteed at every step.

Finally, under the current legislation, it is the responsibility of national public authorities to ensure the enforcement of data protection rules in systems involving technologies such as RFID. In this context, the European Commission promotes the development and adoption of best practices, encouraging clear design guidelines from the start of any project to minimize risk and ensure regulatory compliance. [56]

10 Discussion

This work provides practical insights into the real-world implementation of RFID systems within hospital environments, particularly in specialized areas like surgical storage and operating rooms. Multiple dimensions were addressed, including material compatibility, environmental interference, process integration, and economic feasibility, therefore contributing to a robust understanding of the critical factors that influence successful deployment.

First, the identification of RFID-incompatible envelopes revealed that material properties can critically impact signal performance. Visual inspection for metallic or reflective components effectively identified problematic envelopes, and further testing confirmed their disrupting effects. Results showed that such materials significantly degrade RFID signal strength, aligning with UHF RFID physics, where conductive materials cause interference or total signal blockage. The decision to implement shielded RFID tags for incompatible packaging was justified by its performance difference. However, their increased cost remains a limiting factor, requiring their selective implementation rather than widespread use.

Second, the validation of the shielding paint demonstrated the importance of environmental controls in RFID installations. Since the technology is designed to enable broad signal propagation, such coverage must be carefully constrained in sensitive areas to prevent unintended cross-readings. Tests revealed that the paint effectively blocked signal transmission between adjacent areas without affecting tag readability within rooms, making it a scalable solution for the Villarroel site.

From a financial perspective, the cost-benefit analysis revealed that the RFID system presents economic value over time. A positive NPV of 11,486.7€, means that the project will generate a return greater than the investment cost, indicating the viability of the project. Moreover, an IRR of 6.3% confirms the project's profitability since this value exceeds 2% (estimated discount rate). The resulting ROI shows the project will return an 18.8% profit on the invested capital within the first 5 years. Lastly, the payback period of 4.17 years further supports the project's viability by indicating that the initial investment will be recovered within a reasonable timeframe.

However, it is important to note that this analysis did not account for all potential benefits of real-time RFID tracking, such as reducing expired products or optimizing inventory levels. Moreover, the evaluation was based on currently available data, without including future variables that could further improve financial outcomes. For instance, increased surgical volume would lead to higher usage of consumables and, thereby, RFID tags, and future staff salary adjustments could amplify the efficiency savings.

Beyond financial indicators, the new technology provides enhanced traceability, operational transparency, and security for critical product management, strengthening the hospital's operating model. Additionally, the RFID system generates indirect value by reducing time spent by healthcare professionals on non-clinical tasks, allowing them to focus more on direct patient care.

In terms of the overall performance, the technology validation carried out at the DIVAS unit confirmed that the RFID infrastructure was capable of accurately locating and tracking hospital products. This validation was crucial to verify proper functionality of all hardware components, validate the robustness of software algorithms and logics, and ensure full system readiness before operational deployment in that unit.

Proper task organization in a project of this scale is essential since it involves numerous departments and a large number of interdependent tasks. In complex implementations, delays can always arise and having a structured and well-documented plan helps maintain control over progress, understand dependencies between tasks, and ensure adequate coordination across phases. Furthermore, this highlighted the importance of consistent communication between all teams involved.

Finally, the successful adoption of RFID technology depends heavily on the adaptation of hospital staff, as they are the ones who will be working with it every day. That is also the reason why hospital workflows define where antennas are located, how logical rules are programmed in the software, and how spaces are configured. Providing proper training ensures that staff understand how to work efficiently with the new system. in addition, adapting the implementation to the hospital's daily activities, by scheduling installations and validations outside of peak activity hours, was key to minimizing disruptions and ensuring a smooth transition.

11 Conclusions and Future research directions

The implementation of RFID technology in healthcare represents a significant advancement in the digitalization and modernization of hospital logistics. Through this project, I had the opportunity to contribute directly to a complex transformation at Hospital Clínic de Barcelona, participating in the planning and validation of an RFID system. Collaborating closely with different departments allowed me to gain a deep understanding of the real logistical challenges hospitals face, and how smart technologies can effectively address them. I also experienced the importance of clear communication, documentation, and coordination in large-scale projects involving multiple teams.

The early results observed at HCB are very promising, showing better control of medical products, more streamlined workflows in surgical and interventional areas, and an important reduction in time spent by healthcare professionals on daily tasks, which can now be dedicated to patient care.

During this thesis, some areas were identified as starting points for future study directions.

Firstly, once the RFID system is fully installed and operational across all departments at HCB, a detailed study to assess its real impact on hospital operations could be performed. This would include a full economic analysis, examining actual savings, decreased manual labour, and improved inventory accuracy. Additionally, a comparative study between the pre- and post-implementation performance would provide valuable evidence of the system's effectiveness.

Secondly, the RFID system generates a large volume of real-time data on material consumption, movement patterns, storage locations, and usage frequencies. However, much of this information is currently not used. Future work could focus on the analysis of these datasets through machine learning and artificial intelligence techniques with the goal of creating predictive models to prevent stock shortages, or detection algorithms to identify unusual material usage.

References

[1] Gregory Kipper, Chapter 6 - Visions of the Future, Augmented Reality, Syngress, 2013, Pages 129-142, ISBN 9781597497336, https://doi.org/10.1016/B978-1-59-749733-6.00006-1.

[2] Giorgia Casella, Barbara Bigliardi, Eleonora Bottani. The evolution of RFID technology in the logistics field: a review. Procedia Computer Science. Volume 200. 2022. Pages 1582-1592. ISSN 1877-0509. https://doi.org/10.1016/j.procs.2022.01.359.

[3] Habib, M. , Chowdhury, F. , Sabah, S. and Debnath, D. (2022) A Study on Hospital Supply Chain Management. American Journal of Industrial and Business Management, 12, 806-823. doi: 10.4236/ajibm.2022.125042.

[4] Jonas Volland, Andreas Fügener, Jan Schoenfelder, Jens O. Brunner. Material logistics in hospitals: A literature review. Omega. Volume 69. 2017. Pages 82-101. ISSN 0305-0483. https://doi.org/10.1016/j.omega.2016.08.004.

[5] Karen Moons, Geert Waeyenbergh, Liliane Pintelon. Measuring the logistics performance of internal hospital supply chains – A literature study. Omega. Volume 82. 2019. Pages 205-217. ISSN 0305-0483. https://doi.org/10.1016/j.omega.2018.01.007.

[6] Jinsong Zuo, Jinxia Feng, Marcelo Gonçalves Gameiro, Yaling Tian, Jing Liang, Yingying Wang, Jianhua Ding, Quanguo He, RFID-based sensing in smart packaging for food applications: A review, Future Foods, Volume 6, 2022, 100198, ISSN 2666-8335, https://doi.org/10.1016/j.fufo.2022.100198.
(https://www.sciencedirect.com/science/article/pii/S2666833522000855)

[7] Yvan Duroc; Smail Tedjini. RFID: A key technology for Humanity. Comptes Rendus. Physique, Radio science for Humanity / Radiosciences au service de l'humanité Journées scientifiques URSI-France 2017 – SophiaTech, Sophia Antipolis, France, 1–3 February 2017 / 1er–3 mars 2017, Volume 19 (2018) no. 1-2, pp. 64-71. doi : 10.1016/j.crhy.2018.01.003. https://comptes-rendus.academie-sciences.fr/physique/articles/10.1016/j.crhy.2018.01.003/

[8] R. Want, "An introduction to RFID technology," in IEEE Pervasive Computing, vol. 5, no. 1, pp. 25-33, Jan.-March 2006, doi: 10.1109/MPRV.2006.2.

[9] Nayak, R., Singh, A., Padhye, R. *et al.* RFID in textile and clothing manufacturing: technology and challenges. *Fashion and Textiles* **2**, 9 (2015). https://doi.org/10.1186/s40691-015-0034-9

[10] Jan Chocholac, Dana Sommerauerova, Matej Svab, Andrea Jiraskova, Michal Polak. Logistic Technologies for Tracking Manufactured Passenger Cars on Consolidation Areas: Interpretative Case Study. Transportation Research Procedia. Volume 53. 2021. Pages 266-273. ISSN 2352-1465. https://doi.org/10.1016/j.trpro.2021.02.034.

[11] A. Haibi, K. Oufaska, K. E. Yassini, M. Boulmalf and M. Bouya, "Systematic Mapping Study on RFID Technology," in IEEE Access, vol. 10, pp. 6363-6380, 2022, doi: 10.1109/ACCESS.2022.3140475.

[12] Xu, He & Weiwei, Shen & Li, Peng & Sgandurra, Daniele & Wang, Ruchuan. (2017). VSMURF: A Novel Sliding Window Cleaning Algorithm for RFID Networks. Journal of Sensors. 2017. 1-11. 10.1155/2017/3186482.

[13] Haibi, A., Oufaska, K., El Yassini, K., & Boulmalf, M. (2021). A secure middleware architecture for real-time tracking applications. *Proceedings of the 4th European International*

Conference on Industrial Engineering and Operations Management (pp. 1230–1239). IEOM Society International. http://ieomsociety.org/proceedings/2021rome/475.pdf

[14] Nayak, R., Singh, A., Padhye, R. *et al.* RFID in textile and clothing manufacturing: technology and challenges. *Fashion and Textiles* **2**, 9 (2015). https://doi.org/10.1186/s40691-015-0034-9

[15] Duroc, Y. (2022). From Identification to Sensing: RFID Is One of the Key Technologies in the IoT Field. *Sensors*, *22*(19), 7523. https://doi.org/10.3390/s22197523

[16] Talkin' Things. *RFID glossary*. Retrieved from https://talkinthings.com/rfid-glossary.

[17] Liu, G., Wang, Q.-A., Jiao, G., Dang, P., Nie, G., Liu, Z., & Sun, J. (2023). Review of Wireless RFID Strain Sensing Technology in Structural Health Monitoring. *Sensors*, *23*(15), 6925. https://doi.org/10.3390/s23156925

[18] C. Bajaj, S. Kumar, D. Kumar Upadhyay, B. Kumar Kanaujia, D. Gupta and T. Ali, "Modern RFID Reader Antennas: A Review of the Design, State-of-the-Art, and Research Challenges," in *IEEE Access*, vol. 13, pp. 16427-16443, 2025, doi: 10.1109/ACCESS.2024.3524387.

[19] Zebra Technologies. *FX9600 lector RFID fijo*. Zebra. Retrieved from https://www.zebra.com/es/es/products/rfid/rfid-readers/fx9600.html

[20] Zebra Technologies. Bases de RFID UHF RFD40.Zebra. Retrieved from https://www.zebra.com/la/es/products/rfid/rfid-handhelds/rfd40.html

[21] Roh, S., Nguyen, T. D., & Lee, J. S. (2024). Applications of Nanomaterials in RFID Wireless Sensor Components. *Applied Sciences*, *14*(3), 1216. https://doi.org/10.3390/app14031216

[22] Venot, É. (2015). *Middleware RFID: Traçabilité et objets connectés*. Techniques de l'Ingénieur. https://doi.org/10.51257/a-v1-tr520

[23] Baballe, Muhammad Ahmad, A Study on the Components used in RFID System and its Challenges (October 2021). Global J Res Eng Comput Sci. 2021; 1(1), 21-27, Available at SSRN: https://ssrn.com/abstract=4612377

[24] Ameri A, Salmanizadeh F, Sabet Y, Khajouei R. Potential Challenges of RFID Implementation: A Survey in Teaching Hospitals. Health Man & Info Sci. 2021; 8(2): 98-106. doi: 10.30476/jhmi.2021.89409.1069.

[25] Ali Akbari. The Application of Radio-Frequency Identification (RFID) Technology in the Petroleum Engineering Industry: Mixed Review. Petroleum Research. 2025. ISSN 2096-2495. https://doi.org/10.1016/j.ptlrs.2025.05.001.

[26] Pereira, E., Júnior, S., Silva, L. F. V., Batista, M., Santos, E., Araújo, Í., Araújo, J., Barboza, E., Gomes, F., Fraga, I. T., Dos Santos, D. O., & Davanso, R. (2024). RFID Tags for On-Metal Applications: A Brief Survey. *Technologies*, *12*(5), 58. https://doi.org/10.3390/technologies12050058

[27] Haddara M, Staaby A. RFID Applications and Adoptions in Healthcare: A Review on Patient Safety. Procedia Comput Sci. 2018;138:80-88. doi: 10.1016/j.procs.2018.10.012. Epub 2018 Oct 23. PMID: 32288898; PMCID: PMC7129262.

[28] Coustasse A, Tomblin S, Slack C. Impact of radio-frequency identification (RFID) technologies on the hospital supply chain: a literature review. Perspect Health Inf Manag. 2013 Oct 1;10(Fall):1d. PMID: 24159272; PMCID: PMC3797551.

[29] Pereira, E., Júnior, S., Silva, L. F. V., Batista, M., Santos, E., Araújo, Í., Araújo, J., Barboza, E., Gomes, F., Fraga, I. T., Dos Santos, D. O., & Davanso, R. (2024). RFID Tags for On-Metal Applications: A Brief Survey. *Technologies*, *12*(5), 58. https://doi.org/10.3390/technologies12050058.

[30] M. N. Zahid, Z. Gaofeng, T. Sadiq, H. Rahman and M. S. Anwar, "A Comprehensive Study of Chipless RFID Sensors for Healthcare Applications," in *IEEE Access*, vol. 12, pp. 175647-175665, 2024, doi: 10.1109/ACCESS.2024.3446994.

[31] R. -E. -A. Anee and N. C. Karmakar, Chipless RFID Tag Localization, *IEEE Transactions on Microwave Theory and Techniques*, vol. 61, no. 11, pp. 4008-4017, Nov. 2013, doi: 10.1109/TMTT.2013.2282280.

[32] Xiang, J., Zhao, A., Tian, G. Y., Woo, W., Liu, L., & Li, H. (2022). Prospective RFID Sensors for the IoT Healthcare System. Journal of Sensors, 2022, 1–19. https://doi.org/10.1155/2022/8787275

[33] Xinyu Li, Yanyi Zhang, Mengzhu Li, Ivan Marsic, JaeWon Yang, and Randall S. Burd. 2016. Deep neural network for RFID-based activity recognition. In Proceedings of the Eighth Wireless of the Students, by the Students, and for the Students Workshop (S3). Association for Computing Machinery, New York, NY, USA, 24–26. https://doi.org/10.1145/2987354.2987355

[34] Portillo, J. I., Bermejo A. B., Bernardos A. M. (2008). Informe de Vigilancia Tecnológica madri+d. “Tecnología de identificación por radiofrecuencia (RFID): Aplicaciones en el ámbito de la salud”. Fundación madri+d para el Conocimiento. CEIM Confederación Empresarial de Madrid – CEOE. https://www.madrid.org/bvirtual/BVCM001808.pdf

[35] De la Torre Rodriguez, L. M. (2017). *CONTRIBUCIONES AL PROYECTO DE TAGS CHIPLESS DE RFID CONTRIBUIÇÕES AO PROJETO DE TAGS CHIPLESS DE RFID* (Doctoral dissertation, [sn]).

[36] Kuo, Frank; Lee, Yuehching; and Tang, Chuanyi, "The Development of RFID in Healthcare in Taiwan" (2005). *ICEB 2004 Proceedings (Beijing, China)*. 66. https://aisel.aisnet.org/iceb2004/66

[37] Thiesse, Frederic & Michahelles, Florian. (2006). An overview of EPC technology. University of St.Gallen. 26. 10.1108/02602280610652677.

[38] Das, R. (2015, October 15). *RFID Forecasts, Players and Opportunities 2016-2026: IDTechEX*. IDTechEx. https://www.idtechex.com/en/research-report/rfid-forecasts-players-and-opportunities-2016-2026/451

[39] RFID in Healthcare Market Size, Share, and Trends 2025 to 2034. Precedence Research. (2025). Report Code: 1135). https://www.precedenceresearch.com/rfid-in-healthcare-market [Accessed June 1, 2025]

[40] RFID in Healthcare Market Size, Share & Trends Analysis Report By Product (Systems & Software, Tags), By Application (Asset Tracking, Patient Tracking, Pharmaceutical Tracking, Blood Tracking, Others), By Region, And By Segment Forecasts, 2025-2034. InsightAce Analytic. (2025). Report ID: 1419. https://www.insightaceanalytic.com/report/rfid-in-healthcare-market/1419 [Accessed June 1, 2025]

[41] Vyas, G. (June 2025). *Spain Healthcare RFID Market Research Report by Product Type (Equipment Tracking, Medicine Tracking, Others), by Component (Tags, Readers, Middleware, Printers), and by End User (Pharmaceutical and Biotechnology Companies,*

Hospitals)—Forecast to 2035. Market Research Future. Retrieved from https://www.marketresearchfuture.com/reports/spain-healthcare-rfid-market-50553 [Accessed June 1, 2025]

[42] Zebra Technologies. https://www.zebra.com/es/es.html [Accessed June 4, 2025]

[43] Impinj. https://www.impinj.com/es [Accessed June 4, 2025]

[44] Avery Dennison. https://www.averydennison.com/en/home.html. [Accessed June 4, 2025]

[45] Alien Technologies. https://www.alientechnology.com. [Accessed June 4, 2025]

[46] NXP Semiconductors. Healthcare innovations: Operational excellence with RFID. https://www.nxp.com/docs/en/white-paper/RFID-Healthcare-White-Paper.pdf [Accessed June 1, 2025]

[47] Dipole RFID. https://www.dipolerfid.es. [Accessed June 4, 2025]

[48] WIoT Group. (November 30, 2023). Zebra Technologies Helps NHS Hospital Boost Efficiency. https://wiot-group.com/think/en/news/zebra-technologies-helps-nhs-hospital-boost-efficiency/ [Accessed June 6, 2025]

[49] Impinj. (March 24, 2016). UT Medical Center Automates Supply Management with RAIN RFID. https://www.impinj.com/library/customer-stories/ut-medical-center-automates-supply-management [Accessed June 6, 2025]

[50] Comunidad de Madrid. (May 19, 2022). Digitalización del control de stock del almacén del Hospital Gregorio Marañón. https://www.comunidad.madrid/noticias/2022/05/19/digitalizacion-control-stock-almacen-hospital-gregorio-maranon. [Accessed June 6, 2025]

[51] Hospital Universitario Torrecárdenas. (April 14, 2025). El Hospital Universitario Torrecárdenas, primer centro andaluz en integrar los sistemas Siglo y Diraya con los armarios de Radio Frecuencia. https://www.hospitaltorrecardenas.es/2025/04/14/el-hospital-universitario-torrecardenas-primer-centro-andaluz-en-integrar-los-sistemas-siglo-y-diraya-con-los-armarios-de-radio-frecuencia/. [Accessed June 6, 2025]

[52] ISO/IEC. (2021). ISO/IEC 18000-63:2021 Information technology — Radio frequency identification for item management — Part 63: Parameters for air interface communications at 860 MHz to 960 MHz Type C. International Organization for Standarization. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso-iec:18000:-63:ed-3:v1:en [Accessed June 6, 2025]

[53] GS1. UHF Air Interface Protocol. GS1. Retrieved from https://www.gs1.org/standards/rfid/uhf-air-interface-protocol. [Accessed June 6, 2025]

[54] Alemán Vega, G., Martínez Pérez, M., & Novella Arribas, B. (2018). Analysis of the sefficacy and safety of an RFID system for the identification and monitoring (traceability) of patients in hospitals. Ministerio de Sanidad, Consumo y Bienestar Social.Unidad de Evaluación de Tecnologías Sanitarias de la Comunidad de Madrid. Retrieved from https://www.madrid.org/bvirtual/BVCM020314.pdf

[55] Ministerio de Industria, Turismo y Comercio. (2008, 25 de junio) Resolución de 25 de junio de 2008, de la Secretaría de Estado de Telecomunicaciones y para la Sociedad de la Información, por la que se publican los requisitos técnicos de la interfaz radioeléctrica reglamentada IR-96 para los dispositivos de identificación por radiofrecuencia (RFID) en la banda de 865-868 MHz. BOE-A-2008-11868. Retrieved from https://www.boe.es/diario_boe/txt.php?id=BOE-A-2008-11868. [Accessed June 6, 2025]

[56] European Comission. (2007) Radio Frequency Identification (RFID) in Europe: steps towards a policy framework. Publications Office of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:l24120a. [Accessed June 6, 2025]

Annex A

Product 1

Item: Inflatable penile prosthesis

Supplier: Boston Scientific

A)

B)

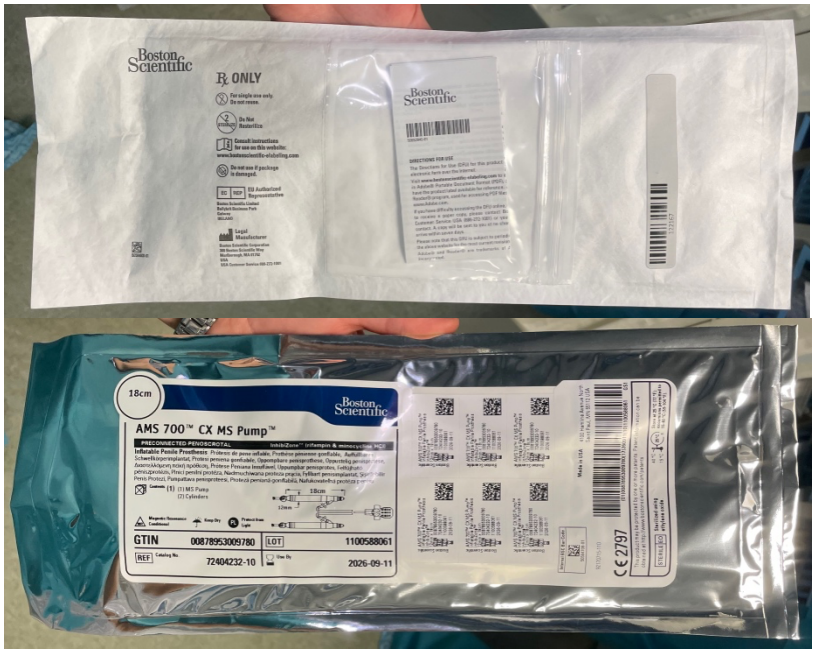

Figure A.1: Product 1, sides A and B.

Side A (paper):

Distance (cm)	Angle (º)	RSSI (dBm)			
		Reading 1	Reading 2	Reading 3	Average
0	**0**	- 24	- 23	- 27	- 25
100	**0**	- 46	- 47	- 52	- 48

Table A.1: Product 1, side A testing results.

Side B (potential RFID-incompatible material):

Distance (cm)	Angle (º)	RSSI (dBm)			
		Reading 1	Reading 2	Reading 3	Average
0	**0**	n/a	n/a	n/a	-
30	**90**	- 74	- 68	n/a	- 71

Table A.2: Product 1, side B testing results.

Result: Partially readable

Product 2

Item: Prosthesis fixation device C/30 points

Supplier: Bard Medical

Distance (cm)	Angle (º)	RSSI (dBm)			
		Reading 1	Reading 2	Reading 3	Average
0	**0**	- 22	- 22	- 22	- 22
30	**0**	- 28	- 27	- 27	- 27
200	**0**	- 51	- 41	- 42	- 45

Table A.3: Product 2 testing results.

Figure A.2: Product 2 testing results.

Result: Fully readable

Product 3

Item: Infla10 RTE ConnectSecure Extenders

Supplier: Rigicon

Distance (cm)	Angle (º)	RSSI (dBm)			
		Reading 1	Reading 2	Reading 3	Average
0	**0**	- 56	- 68	- 67	- 64
30	**90**	- 69	- 68	- 71	- 69

Table A.4: Product 3 testing results.

Figure A.3: Product 3.

Result: Partially readable

Product 4

Item: Size 1 polydioxanone endoligation

Supplier: Ethicon

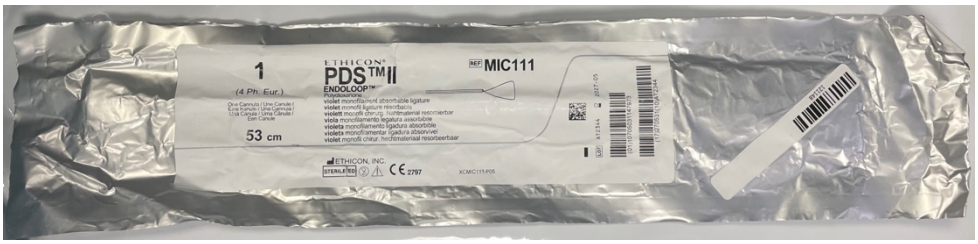

Figure A.4: Product 4.

No readings from this tag were detected at any distance or angle

Result: Unreadable

Product 5

Item: Hemostatic ABS cellulose powder 3g

Supplier: Ethicon

Distance (cm)	Angle (º)	RSSI (dBm)			
		Reading 1	Reading 2	Reading 3	Average
0	**0**	- 66	- 63	- 68	- 66
30	**90**	- 74	- 73	- 69	- 72

Table A.5: Product 5 testing results.

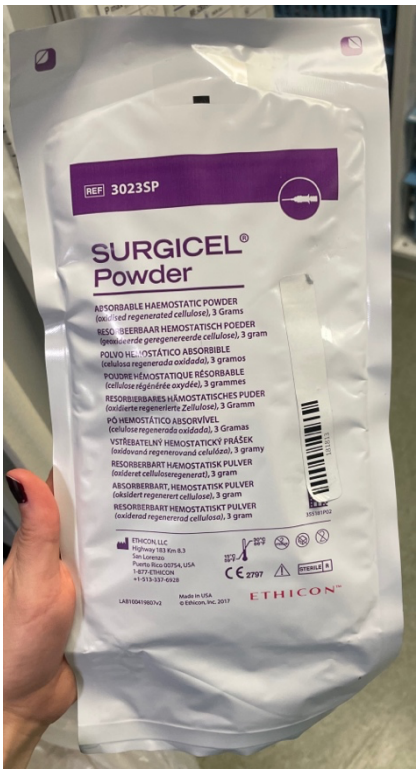

Figure A.5: Product 5.

Result: Partially readable

Product 6 (control item)

The envelope of this medical item is known to be compatible with the present UHF RFID technology.

Distance (cm)	Angle (º)	RSSI (dBm)			
		Reading 1	Reading 2	Reading 3	Average
0	**0**	- 27	- 24	- 30	- 27
30	**0**	- 34	- 41	- 38	- 38
200	**0**	- 59	- 57	- 62	- 59

Table A.6: Product 6 testing results.

Result: Fully readable