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# Life Cycle Analysis of Imaging Equipment

Internship Report submitted in partial fulfilment to the requirements for the degree of Master in Physical Assets Engineering.

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*The end of one journey is just the beginning of another. You have to see what you haven't seen, see again what you've already seen, see in spring what you saw in summer, see by day what you saw at night, with the sun where the rain first fell, see the green field, the ripe fruit, the stone that has moved, the shadow that wasn't there. You have to go back to the steps you've taken, to repeat them, and to trace new paths alongside them. You have to start the journey all over again. Always.*

José Saramago, *Travel to Portugal*

*Cristiana Sofia Pereira Afonso*

## ABSTRACT

This report was developed by the author during her internship in the hospital sector, on the subject of "Analysis of the life cycle of imaging equipment", as part of the Master's Degree in Engineering and Management of Physical Assets, at the Coimbra Institute of Engineering. The purpose of the internship is to reinforce academic training by giving students the opportunity to broaden their knowledge through a practical approach, as well as providing them with the opportunity to apply the knowledge acquired during their undergraduate and master's degrees.

Currently, any organization that provides healthcare with medical technology relies mostly on medical devices and equipment to benefit patients. As the technology of these physical assets in healthcare becomes more complex, the same happens with the demands to be made in managing them. Furthermore, in hospital organizations, physical medical assets are increasing rapidly, which makes it essential for all entities (public or private) to take a financial approach to the asset to understand the level of operation of the investment.

The aim of this study is to implement LCI (Life Cycle Investment) in imaging equipment. To this end, the report presents the use of a structured life cycle analysis model, LCI, applied to medical imaging equipment. The purpose of this method is to assist in the management of physical assets, since it is developed considering all the returns and expenses associated with the investment made, which makes it possible to determine the best course of action for the entity throughout the life cycle of the respective asset.

The model is applied to three pieces of medical equipment in the imaging sector, namely an ultrasound scanner, mammography equipment and an X-ray. This application makes it possible to reflect on the direct impact of all the benefits and expenses associated with the asset throughout its life cycle, as well as calculating the return on investment. In addition to the application of the life cycle analysis model mentioned above, the report emphasizes various considerations involving the management of physical assets, namely standardization, performance indicators, among others.

**Keywords:** Life Cycle, Life Cycle Analysis Model, Physical Assets, Maintenance, Medical Equipment, Hospital Management, Imaging Equipment

# RESUMO

O presente relatório foi desenvolvido pela autora, no decorrer do estágio realizado no sector hospitalar, alinhado ao tema "Análise do ciclo de vida de equipamentos de imagiologia", ao abrigo do Mestrado em Engenharia e Gestão de Ativos Físicos, do Instituto Superior de Engenharia de Coimbra. O estágio tem como principal objetivo incrementar a formação académica, através da possibilidade de ampliar o conhecimento por meio de uma visão prática, bem como proporciona a aplicação dos conhecimentos adquiridos durante a licenciatura e o mestrado.

Atualmente, qualquer organização que preste cuidados de saúde com tecnologia médica depende, maioritariamente, de dispositivos e equipamentos médicos para beneficiar os doentes. À medida que a tecnologia destes ativos físicos nos cuidados de saúde se torna mais complexa, o mesmo acontece com as exigências a adquirir na gestão dos respetivos ativos. Além disso, nas organizações hospitalares, os ativos físicos médicos está a aumentar rapidamente, o que torna indispensável, para todas as entidades (públicas ou privadas), uma abordagem financeira do ativo, para compreender o nível de operação do investimento.

Neste sentido, o relatório apresenta a aplicação direta de um estruturado modelo de analise de ciclo de vida, designado de ciclo de vida do investimento, em equipamentos de imagem médica. Este método tem como finalidade auxiliar na gestão de ativos físicos, uma vez que é desenvolvido considerando todos os retornos e despesas associados ao investimento efetuado, o que permite determinar o melhor curso de ação por parte da entidade ao longo do ciclo de vida do respetivo ativo.

O modelo é aplicado a três equipamentos médicos do sector da imagiologia, nomeadamente, um ecógrafo, um mamógrafo e um raio X. Esta aplicação permite refletir sobre impacto direto de todos os benefícios e despesas associadas ao ativo, ao longo do seu ciclo de vida, bem como calcular o retorno sobre o investimento. Para além da aplicação do modelo econométrico referido, no decorrer do relatório é enfatizado diversas considerações que envolvem a gestão de ativos físicos, designadamente, normalização, indicadores de desempenho, entre outros.

**Palavras-chave:** Ciclo de Vida, Modelo de Análise do Ciclo de Vida, Ativos Físicos, Manutenção, Equipamentos Médicos, Gestão Hospitalar, Equipamento de Imagem

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## ABBREVIATURES

| | |
|---|---|
| EDM | Exponent Depreciation Method |
| IEC | International Electrotechnical Commission |
| ISO | International Organization for Standardization |
| KPI | Key Performance Indicator |
| LCC | Life Cycle Cost |
| LCI | Life Cycle Investment |
| MTBF | Mean Time Between Failures |
| MTTR | Mean Repair Time |
| MWT | Mean Waiting Time |
| NSB | National Standardization Body |
| PQI | Portuguese Quality Institute |
| ROI | Return on Investment |
| SDM | Sum-of-the-Digits Depreciation Method |
| SLDM | Straight Line Depreciation Method |
| WHO | World Health Organization |

# 1 INTRODUCTION

Throughout this report, various topics related to asset management are covered as a way of contextualizing the different parameters to be taken into account in asset management, since as organizations become more complex, they require more diverse information through different studies to support the existing variety of assets.

This chapter presents a brief contextualization of the subjects covered throughout the report, starting with the framework, as a way of explaining the emergence of this study, followed by the motivation and objectives and the structure of the report, which briefly presents the chapters developed.

## 1.1 Framework

This report is the result of a curricular internship for the Master's Degree in Engineering and Management of Physical Assets at the Coimbra Institute of Engineering, which takes place in the first and second semester of the second year. The curricular internship derives from the context of the subject of hospital management and engineering, where, from a real environment and surroundings, such as the hospital sector, the aim is to add professional training and apply well-founded concepts.

The master's program in Engineering and Management of Physical Assets covers various topics related to the management of physical assets, a growing area due to the evolution of physical assets. This evolution has been reflected in the increase and complexity of physical assets in organizations, especially in the hospital sector. This technological advance has brought about changes in the hospital environment, to the extent that it has become essential for a multidisciplinary team to be involved, with professionals specializing in this area, who are able to make the connection between the health and technology areas, supported simultaneously by engineering and physical asset management solutions.

In this way, the involvement of professionals specializing in this area makes it possible to obtain a broader view of the organization's existing physical assets. Through the application of improved strategies and techniques, according to the different characteristics of the assets, consciously and clearly assisting the condition of each asset throughout its life cycle and meeting the entity's intended objectives.

In the hospital sector, the evolution of physical assets has been accentuated in recent decades and Portugal's investment in the high increase in high-tech medical physical assets reinforces the inevitability of effective physical asset management, in order to extract the best potential from the assets in favor of the hospital sector's goal [1]. The strong commitment to new technologies allows us to improve the quality of diagnoses, patient treatment and the well-being of all those involved in the hospital environment [1].

Today, physical assets such as medical equipment are widely used in all areas of health services, making it impossible to provide services without them. Their use ranges from prevention, screening, diagnosis, monitoring, therapy and rehabilitation. This increase in physical assets and their complexity reinforces the importance of Physical Asset Management, since as the sophistication and cost of medical assets increases, so does the complexity and cost of maintaining them. Unlike other health technologies, such as disposable products, medical equipment requires maintenance (scheduled and unscheduled) throughout its life cycle [2].

When a physical asset is acquired, the costs of using the asset during its life cycle, known as Life Cycle Costs (LCC), are usually known. However, the investment made by an entity in an asset has a direct impact and is intended to be strategic in helping the organization produce goods and services. It is therefore necessary to study the level of operation of each investment in assets, analyzing the maximum profit or otherwise from each asset and developing appropriate management throughout the life cycle in order to optimize the services and associated costs. In this sense, the study carried out throughout the life cycle of a physical asset should be analyzed from an LCI (Life Cycle Investment) perspective [3].

In this sense, LCI (Life Cycle Investment) appears to be a fundamental model for asset management, since it is developed taking into account all the investments made from the acquisition of the physical asset to its residual value, demonstrating the year in which the organization will have recovered the amount invested in the asset through the benefits generated, the total benefits obtained, as well as the total expenses and the best time to replace it. Life cycle analysis models such as this are an asset for the hospital sector, whether private or public, because they make it possible to determine the level at which an investment will be viable and to consider the costs and returns associated with the investment made in exact monetary terms [4].

## 1.2 Motivation

This work was carried out as part of an interest in asset management, specifically physical assets in the hospital sector, since these assets are of great importance and impact on society, particularly on patient health. A vision of effective and efficient management has an impact on the motivation to cooperate in resolving problems that may exist, and on the development of studies that awaken new perspectives and points of view to improve the assets of this sector.

There are concepts to take into account when owning a physical asset, such as the economic perspective, and it is necessary to study the impact that this investment will have on the hospital, how the global economy can influence existing assets, what their residual value is, what the depreciation value is over the years, obsolescence, the costs associated with maintenance, among others. This economic perspective seems to be abstract in the hospital environment and this can influence decision-making, particularly when choosing which asset to acquire and when to replace it [5]. Failure to associate these factors with hospital assets can lead to failures and malfunctions, which is barely tolerable, since these assets deal with and directly impact the health of patients, through diagnoses and treatments [5].

Physical asset management in the hospital sector can play an important role in the development of studies, well-founded methodologies and subsequent application in practical life. These factors may be able to assist and collaborate with all the different groups in the hospital organization, resulting in correctly functioning physical assets, capable of performing their function in accordance with the objective of the entire hospital service.

## 1.3 Objectives

The aim of this study is to implement LCI (Life Cycle Investment) in imaging equipment. LCI is an life cycle analysis model developed to help with the management of physical assets, as it makes it possible to analyze the year in which the organization will have recovered the amount invested in the asset, the total benefits and expenses over the years and the best time to replace it. To calculate this model, all the values involved are taken into account, namely the initial acquisition value, operating value, maintenance value, residual value, depreciation value, inflation value and monetary restatement value [3].

The aim of this model is to apply it directly to medical imaging assets, namely ultrasound, mammography and X-ray, which are operational in a hospital organization. The fact that these are three different assets allows the model presented to be understood more comprehensively, based on different values, performance and functionality.

In addition, the purpose of this report is to understand:

- The importance of the assets under study and their operation;
- The importance of management in the interdependence of medical imaging equipment;
- The types of maintenance and their importance;
- Values associated throughout the life cycle of an asset;
- The importance of performance indicators (KPI'S);

- Return on Investment (ROI) of each asset.

The document discusses some of the crucial issues to be considered when managing physical medical assets and the relationship between them. In a practical way, they can result in the life cycle analysis model known as LCI, which makes it possible to graphically visualize the impact that all the variables considered represent throughout the asset's life cycle.

## 1.4 Report structure

This report is divided into seven chapters, the first of which is called the Introduction, in which the subject of the report is contextualized by describing the motivation, the objectives for the development of this report and the structure of the report.

The second chapter, called "Theoretical ground" presents and develops, as the name suggests, important theoretical foundations for contextualizing the topic, such as a description of what medical devices and equipment are and a description of the medical imaging equipment studied in this report.

The third chapter, "Asset Management", presents the fundamentals of asset management. This chapter begins with the definition of a physical asset, covering the objectives and procedures to be taken into account in asset management. It also discusses the various phases that can occur throughout an asset's life cycle and provides a description of the values to be considered throughout this period. The chapter ends with the importance of standardization in physical assets and a list of some of the existing standards for medical devices and equipment.

The fourth chapter, described as "Importance and ways of helping the asset throughout its life cycle", analyzes various indicators to take into consideration throughout the life cycle of an asset, in addition to those described in the third chapter. This chapter begins by highlighting the importance of maintenance and the various types of maintenance that exist, followed by a presentation of some performance indicators and problems that can arise when extending an asset's life cycle. The chapter ends by presenting the impact that asset management has on sustainability and the role and importance of an asset management engineer.

The fifth chapter, "Application of the Model - Life Cycle Investment", describes the entire methodology and all the considerations and interpretations of the model, as well as the direct application of the model to all the medical imaging equipment under study.

The sixth chapter is, as the name suggests, "Discussion of results", as it presents the discussion and considerations on the results obtained in the fifth chapter.

The seventh and final chapter presents the conclusions drawn from the work carried out and suggestions for future work.

At the end, the bibliography and annexes complement the body of this work.

# 2 THEORETICAL GROUND

Knowing the existing assets in an organization according to their characteristics, specificities and all the procedures to keep them functional is an important step in monitoring the asset throughout its life cycle and therefore allows for better results in the asset's objective and, consequently, support for the organization as a whole.

This chapter discusses the difference between a medical device and medical equipment, as well as the characteristics and requirements of each. Next, the three medical imaging assets studied throughout the report are named, characterized and their functionality, components, necessary structure and radiological protection, should they need it, are briefly explained.

## 2.1 Difference between Medical Devices and Equipment

Medical equipment and medical devices are both fundamental tools to be used in the healthcare sector, as their main purpose is to help solve medical problems. However, these tools are different, and it is necessary to adopt a categorization approach, through their constitution, functionality and risk [6] [7]. The different definitions of each one are given below.

### 2.1.1 Medical Devices

Medicine has relied on various medical devices as essential tools to support the treatment, cure or alleviation of diseases. The medical devices used today are engineered instruments with materials and combinations of parts, used to complement and assist the skills of doctors, nurses and other healthcare providers. Medical devices can be single-use and reusable devices, according to United States of America regulations [8].

Single-use devices, also known as disposable devices, are defined as devices that are used in a single procedure, only on a single patient and “are not intended to be reprocessed (cleaned, disinfected/sterilized)”. On the other hand, reusable devices are defined as “devices that can be reprocessed and reused on several patients”, based on their risk of transmitting infection and according to the areas of the body with which they will come into contact. However, reusable medical devices can be subdivided into [9]:

- Critical reusable medical devices: those that come into contact with blood or tissue, such as surgical tweezers;

- Semi-critical reusable medical devices: those that come into contact with mucous membranes, such as endoscopes and colonoscopes;

- Non-critical reusable medical devices: those that come into contact with intact skin, such as stethoscopes;

Reusable medical devices undergo thorough cleaning through disinfection and sterilization processes. These devices are made from materials that can withstand repeated, high-temperature cleaning, disinfection and sterilization in order to remove all infectious and biological residues from a patient that could harm the next patient [9].

### 2.1.2 Medical Equipment

The Joint Commission defines equipment as "electronic, electrical or mechanical instruments used in the direct care of patients". It adds that it can be fixed or portable equipment, used for diagnosis/laboratory, treatment and monitoring, whose function is to provide health care to individuals. Medical equipment has various characteristics depending on its purpose and size, but it should be noted that [8]:

- It is necessary to ensure that electrical safety and proper operation are not compromised, especially if it is being transported;

- Include maintenance tasks, maintenance frequency and execution strategies until failure;

- They must include an alert component for life-support assistance or any other assistance, in the event of a risk of serious injury or death to a patient or any failure on the part of members of the treatment team.

The Joint Commission subdivides the broad type of medical equipment into high-risk medical equipment. High-risk medical equipment is all life-support equipment or any other equipment in which there is a risk of serious injury or death of a patient or member of hospital staff in the event of a malfunction, such as defibrillators. For medical equipment considered to be high risk, there is a set of best practices in place to combat any life-threatening problems, such as battery charging or power problems [9].

## 2.2 Imaging Equipments

Imaging equipment is developed with the aim of making it possible to visualize one or more parts of the body, in order to help with the prognosis and monitoring of possible diseases. To this end, imaging equipment is made up of high-tech materials, supported and developed by advanced engineering and functional design [10].

Decades after decades, technological progress has made it possible to improve the quality of examinations, results and safety for both the specialist and the patient [10]. These technological advances, coupled with the investment made in the field of medical imaging, have enabled the implementation of new medical imaging methods, with more developed imaging facilities, greater availability and quality. These factors are some of the reasons behind the significant increase in the number of imaging exams in recent years [11].

All these advances in medical imaging have led to an increase in the amount and type of equipment with different characteristics, particularly medical imaging assets such as ultrasound scanners, mammography equipment and X-rays. It is therefore necessary for physical asset management to be efficient and effective, in order to keep these assets functional throughout their life cycle [12].

### 2.2.1 Ultrasound scanner

An ultrasound scanner is a diagnostic system that allows real-time visualization of dynamic structures and processes in the human body using ultrasound. The diagnosis made with an ultrasound scanner transmits highly accurate scenarios, since it uses very realistic, high-precision tools with a high update rate. The images provided can be transversal to the abdomen and of various internal organs, which allows diagnosis of many clinical practices [13].

The ultrasound technique is the second most widely used clinical imaging modality, behind conventional radiography [14]. This exponential growth is due to the fact that it is widely used by many professionals in daily clinical routine techniques, describing it as a practical, fast technique that doesn't cause discomfort to the patient. This technique is used on its own, but also as a complement and aid to other medical imaging modalities, such as mammography [15].

#### 2.2.1.1 Functioning

The ultrasound scanner consists of a variety of portable probes, which are used depending on the anatomical structure to be studied, called transducers, which allow information to be captured for later visualization (**Error! Reference source not found.**). The transducer is placed directly on the patient and moved, using a water-based gel to couple the ultrasound between the transducer and the patient [16].

Transducer works from a series of various piezoelectric crystals that vibrate when an electrical signal is applied, producing high-frequency sound pressure waves, which are ultrasounds [17]. This process occurs when ultrasound directs ultrasound waves at the body, which pass through the skin and enter the body. As the waves encounter tissues with different characteristics and densities, they produce echoes that reflect back to the piezoelectric crystal, allowing a series of image lines to be made, corresponding to the anatomical position and the intensity of the reflected echoes. This process gives rise to a complete image picture called ultrasound [18]. This method also works inversely, i.e. when acoustic pressures on the body cause variations in the dimensions of the piezoelectric crystals, magnetic fields appear [17].

Diagnostic ultrasound scanners operate in the frequency range of 3 to 10 Megahertz, hundreds of times higher than the limit of human hearing. This technique operates at high frequencies which allows for better discernment of image details, as the higher frequencies have a correspondingly shorter wavelength, thus obtaining sonograms with sharper details [16].

#### 2.2.1.2 Components

An ultrasound scanner consists of one or more probes connected to a scanner unit that provides the controls and displays the images. Typically, ultrasound scanners have several probes, such as an abdominal probe, linear probe, micro convex probe, trans vaginal probe and trans rectal probe, which come in different shapes and sizes, in order to facilitate the specific body area of interest, as well as a monitor for viewing, a control panel and a keyboard [16] (Figure 1).

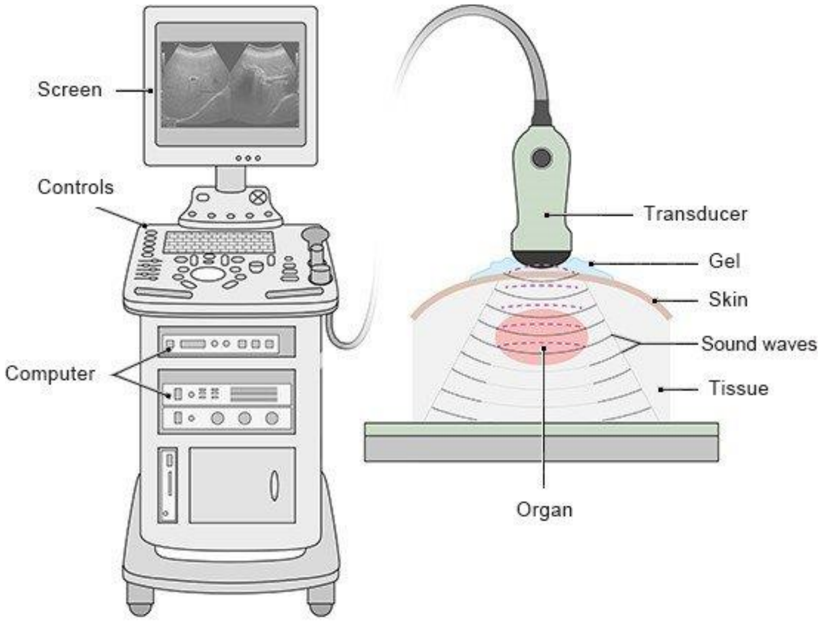


Figure 1 - Simplistic image of an ultrasound scanner and how it works. Source: [88].

### 2.2.2 Mammography Equipment

Mammography equipment is normally used in a so-called mammography examination, built to generate ideal mammography images. Mammography equipment is developed and designed in such a way that it is easy and light to manipulate, being easily movable to achieve multiple projections from various angles of the breast tissue, using low-dose X-rays [19].

#### 2.2.2.1 Functioning

To carry out the examination, the patient must stand in front of the mammography equipment, the breast is placed on the flat detector and then the compression paddle is gradually lowered to compress the breast for a few seconds. In order to obtain high quality mammography, several factors are required, such as breast positioning, compression, optimal exposure, sharpness, noise and contrast [19].

Increased attention is required during the examination, since the positioning of the equipment and compression are monitored by the operator. These two well-suited aspects eliminate mammographic artifacts, allowing the greatest amount of breast tissue to be visualized, as well as better quality and greater detail in the image generated [19]. During mammography, assessing patient doses is crucial to evaluating practice and ensuring compliance with national and international diagnostic reference levels [20].

#### 2.2.2.3 Components

All areas of the equipment that come into contact with the patient should be smooth, with no sharp edges or corners, and no external parts should become excessively hot. Since it is a vertically positioned piece of equipment, it should be designed with handles available for patient assistance, without compromising the exact positioning of the image acquisition [21].

The basic mammography equipment consists of: an upright gantry with angling capability, an X-ray tube, X-ray filters, collimator, detection plates, automatic exposure devices, pressure paddles, face shields, handles, foot and hand controls, compression and height adjustment controls, manual grasp controls, etc [21]. In addition, it is essential to use protective equipment for the technical staff carrying out the mammograms, namely a protective shield with a remote control station to operate the equipment (Figure 2) [22].

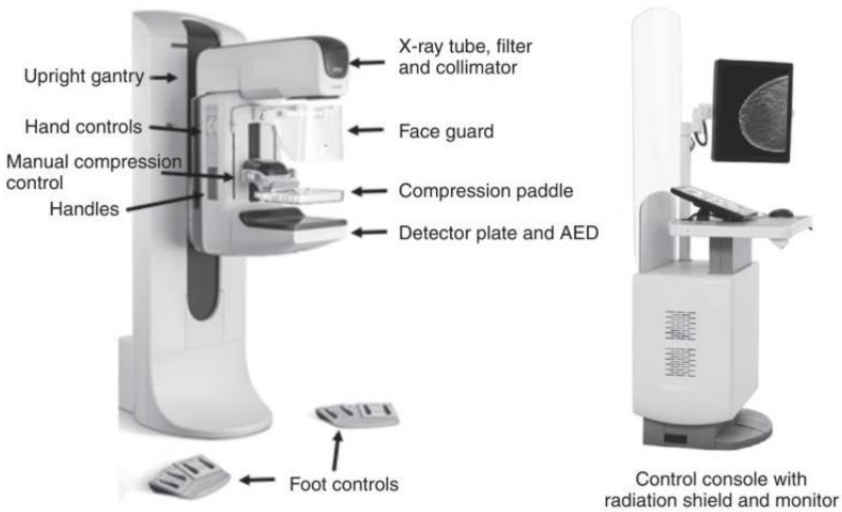


Figure 2 - Basic mammography equipment. Source: [21].

### 2.2.2 X-ray

X-ray diagnostic equipment makes it possible to directly generate, control, capture and convert X-ray energy into digital signals which are then processed and displayed on an observation screen. In this way, it is possible to obtain the visualization of radiographic images of anatomical structures generated by X-rays for the diagnosis of human tissues and organs [23].

X-ray imaging is a powerful and low-cost technology that has been widely used in medical diagnostics, since through the excellent penetration capacity of X-rays anatomical images can be obtained in a non-invasive way [23].

#### 2.2.2.2 Functioning

The patient can stand horizontally or vertically, depending on the anatomical structure being diagnosed, where an X-ray beam will be directed.

X-rays are a type of ionizing radiation with a wavelength ranging from 0.01 to 10 nm. X-rays travel through matter and are transmitted, absorbed or scattered. The amount of X-rays is determined by both the nature of the matter and the energy of the incident X-rays [24] [25].

The X-rays are released by a potential difference in the electrons between the cathode and anode in the X-ray tube. The X-ray detector is placed behind the object to record the transmitted X-rays, where the X-ray imaging system converts the X-rays transmitted by the object into a visible image. In this sense, radiographic images are based on the contrast of the difference in attenuation of objects within matter in relation to X-rays. It is from these images that the internal structures are subsequently assessed [25].

#### 2.2.2.3 Components

The components of an X-ray diagnostic system are (Figure 3) [26]:

- X-ray tube, X-ray generator, tube holder (support), examination table (patient support) and control unit (patient support);

- Accessories such as: intensifier screens, cassettes, films, etc;

- Darkroom equipment and other materials for processing radiological films;

- Radiation protection devices.

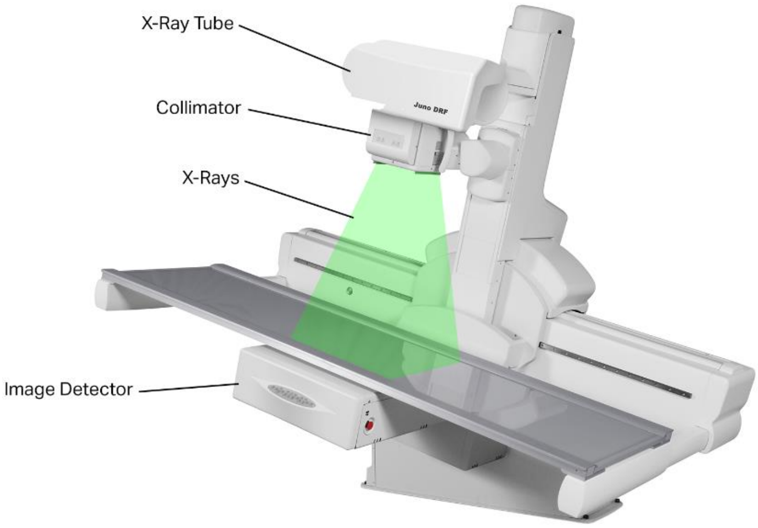


Figure 3 - Simplified X-ray equipment. Source: [94].

#### 2.2.2.4 Structure and Radiation Protection

In a room where examinations are carried out using equipment with ionizing radiation, the surrounding structure must follow the rules laid down for radiological protection and safety. In this sense, a room with X-ray equipment must follow guidelines during its construction. A room must include a shielded control booth outside the X-ray room or a protective separator (large enough to protect the operator), with a lead equivalence of at least 0.5 mm, a leaded glass window and a leaded door. There should also be accessories for operators such as protective aprons with lead of at least 0.25 mm, as well as rubber or plastic strips with lead, with an equivalence of at least 0.5 mm, for use as gonad shields [26].

# 3 ASSET MANAGEMENT

A dynamic and competitive environment such as today's society makes asset management indispensable. It is an activity that requires in-depth knowledge of the assets themselves and their environment and requires the coordination of all the processes and parties involved and related to that asset.

This chapter covers the basics of asset management, namely what an asset is, what asset management consists of and the objectives of asset management. This is followed by the procedures to be taken into account in asset management, namely the information management and optimization strategy and the list of values required throughout the life cycle. Finally, the different phases throughout the life cycle are presented, as well as standardization for the different types of hospital assets.

## 3.1 Fundamentals of Asset Management

Asset management makes organizations look for new ways to manage their resources and production processes more efficiently. In this sense, it is necessary to compress and classify the different assets and their objectives.

### 3.1.1 An Asset

The International Organization for Standardization (ISO) classifies an asset as something that has “actual or potential value to an organization”, depending on the organization's framework, the asset can be tangible or intangible, financial or non-financial [27].

In this sense, the following assets can be recognized, which can usually be identified in various organizations [28]:

- Physical assets;
- Financial assets;
- Human assets;
- Information assets;
- Intangible assets;

Physical assets are elements such as facilities, machinery, roads, vehicles, aircraft, equipment, medical equipment, medical devices and others. In addition to physical assets, financial, human and information assets are also of great importance to physical assets, as they support the management of physical assets, providing information and a solid basis for effectively managing them [28].

### 3.1.2 Asset Management

Asset management is generally defined as the activity associated with the identification of assets, which includes processes, resources, skills and technologies that enable the construction and development of effective and efficient delivery of management plans [29]. He [28] adds that asset management supports the realization of an entity's production by helping to study the financial, environmental, social, quality and performance costs of assets.

Asset management is also the set of management activities associated with the life cycle of an asset, namely [28]:

- Identification of the necessary assets;
- Identify financing needs;
- Acquisition of assets;
- Logistical and maintenance support;
- Support for the disposal and renovation of assets.

Asset management is a meeting point between the technical and business domains. The aim of asset management is to combine technical expertise with business knowledge in order to effectively and efficiently meet the needs of the company as a whole. This requires the involvement of diverse areas from asset evaluation to asset acquisition, to logistical support, to understanding asset support standards and compliance throughout the lifecycle process [28].

### 3.1.3 Objectives of Asset Management

In order to achieve good results, an entity effectively depends on strategic plans implemented and developed by efficient asset management aimed at [30]:

- Maximize uptime (productive capacity);
- Maximize the capacity to produce according to specific quality levels;
- Minimize costs per unit produced;
- Minimize the risk of loss of production capacity, quality or economic;
- Preventing safety risks for workers and users;
- Ensure the least possible risk of damage to the environment;
- Comply with national and international due diligence regulations.

In order to build efficient asset management, it is important to build a targeted and integrated organizational structure throughout the asset's life cycle. It is necessary to build standard systems, rules and regulations into the management system in order to build a long-term feedback system. In addition, it is necessary to develop information platforms, where it is possible to access all relevant asset information in various departments, in order to share resources and information between different work sectors [31].

As far as the management of imaging equipment is concerned, effective management is crucial, since this is expensive equipment, from the moment it is purchased to the entire surrounding structure (if necessary), maintenance and continuous improvement of quality levels [32]. In addition, this equipment inevitably suffers a decline or loss of image quality after a certain period, which adds to the importance of maintenance and the requirement for continuous monitoring [10].

In order to help manage hospital physical assets, there are projects being implemented, such as platforms that help optimize inventories and stocks [33] and the implementation of asset management systems, such as radio frequency identification [34], this is an added value for the entire hospital environment involved [35].

## 3.2 Asset Management Procedures

Physical assets have a life cycle that must be understood in order to support better decision making in the pre-acquisition phase. Normally, in an organization, the decision-makers and their respective costs are different from those responsible for the operational side and maintenance of the assets and, subsequently, they are different from those responsible for disposing of the asset. This fragmentation of groups of people with different responsibilities throughout the lifecycle can cause problems throughout the asset's lifecycle [36].

Ideal asset management requires asset managers to be familiar with their organization's assets in a technical business and operational context. It is essential to have a comprehensive view of the assets as a whole, to understand the relationships between them, the interdependence and degree of criticality between the assets deployed, in order to be aware of the condition of each asset [37].

In this sense, it is necessary to have an aligned strategic plan, with the main components in a program that may include [38]:

- Interaction with the capital budget;
- Acquisition and implementation;
- Constant monitoring and evaluation;
- Waste management.

### 3.2.1 Information Management Strategies

When acquiring an asset, it is necessary to verify guarantees and safeguards for both the entity acquiring the asset and the supplier, throughout the asset's life cycle. These guarantees and safeguards must be made through a clear, simple and properly structured description of all the processes and needs that it requires or may require for the asset to function throughout its life cycle. This asset management plan in a medical facility provides a clear vision of the future needs of the equipment and allows decisions to be made based on expenses that can be planned in good time [39].

Furthermore, in the case of an asset that captures information, such as imaging equipment, it is extremely important to understand the entire process of information collection and subsequent visualization. In this sense, [40] structure some of the steps to take into account when acquiring knowledge of an asset:

1 Asset information strategy:

Adopt an asset information strategy, which consists of implementing a plan capable of holding all asset information, such as: definition, collection, communication management and general asset information policy.

2 Existing asset reporting standards:

Examine the standards developed to support asset management and create a communication plan so that the standards are implemented.

3 Asset information systems:

Understanding the asset's information systems, i.e. analyzing whether the entity's information systems have the storage and support capacity to ensure that data is centralized and accessible to the respective entities that have access to it throughout the asset's life cycle.

4 Asset data and information management:

The subject of data and information management analyzes how the storage systems and procedures that an entity uses to store information, in other words, it examines the various processes and plans that frame the management and coordination of information for as long as necessary.

The topic of information systems and data management is a crucial one to analyze when purchasing medical imaging equipment, since most medical images today are in digital form. It is crucial to check these parameters carefully, since a unit that provides and assists medical care must take care of the storage, accessibility and durability of all the information of many patients over several years.

### 3.2.2 Optimize

Asset management seeks to obtain the best productivity solution taking into account existing assets in accordance with their management. This is done by setting priorities. In this sense, seeking to balance factors that can maximize the profitability of assets with other factors that can be minimized is the balance that asset management aims for, in order to obtain maximum profitability from them [41].

Factors to maximize:

- Quality: in repair, precision, techniques;
- Service level: fault resolution and prevention;
- Performance: asset reliability and uptime.

Factors to minimize:

- Time: response and resolution times and average resolution times;
- Costs: costs per unit of production;
- Risks: predictability of inevitable failures.

This balancing process is an optimization process stemming from effective and efficient asset management, focusing on continuous improvement and commitment throughout the life cycle of all processes, getting the best out of the assets in order to achieve the entity's ultimate goal from the assets.

## 3.3 Life Cycle of a Physical Asset

All physical assets go through various phases throughout their life cycle, which begin when they are acquired, built or installed and end when they are no longer used [42]. Second [43], the life of an asset can be defined in three different ways: physical life, useful life and economic life.

### 3.3.1 Physical Life

The physical life phase consists of the period in which the physical asset is expected to last physically, i.e. it begins when it is acquired and ends when the asset is worn out and can no longer reliably produce its functionality at the required level. This phase usually begins with planning and development, followed by acquisition and commissioning (S1), productivity growth (S2), maturity (S3) and decline (S4) (**Error! Reference source not found.**). It is in the maturity phase (S3) that the physical asset reaches peak productivity, i.e. it is in this phase that it is operating at its maximum capacity [42]. When the physical asset reaches the end of its physical life, it is uninstalled, dismantled and replaced [43].

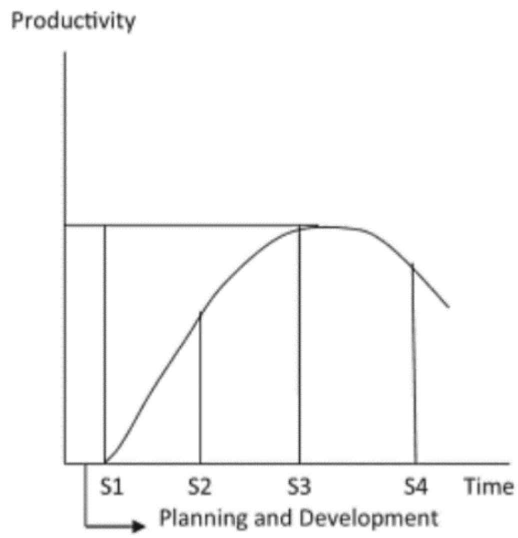


Figure 4 - Relationship between the physical life of physical assets and productivity. Source: [43].

Throughout this life phase, as equipment ages, maintenance costs and operating costs increase. Obviously, this is influenced by various factors throughout this period, including manufacturing (production processes and type of materials), working environment conditions, performance levels and quality strategies, quantity and quality of maintenance [44].

### 3.3.2 Useful Life

The useful life phase begins when the physical asset is acquired and, according to [45], ends when the sum of its maintenance costs exceeds the capital cost of equivalent new equipment. The end of a useful piece of equipment's life is characterized by an increase in the number of maintenance tasks and the corresponding cost, which makes the asset more expensive.

Neste sentido, o final de fase de vida útil deve ser acompanhado e identificado, de forma a não comprometer o processo operacional. Segundo [43], the end of this phase shows that the end of the physical life phase is approaching, which may indicate a greater likelihood of the asset's reliability diminishing.

### 3.3.3 Economic Life

The economic life phase begins when the physical asset is acquired and is analyzed by means of the expenses and the profit derived from it. The study of the economic life phase begins when the physical asset is acquired and consists of the continuous study of all the surrounding values throughout the life cycle, through the calculation of economic models [43].

Life cycle analysis models make it possible to make more informed decisions, as they allow for a detailed analysis of profits and costs, since this analysis encompasses: acquisition, operating, maintenance, depreciation and downtime costs, inflation, among others. In this sense, these models can help with buying and selling decisions and reveal the optimum replacement year [44].

Economic life is shorter than the physical life of the asset, since the asset may continue to have the capacity to perform its function, however the erosion caused by profitability requires increased operating and maintenance costs [43].

### 3.3.4 Technological Life

The technological life of a physical asset is defined as the period until technological change dictates its replacement, due to the development of a technologically superior alternative. Technological life is important to be properly updated throughout the life cycle of an asset, since the productivity and competitiveness of companies can depend on technological evolution. In this sense, technological life can be quantified by improving efficiency, comparing production with costs, for example, higher production rates, lower operating and maintenance costs and/or higher scrap values [44].

Technological changes in equipment are classified as: continuous changes or discontinuous changes. A continuous change appears as incremental improvements to the physical asset so that it performs its function in a more optimized and improved way, seeking to increase performance and efficiency. On the other hand, discontinuous technological change arises from the discontinuation of the technology that the asset uses, i.e. the total reformulation of the existing technology in the asset [44].

### 3.3.5 Social and Environmental Life

The social and environmental life of a physical asset is defined as the period until the will of the entity or legal requirements encourage replacement due to environmental and social conditions. These conditions may derive from the entity holding the physical asset needing to ascertain and correct possible legal and governmental requirements, which are being introduced with principles and bases geared towards a more sustainable vision. The degradation of physical assets has become a major environmental concern, leading to an increase in policies aimed at companies manufacturing products and providing services that minimize the ecological burden. In this sense, both social and environmental issues are covered in favor of sustainable development [44].

The social and environmental life stage must be taken into account from the manufacturing process to the disposal of the physical asset. Throughout this process, it is necessary to assess the consequences for the environment, such as the resources expended at all stages, namely the processing of raw materials, production, transportation, distribution, recycling and final disposal. Social and environmental life evaluates and quantifies energy, materials used and wasted and assesses the product's impact on the environment [44].

All these theories, with different approaches and analyses, complement each other so that it is possible to build a robust physical asset life cycle. These approaches are intended to help organizations that depend on their physical assets to provide goods and services to make timely, informed and well-founded decisions from the moment of acquisition to the moment of replacement, so as not to jeopardize the organization's operability and economy.

## 3.4 Values Throughout the Life Cycle

The management of a physical asset includes an understanding of all the costs involved during its life cycle, namely ownership costs. Ownership costs encompass all direct and indirect expenses associated with the respective physical assets, including: all costs associated with the acquisition of the asset, operating costs and disposal costs [38].

On the other hand, [46], suggests a different view on the designation of these amounts paid, in the sense that investment and costs usually have different meanings. The initial cost paid for an asset is referred to as an investment and the amounts that come from operating the asset are referred to as costs. In this sense, the author suggests calling the initial cost an initial investment and the operating costs investments [46].

Identifying all these values involved during the life cycle of an asset is the knowledge base for making more accurate decisions, which helps in the process of comparison, planning and deciding when to replace the asset [38].

### 3.4.1 Initial Acquisition Value

The acquisition value is usually the payment to the supplier for the respective physical asset. This acquisition value usually includes not only the actual value of the equipment itself, but also: associated fees and charges, delivery, installation (including, for some equipment, specialized construction work), mobilization and sometimes demobilization, commissioning and operational training. [47] [36]. In order to acquire a physical medical asset, the hospital needs access to a source of capital funding [47].

**Private Public Hospital Sector**

In the private hospital sector, capital can be obtained from the organization's capital reserve, or it can be a loan from banks, paid overtime, plus interest [47]. On the other hand, in the public hospital sector, since they are government-funded organizations, funding is acquired through various pre-contractual procedures, including direct award and public tender. Direct award is a procedure in which the contracting authority directly invites an entity of its choice to submit a tender. For a direct award to take place under the simplified regime, the value of the procurement contract must be less than €50,000. If this is not the case, the procedure known as a public tender takes place, in which those interested in the contract start by submitting bids in order to be chosen for the acquisition of the respective asset. In this procedure there is no prior assessment of the bidders' qualifications, nor any history of technical and financial capabilities [48].

An organization, particularly a healthcare organization, benefits from the acquisition of available assets in that it enables better healthcare for those who provide it and those who receive it. The expense incurred when acquiring a physical asset provides benefits in helping to apply its functionality during its financial lifetime [38].

Physical assets increase the organization's assets and therefore its capital value, since these assets are attached to the entity's financial capital, however these capital asset values are depreciated over time [47].

### 3.4.2 Depreciation

Depreciation of a physical asset can be seen as "a portion of the value charged to the cost of production, corresponding to the wear and tear suffered during the use of the physical asset in the production process. Regardless of the method used, the annual depreciation charge is a function of the initial value of the asset and its useful life" [49]. This will result in a value, also known as the residual value, which is intended to be received if the asset is sold and taken out of service [49]. Since depreciation corresponds to the capital value of the physical asset that depreciates, the value of the asset usually decreases, reaching zero at the end of its useful life [47].

Depreciation calculation methods can vary. The basis used to know the value of a physical asset when carrying out a depreciation calculation should be its initial cost minus any residual value the company expects to receive if the asset is taken out of service. There are some assets where the residual value can be difficult to determine for various reasons. For example, if the asset is too large or involves some use of a radioactive substance or causes an environmental risk, the cost of removal may exceed the residual value, which could be negative [50].

### 3.4.3 Operating Values

Operating values encompass all the operational values for the equipment to perform its function correctly throughout its life cycle.

#### 3.4.3.1 Maintenance Value

Maintenance values guarantee the expected benefits of the asset in its production process. These values are usually financed by revenues which, as they do not add to the capital benefits, are not recorded in the financial capital of the asset but are noted and added as operating revenue records [47].

In the first few years after the equipment is purchased, the warranty period is negotiated between the entity and the supplier. This period consists of the time in which the maintenance and spare parts costs are included in the warranty terms, i.e. the period in which the supplier is responsible for these costs and not the entity that acquired the asset. After this warranty period, the entity that acquired the asset is responsible for the maintenance costs [47].

After the physical asset's warranty years maintenance can be carried out through a combination of external contract maintenance with manufacturers and/or by in-house teams. Deciding on the ideal balance between the two forms of maintenance should be weighed up according to the benefits provided (ratio of benefits to costs) for example covering only corrective maintenance or only preventive maintenance to optimize value [47].

#### *3.4.3.2* Energy Values

The energy value is an operational value that must be taken into account if the physical asset requires energy for its operation. In this value, it is necessary to consider the cost of the amount of electricity used, which varies depending on a number of factors such as: the type of equipment, the power of the equipment, the period of use, among others [36].

#### *3.4.3.3* Consumables Values

There are devices that may require one or more consumables, as they may need to consume a particular accessory/item during the use process.

There are two ways of acquiring consumables for assets. On the one hand, there are contracts where consumables are paid for separately and the organization chooses the supplier from whom it wants to purchase them. On the other hand, there are contracts in which the supplier can offer the equipment to the organization, without any initial purchase price, as long as the organization contracts to purchase a specific number of consumables over a certain period. In this case, the accumulated value of the consumables over a number of years makes up or may exceed the initial acquisition value of the asset, since the value of the asset is included in the value of the consumables and spread over a number of years [47].

## 3.5 Standardization in Asset Management

With increasing globalization, companies are increasingly implementing management standards developed by the International Organization for Standardization (ISO) [51]. ISO classifies a standard as being able to provide rules, guidelines or characteristics for a certain activity or for certain results, with the aim of achieving the ideal degree of order in a given context [52].

In order to achieve consolidated and well-founded standards, ISO also collaborates with the International Electrotechnical Commission (IEC) on electronic standardization issues. In addition, each country has its own formal representatives who coordinate the standardization subsystem, and in Portugal the Portuguese Quality Institute (PQI) is the National Standardization Body (NSB) [53].

The development and implementation of standards allows many organizations to dedicate resources at a corporate level to evaluate, monitor and implement new management standards throughout the organization. In addition, one of the main objectives of standards is to enforce coherence, compatibility, safety, reduce performance variability between suppliers and promote global trade [54]. Implementing standards allows companies not only to make strategic decisions, but also to look for synergies between standards [51].

#### 3.5.1 ISO 55000:2014 – Asset Management

In January 2014, the ISO 55000 series of asset management standards was launched, along with the other associated standards that provide context, namely ISO 55001 and ISO 55002. The publication of these standards is attracting a great deal of attention in the way various assets are organized [55]

The international standard ISO 55000:2014 considers that [55]:

> "Asset management involves balancing costs, opportunities and risks against desired performance in order to achieve organizational objectives. The balance may require consideration at different stages over time.
>
> Asset management guides an organization to examine the need for and performance of assets and their systems at different levels. In addition, it guides them through the different stages of their life cycle (which can start from the conception of their need to their decommissioning, including the handling of any possible disposal of unneeded assets).".

Based on this standard, companies are implementing systems with the aim of obtaining more capable and critical systems, in order to achieve greater efficiency and improvement in their assets, which will consequently have an impact on their economic prospects. Following the context of ISO 55000, companies should consider maintenance plans, focusing on asset condition monitoring and reliability methodologies in order to assess the risks of their assets and information systems (Figure 5) [56].

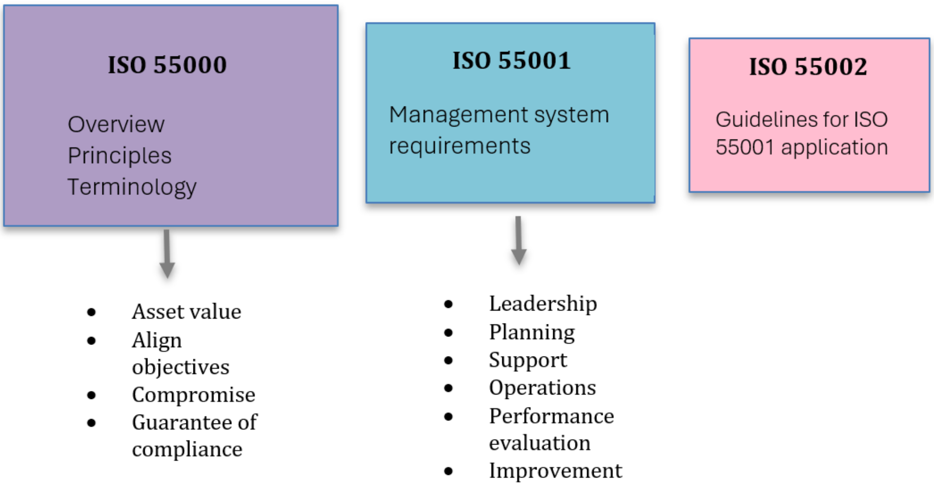


Figure 5 - Simple representation of the iso 55000 standard and others. Own author.

This ISO 55000 series is the world's first attempt at a vision of the relevance of managing any type of asset. This standard does not attempt to define "how to", since it depends on the organizational context and the respective assets. However, it guides and enables a strategic view to be taken of an organization's existing assets, providing greater trust between asset owners and service providers, customer relations and the trust of other interested parties [57].

### 3.5.2 Standards for Health Services

There are several standards aimed at the healthcare services sector. These standards are presented with described requirements for organizations that supply medical equipment and/or devices and provide services to the healthcare sector. These standards aim to provide guidance on management and best practices for both medical devices and equipment, in order to ensure legal compliance, patient and employee safety, efficiency and transparency in the management of assets that assist in the provision of health care [58].

In this sense, there are a variety of standards aimed at physical assets such as medical equipment, such as [58]:

- ISO 19054:2005 – Railway systems to support medical equipment;
- ISO 12052:2017 – Health informatics: imaging and communication in medicine, including workflow and data management. Standard intended to facilitate the interoperability of medical imaging equipment;
- Series of standards IEC 60601 – Technical standards and essential performance of medical electrical equipment;

- Serie rule IEC 60601-1 and derivatives Medical electrical equipment: general requirements for basic safety and essential performance.

On the other hand, standards are also being developed for medical devices, such as:

- ISO 15223-2:2010 – Medical devices: symbols to be used on medical device labels, labeling and information to be provided;
- ISO 13485:2016 Medical devices: quality management systems;
- ISO 14971:2019 – Medical devices: applying risk management to doctors;
- ISO 25424:2018 – Sterilization of health products: requirements for the development, validation and routine control of a sterilization process for medical devices;
- ISO/TR 20416:2020 – Medical devices: post-market surveillance for manufacturers;
- ISO 17664:2021 – Processing of healthcare products: information to be provided by the medical device manufacturer for the processing of medical devices;
- ISO 20417:2021 – Medical devices: information to be provided by the manufacturer.

Standards certification is an asset and helps asset management, as it is a great tool for harmonizing the various essential requirements. On the other hand, it can facilitate the reduction of waste and defects by controlling and improving the suppliers' performance. In the healthcare sector it becomes even more essential, as there is a huge diversity of physical assets with very specific characteristics, which has led to the creation of systematic assessments of medical technologies. These assessments are a common task in many European Union countries and Infarmed recognizes the importance of these assessments, as they maximize health benefits and quality of life, contribute to the sustainability of the hospital system, ensure the efficient use of resources, evaluate the use and effectiveness of technologies, reduce waste and inefficiencies and promote equitable access to physical assets that must be constantly managed, as they are in contact with the patient [59].

# 4 IMPORTANCE AND WAYS TO HELP ASSETS THROUGHOUT THE LIFE CYCLE

Nowadays, institutions have more technologically advanced and, at the same time, more complex physical healthcare assets, which reinforce the importance of operational performance, which is a differentiating factor. Operational performance is also based on the various types of maintenance implemented and tools that aid and promote continuous improvement and process optimization.

This chapter covers tools that help an asset throughout its life cycle, namely the importance of maintenance and frequently used performance indicators, as well as problems that can arise in extending an asset's life cycle. This chapter also briefly discusses the impact that asset management has on sustainability and the role of the engineer in physical asset management.

## 4.1 The Importance of Maintenance

Maintenance is defined as the combination of all technical and administrative activities in order to maintain the asset, installation and others, in the desired operating conditions. Desirable operating conditions involve keeping the asset in normal operating conditions, increasing reliability and availability while reducing the rate of breakdowns [60]. According to the Portuguese version of standard EN 13306:2007, maintenance is "the combination of all technical, administrative and management actions, during the life cycle of an asset, aimed at maintaining or restoring it to a state in which it can perform its required function" [61].

Maintenance allows entities to increase production capacity and/or provide services, reducing future capital expenditure through [41]:

- Maximize uptime;
- Maximize production/service accuracy;
- Minimize costs per unit produced/service provided;
- Practical and economic risk control;
- Increased security.

Asset management linked to maintenance makes it possible to intervene proactively in physical assets, increasing reliability, availability and productivity, which will consequently increase profitability and excellence in service provision. This is because maximizing profits depends on the ability to keep assets in working order, which is supported by maintenance, which sometimes requires downtime, taking away the asset's capacity for use. In this sense, minimizing downtime is fundamental to maximizing asset availability [41]. In addition, there is a direct relationship between the physical life stage of the asset and its maintenance, since an asset that is properly maintained will deteriorate at a slower rate than one that is improperly maintained [42].

In the hospital context, the maintenance of physical assets is fundamental to creating value in healthcare services, through availability and guaranteeing reliability, as well as reducing costs and saving hospital resources. The importance of maintenance in reducing risks is highlighted, as maintenance reduces the risk of exposure to clients and employees, resulting in an increase in the value of services [62].

The process of maintaining physical assets must be planned, implemented, monitored and continuously improved. Implementing appropriate maintenance strategies requires the following types of resources: human resources, material resources, financial resources and documentation [62]. To facilitate these processes, there are tools that help manage the maintenance of physical assets and that allow the actual performance of the asset to be monitored, helping to keep track of maintenance and prioritize maintenance requests received by health service parties [63].

In order to guarantee these aspects in physical assets, it is prudent for asset management, associated with a maintenance vision, to develop maintenance plans for all assets. A maintenance strategy involves creating maintenance plans based on existing types of maintenance, as shown in **Error! Reference source not found.**:

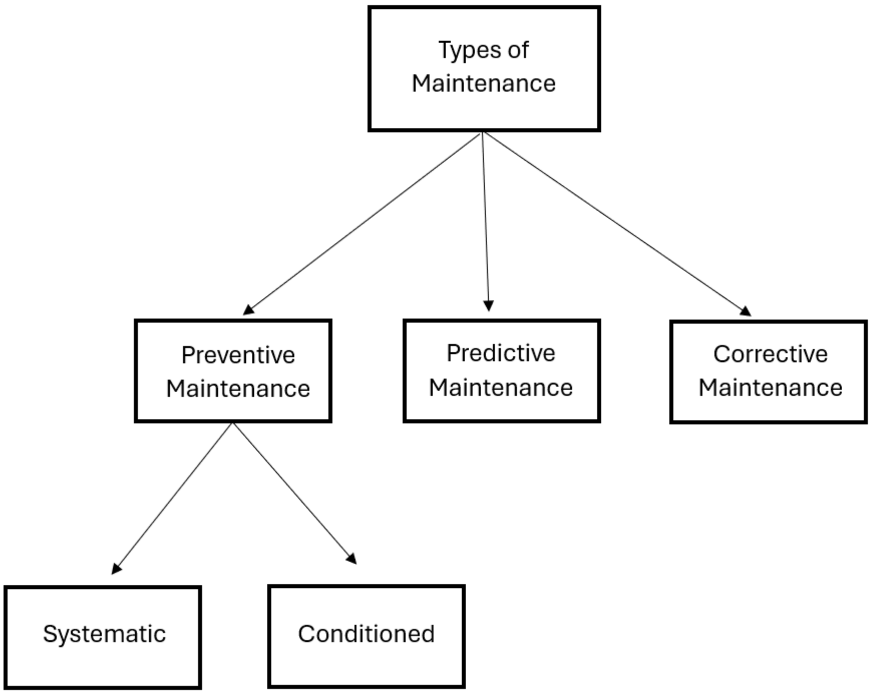


Figure 6 - Types of maintenance. Source: [99].

### 4.1.1 Preventive Maintenance

Preventive maintenance management is a maintenance management activity that involves various factors ranging from the availability of technicians, maintenance skills, available asset periods, task duration and the respective date set for the procedure. Preventive maintenance involves creating a predetermined schedule for routine inspections and replacement components that are planned in advance according to the respective asset. Preventive maintenance, once it is scheduled, helps to avoid unexpected breakdowns and ensures that the equipment functions optimally [64].

Systematic preventive maintenance is based on a previously developed plan to be carried out periodically. The programs are developed according to a parameter, such as a unit of time, which represents and clarifies the operation of the asset, as a way of monitoring the main parameters and trends to be analyzed [65].

In conditioned preventive maintenance, interventions are carried out according to a previously developed plan, linked to one or more parameters that the asset requires, when it reaches a certain limit, it inevitably requires an intervention [65].

### 4.1.2 Predictive Maintenance

In predictive maintenance, the use of advanced technologies is involved in monitoring operating conditions and analyzing asset data in order to control and warn of possible failures before they actually occur. When a monitoring alert occurs, interventions are made that are timely and allow the asset's downtime to be minimized [66].

### 4.1.3 Corrective Maintenance

Corrective maintenance includes all unscheduled interventions. In this type of maintenance, the problem that requires intervention is identified, corrected once it has occurred and the asset's operation is resumed. Despite being maintenance based on non-programming, it must be itemized and included in maintenance plans, as it can be difficult to predict the exact moment when it will occur, but it can happen and must therefore be safeguarded against [65].

## 4.2 Performance and Risk Indicators

There are crucial fundamentals in physical asset management that help analyze various metrics throughout an asset's life cycle, namely the concept of reliability, availability, continuous improvement and risk management. These terms play an important role, as they allow for better control over the asset and continuous monitoring, particularly of the overall functioning of various components, processes and systems [67].

### 4.2.1 Reliability

Reliability is defined as "the ability of a system to perform a required function under certain conditions, within a certain scope and over a certain period". In addition, reliability is directly related to asset safety, since in order to have a safe asset, it needs to be working properly [67].

In order to better understand the reliability of an asset, we use an illustration, shown in Figure 7, called the "bathub-curve".

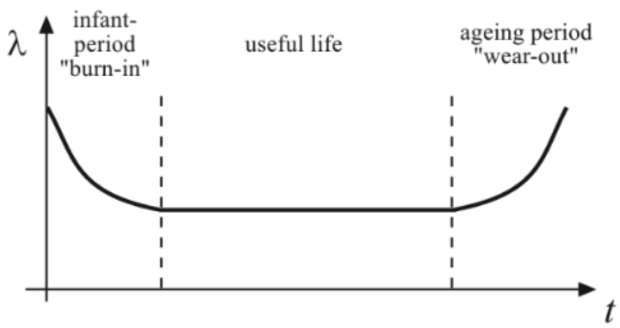


Figure 7 -Bathtub curve. Source [67].

The bathub-curve is the representation of the failure distribution curve of an asset, in that it is the statistic of the failure rate $(\lambda)$ over the lifetime $(t)$ the useful life of an asset [67].

The bathub-curve representation follows the idea of dividing the failure rate over the useful life of an asset, which can be divided into three distinct periods [67]:

- Infant- period: In this period, failures are referred to as early failures. These failures can occur at the beginning of the asset's acquisition, for example due to defects in manufacturing materials, structural or installation faults. The failure rate $(\lambda)$ decreases over time, since after this period there is a stabilization of the asset's failure rate.

- Useful life: In this period, failures are referred to as constant failures, since the continuous use of the asset causes wear and accumulated stresses that result in failures caused by use. The failure rate $(\lambda)$ is constant over time, since these failures can occur periodically and constantly.

- Ageing period: In this period, also known as wear out, the failure rate $(\lambda)$ increases considerably, since, as the name suggests, it is due to the long years of use of the asset. Over time, with constant use of the asset, wear and tear and faults accumulate, causing the number of faults to increase, resulting in a region of linear growth.

### 4.2.2 Availability

Availability is defined as "the probability of a given system working correctly at a given time. For repairable systems, it is a time-dependent function, just like reliability”. Reliability describes the probability that the operation will be fault-free by time t. Availability considers the probability of the operation being fault-free at time t, including possible downtime for repair [67].

Availability considers reliability, maintenance capacity and efficiency (by taking repair time into account) to calculate the probability of an asset being operational. This indicator is of great interest for entities to monitor more broadly how available their assets are, what impact reliability and maintenance have on them and, consequently, on the entity's final objectives [68].

### 4.2.3 Return On Investment - ROI

Return On Investment (ROI) is a performance metric that makes it possible to assess the efficiency or profitability of an investment. This indicator allows an entity to directly measure the percentage of return obtained on a specific investment [69]. Tracking ROI allows the entity to make more informed decisions, such as whether to buy or continue with the asset throughout its life cycle, since it is based on cash flows over the amount invested.

ROI analysis allows an entity to have a clear and quantitative metric of the investments made, allowing it to readjust, if necessary, the efficient allocation of resources. This metric is calculated on net return (rather than net profit or earned value), as it does not consider the value of depreciation, which can be negative [69].

If the ROI is positive, it means that the total return has exceeded the sum of the costs, meaning that it is a viable investment. Otherwise, when the ROI value is negative, the total expenses exceed the return, it is an unviable investment. ROI is considered good when the value generated by the investment significantly exceeds the initial cost. The higher the return, the more efficiently the resources invested were used [69].

The main factors influencing ROI include the value of the initial investment, the cost of ongoing maintenance and the cash flow generated by the investment as well as asset availability [69].

### 4.2.4 Continuous Improvement

Continuous improvement in a continuous process, such as asset management, aims to improve final products or services through processes of constant improvement in performance, in order to achieve better results overall. This improvement is focused in particular on the respective assets and, in general, on the entity's services, in a continuous and gradual manner. In this sense, an approach aimed at continuous improvement makes it possible to support an entity from a basic management level to an advanced management level over time [70].

To achieve this, it is necessary to raise standards in various sectors, such as [28]:

- Cleaning;

- Maintenance;
- Recording performance data;
- Identification of losses and their causes.

In this sense, the use of support tools facilitates and improves the quantity and quality of information, such as [28]:

- Performance indicators (KPI'S);
- Reliability and availability calculation methods;
- Auxiliary continuous improvement methods.

#### 4.2.4.1 Deming wheel

The Deming wheel (Figure 8) is an interactive method that aids continuous improvement. This method is made up of four steps that are ordered in such a way as to break down key stages with specificity and is adaptable to all systems and assets. The four steps follow the following order: plan, do, check and act [28].

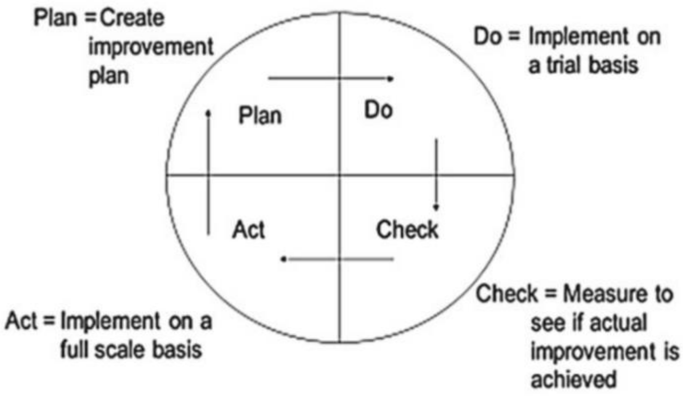


Figure 8 - Continuous improvement cycle - Deming wheel. Source: [28]

#### 4.2.4.2 Fishbone Diagram (Ishikawa)

The fishbone diagram (Figure 9) is a very important tool in the process of continuous improvement, as it is possible to follow the diagram in order to see if the surroundings, beyond the asset, are being properly executed, as this directly reflects on the productivity of the asset, such as [28]:

- Materials: suitability, wear, corrosion, fatigue, etc;
- Equipment: capacity, status, instrumentation, calibration, etc;
- Information: documentation, access, updating, etc;
- People: knowledge, training, skills, feedback, etc;
- Environment: temperature, humidity, lighting, cleanliness, etc;
- Methods: structure, appropriate, documented, compliance, etc.

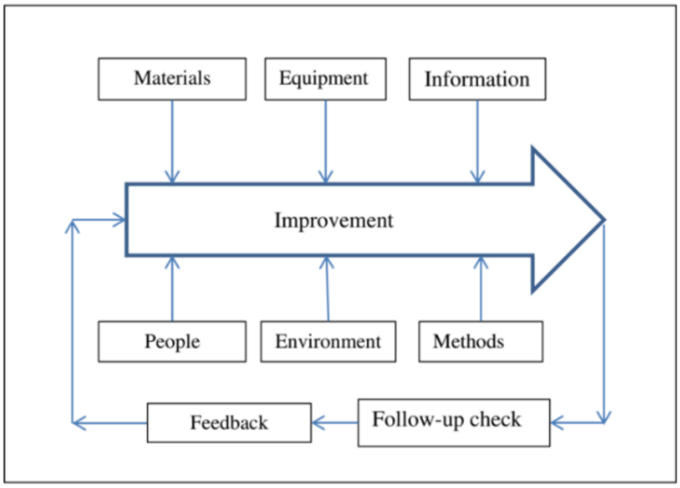


Figure 9 - Fishbone Diagram (Ishikawa) -
Simplified- Source: [28].

#### 4.2.4.3 Benchmarking Hospital

In order to monitor an entity's procedures and its assets, performance evaluations and audits are usually carried out. Both performance evaluations and audits are ways of monitoring process compliance and promoting continuous improvement of the system as a whole. In this method, verification of the processes used in physical assets is one of the sectors that is analyzed. In these benchmarking moments, various parameters are assessed, including [28]:

- Business policy and commercial planning;
- Asset planning;
- Acquisition of assets;
- Asset transactions;
- Asset maintenance;
- Asset replacement;
- Decision support tools;

At hospital level, the General Inspection of Health Activities is responsible for auditing, inspecting, disciplining and developing hospital action in the health sector. This analysis, according to the General Inspection of Health Activities, aims to ensure compliance with the law, to raise the technical standards of action in all areas of activity and health care provision, provided both by the services of establishments and bodies of the Ministry of Health and by private entities. [71].

### 4.2.5 Risk Management

Risk management is defined as the continuous process of identifying, evaluating and treating potential risks that may occur in an organization. Risk management is a process designed to protect the organization's assets and minimize financial losses, in that it is proactive management that aims to reduce the frequency and severity of unexpected incidents, reduce the impact of legal action and promote highly reliable performance. For this to work, risk management must be agreed and structured with the entire surrounding organization [72].

For risk management to be a control process embedded in the normal practices and activities of the entity, in this case in the hospital sector, a consolidated management program is necessary in order to [72]:

1 Identify and detect risks;

2 Assign risk values;

3 Loss anticipation;

4 Decide on objective and achievable measures to minimize the impact between the patient and the hospital.

#### 4.2.5.1 Risk Management Program

For risk management to be carried out correctly in the hospital sector, [72], structured a program that suggests elements to take into account:

1 The appointment of a Manager in charge of risk management, supported by all segments of the hospital community, from the Executive Director to the medical teams.

2 The Manager's role is to make rounds and meet with the heads of departments in order to familiarize everyone with the concept of risk management and their respective responsibilities.

3 Implement a program where risk management encompasses various parts of the hospital and its history:

   a) Identify situations in the hospital that could produce incidents and result in financial losses;

   b) Evaluate reports and incidents for at least six months and compare available data on incidents in other hospitals in order to be able to identify situations in the hospital that are likely to cause incidents;

   c) Eliminate unnecessary and dangerous procedures carried out on the premises;

   d) Analyze the history of buying and selling equipment that could result in legal action;

e) Transfer responsibility through "indemnity" agreements to the manufacturers of hospital physical assets;
f) Finding agreeable options between asset manufacturers and hospitals in order to meet the hospital's needs in the most reliable and cost-effective way;
g) Implementation of a complaint mechanism in the hospital by patients;
h) Implementation of continuous collection of negative healthcare data;
i) Identification of high-risk areas in the hospital;
j) Insert methods of continuous improvement in risk management.

To achieve these risk management objectives, it is essential for all organizations to involve teams in order to achieve the desired organizational results, such as productivity and safety. Of course, in a hospital environment, staff training is essential for successful management, since complex medical devices and equipment are handled, and they are in direct contact with patients [73].

In addition, risk management involves the involvement and interaction between the medical staff of the daily teams and the commercial companies, in particular the workers responsible for training hospital physical assets. In addition to these, other people whose responsibilities include maintenance or calibration, such as biomedical engineering staff, who are responsible for the routine cleaning, disinfection or sterilization of certain physical assets also need personalized training [73].

Contact between the different teams can range from initial training, usually aimed at using and supporting a new physical asset, to ongoing in-service training and individualized training, when indicated. Understanding the complexity of the asset technology in use is fundamental to reducing the risk involved [72].

#### 4.2.5.2 Risk Areas and Assessment

In addition to a structured program to find risks in order to mitigate them, an organization must also develop a standard risk classification system, with the aim of, after identifying the risk, categorizing it into types, such as "risk domains", "risk categories" or "risk areas". Categorizing risks into domains will help ensure that all areas are categorized [73].

Common risk domains identified in healthcare include: economic, operational, human capital, strategic, regulatory, technological and natural causes. Risk domains should be well defined, with the help of the entire organization, in the risk identification and analysis process, using a predetermined set of risk categories and exposures [73] (Table 1).

| Risk categories | Domains |
| --- | --- |
| **Economic** | This is a risk that affects capital structure, such as profitability, access to capital, commercial relations and the recognition of income and expenses. |
| **Operational/Clinical** | Risks related to the conduct of the activity and operation result from inadequate internal processes, which affect patient safety. |
| **Human capital** | Regarding the role of employees in the labor market, such as turnover and remuneration. |
| **Strategic** | Inability to adapt to changes in the environment, risk of competition and clinical research. Risk associated with brand, reputation, advertising and business strategies. |
| **Legal/Regulatory** | Incorporates risks arising from product liability, management liability, non-compliance with statutes, standards, rules and regulations. |
| **Technology** | Risks associated with adopting new systems and processes. |
| **Natural/Disaster** | Risks associated with natural causes, causing physical loss of assets or a reduction in their value, such as earthquakes, floods and fires. |

Table 1 - Characterization of risk categories and domains. Source: [73].

The relationships between risks need to be identified and analyzed in order to support the main organizational objectives of a hospital environment, such as providing safe, quality healthcare to patients. Once the major risks have been identified, organizations are able to determine an appropriate response, through prevention, mitigation, management and financing [73].

In order to carry out a risk assessment and classification, after identifying the risk events, it is necessary to assess them in two different dimensions: probability (frequency or period up to impact) and financial impact (severity) and recognize that there may be a variety of possible outcomes directed at an event [73].

## 4.3 Problems with Extending the Life Cycle of an Asset

The decision to extend the life cycle of an asset is a challenging problem, especially when it comes to complex assets that are crucial to achieving the organization's objectives. Sometimes, the greatest difficulty in making a decision about the ideal time to replace physical assets is due to the lack of data collection and subsequent analysis, which can generate more uncertainty in decision-making. These factors can increase the risk that the organization may run in several areas, such as [74]:

1. Capacity: loss of some of the asset's functionality;
2. Economic: direct or indirect loss of revenue due to production failure as a result of asset degradation
3. Safety: injury or death to operators or patients;
4. Environment: environmental damage;
5. Regulatory: ability to have the asset certified or licensed to operate;
6. Logistics: ability to obtain spare parts.

In this sense, the problems that can arise highlight the importance of physical asset management, in that detailed planning makes it possible to monitor the asset, namely through the existence of support systems for collecting data and information during its life cycle, in order to avoid unpleasant surprises in the future [28].

## 4.4 The Importance of Asset Management in Sustainability

The World Health Organization (WHO) defines the term healthcare waste as "all waste produced in healthcare facilities, research centers and laboratories related to medical procedures" [75]. The amount of healthcare waste is increasing as the global population grows and the demand for medical services also increases. Medical waste management is therefore becoming a highly important issue, as a way of helping to achieve increasingly sustainable hospital management [76].

By definition, sustainability is the ability to obtain resources for present needs without compromising the ability of future generations to meet their own needs. In this way, more and more studies are proving the importance of adopting a sustainable vision in the health sector [77]. The WHO calls on hospitals and healthcare facilities to collect and implement environmentally sustainable ways to mitigate the impact of waste on their facilities [75].

Sustainability projects for physical assets in the hospital environment range from the structure and entire construction of a hospital, to methods of achieving water efficiency, energy-saving techniques, sourcing green materials and resources, quality inside facilities, ensuring the proper storage and transportation of waste on and off the hospital site [78] [79] [80].

The entire process of managing physical assets, from purchase to maintenance and replacement, is of the utmost importance and must be taken into account if hospitals are guaranteeing the quality of healthcare provision with a sustainable vision [62].

To this end, the inclusion of engineers, whose role is to manage physical assets, makes it possible to assist in the process of creating a more sustainable hospital system. Through the implementation of new techniques such as structured and planned physical asset maintenance management programs, it is possible to minimize breakdowns or failures and strengthen the technological situation of the facilities. Consequently, this leads to greater efficiency and productivity of health technology resources, as well as providing good health services and saving resources and alternatives [81] [82].

## 4.5 O The Role of the Engineer in Physical Asset Management

The healthcare system, in some medical specialties more than others, has become dependent on technology, insofar as the proper implementation of technological innovation is intended to promote and improve the quality of the healthcare provided. The increase in technology has boosted engineering activities in the same proportion, in order to monitor the respective technological assets implemented.

In the huge hospital sector, engineering activities play an indispensable role, since they aggregate and support the entire built-in structure necessary for the smooth running of the organization, which is reflected in the provision of healthcare. Engineering and Asset Management, in particular, has the function of guiding all the processes that are crucial for the effective and efficient performance of an asset, which allow the organization's ultimate goal to be achieved [83].

Asset Engineering and Management emerged from maintenance as a need for a broader and more systematic look at the evaluation of physical assets and to broaden involvement in strategic planning issues, production capacity or planning the renewal of physical assets. This includes the study of the consequences of the investment made in physical assets, ranging from the choice of appropriate technological solutions, their values, optimization of LCI and disposal of the physical asset [36].

In addition, Asset Engineering and Management is more comprehensive, as it enables:

- ✓ Better and more effective decision-making in interventions;
- ✓ Improving the efficiency and effectiveness of operation and maintenance;

- ✓ Effect on development or current service offer;
- ✓ Increase compliance with regulations and standards;
- ✓ Improve return on investment or cash flow;
- ✓ Controlling the stock of existing assets;
- ✓ Analyze maintenance contracts;
- ✓ Inventory control.

In the hospital sector, physical asset management makes it possible to overcome problems such as: the random replacement of expensive medical technology, the lack of a technology integration plan in strategic planning and limited opportunities for interdisciplinary exchange between engineering and clinical professionals. This whole study is of great relevance in the hospital area, as these are complex physical assets with high investment values [84].

In short, the role of an engineer trained to administer Physical Asset Management is increasingly crucial, particularly in the hospital area, since the ability to predict and manage the continuous evolution of an asset has become an indispensable component in all decisions, bridging gaps that might otherwise occur between the organization and the physical assets acquired.

# 5 APPLICATION OF THE MODEL - LIFE CYCLE INVESTMENT

The financial aspect is fundamental for all organizations (public, private or non-profit) in order to determine the level of operation at which they will make the maximum profit on their investments, the moment at which an investment pays off and the moment at which the investment is no longer viable. Without knowledge of all the values involved in an asset, it would be difficult for organizations to carry out their routine operations.

This chapter discusses a method for determining life cycle investment (LCI). The main objective is to gather in detail the values invested throughout the life cycle, the benefits derived from the respective asset and apply the LCI model, so that it is possible to assist and complement decision-making throughout the life cycle of three medical imaging assets.

## 5.1 Methodology

In this study, the LCI method is applied, taking into account three depreciation methods, to three different pieces of imaging equipment: an ultrasound scanner, a mammography equipment and an X-ray. In order to carry out the calculations, it is necessary to gather information on the history of each piece of equipment and then apply it to the respective variables. The history of the equipment is provided by the organization where the imaging equipment described is located.

Initially, using the figures provided, a general LCI study is carried out for each piece of equipment, based on the profits and expenses of the respective entity, considering each depreciation method. The aim is to analyze the year in which the entity will recover the investment made in the asset, the maximum total return on total expenses, a projection of the appropriate time interval for the entity to replace it and the ROI calculation. On the other hand, based on the results obtained, a study is carried out varying the values considered, namely maintenance and availability, in order to effectively determine the impact and direct influence that these values have on the LCI and ROI.

### 5.1.1 Calculate the useful life of an asset

At the start of the study, it is essential to calculate the useful life of each piece of equipment under study. In this sense, following the definition which states that "the useful life of a physical asset ends when the sum of its maintenance costs exceeds the capital amortization costs of equivalent new equipment" [85], the years of useful life of each physical imaging asset are obtained (equation (1)).

$$\sum_{j=1}^{n} \frac{M_j}{(1+ia)^j} > II \tag{1}$$

Therefore:

$M_j$ – Value of maintenance in year $j = 1,2,3 \dots n$;

$II$ – Initial asset investment;

$ia$ – Apparent rate;

$j$ – Period $j = 1, 2, 3 \dots n$.

From the resulting year, with this definition in mind, it is possible to calculate the depreciation values of the different methods over the years, developed later in this report.

### 5.1.2 Life Cycle Investment - LCI

Life Cycle Investment (LCI) is a method that presents all the amounts spent over the asset's life cycle from an investment point of view, rather than a cost point of view. In this way, the aim is to maximize the asset's production capacity by investing in methods, such as maintenance and performance indicators, that allow the investment to be maximized. With this objective in mind, the LCI method considers the benefits and expenses over the entire life cycle. This method makes it possible to assess the right moment when an investment does not return to a positive value, using the approach in the equation $GR_n = II - j = 0\square n\square \frac{B_j}{(1+ia)^j} - \sum_{j=0}^{n} \frac{F_j}{(1+ia)^j} - \sum_{j=0}^{n} \frac{M_j}{(1+ia)^j} - j = 0\square n\square \frac{D_j}{(1+ia)^j}$ (2).

$$GR_n = II - \sum_{j=0}^{n} \frac{B_j}{(1+ia)^j} - \sum_{j=0}^{n} \frac{F_j}{(1+ia)^j} - \sum_{j=0}^{n} \frac{M_j}{(1+ia)^j} - \sum_{j=0}^{n} \frac{D_j}{(1+ia)^j} \tag{2}$$

Therefore:

$GR_n$ – Global result from benefits and expenses in year $n$;

$ia$ – Apparent rate;

$II$ – Initial asset investment;

$B_j$ – Value of benefits in $j = 1,2,3 \dots n$;

$F_j$ – Value of functioning in $j = 1,2,3 \dots n$;

$M_j$– Value of maintenance in $j = 1,2,3 \dots n$;

$D_j$ – Value of depreciation in $j = 1,2,3 \dots n$;

$j$ – Period in $j = 1, 2, 3 \dots n$.

It should be noted that the risk factor is an important and necessary component to consider in management and, in particular, in decision-making regarding physical assets [86]. However, this component has not been taken into account, since it is so far an extremely subjective indicator, in that it depends on various criteria, factors, points of view and perspectives of analysis. At the moment, not all organizations have this indicator estimated in a pragmatic and quantified way.

### 5.1.3 Temporal Value of Money

The management of physical assets implies, as already mentioned, the financial allocation of a physical asset. This financial allocation implies the commitment of resources that you want to have over several years. It is therefore necessary to introduce one of the structural principles of economics, the notion of the time value of money, thus making it possible to analyze what the updated value of a given amount will be over time.

The time value of money is based on the decrease that occurs in the value of money as time passes, i.e. money loses its value over time. Several factors contribute to this, such as inflation (it will cost us more tomorrow to buy the same thing as it costs us today) [87].

When you own a physical asset, considering the current value allows you to understand what the future flow will produce in current terms, because when you make the decision to acquire an asset, it involves a commitment of resources, although the actual returns from the decision will occur over a future period [87]. This reinforces the fact that, normally, any amount invested today in a physical asset that produces a return at some point in the future will be worth much less when expressed in today's terms [87].

On this basis, it is necessary to adjust all the values involved in the asset in order to obtain an accurate picture of its real value. To calculate the monetary Present Value (PV) the discount rate considered is discounted from the amount equation (3). In the equation (3), it is shown that if we invest an amount $(A)$ today, in 2 years' time, we will obtain the present value ($PV_A$) discounted at the rate $(ia)$.

$$PV_A = \frac{A_2}{(1 + ia)^2} \tag{3}$$

To calculate the Apparent Rate $(ia)$, Fisher's equation was used, as described by [88], which considers the real interest rate and the inflation rate. The relationship between them can be obtained using the Fisher equation, described in (equation (4)).

$$(1 + ia) = (1 + r) \times (1 + h) \tag{4}$$

Therefore:

- $ia$: Apparent rate;
- $r$: Interest Rate;
- $h$: Inflation rate.

In order to calculate the apparent rate for the years prior to the date of this report, the historical inflation and interest data available were accessed [89] [90]. However, there are no long-term forecasts available on the behavior of these values. We therefore opted to carry out a forecast calculation using one of the existing models in the literature.

#### 5.1.3.1 Forecasting Models – Simple Exponential Smoothing

Forecasting methods are a fundamental tool in decision-making processes in various areas and sectors, as they are widely used to calculate forecasts based on present and past values. For a forecast to be made, a time series is needed, which is a set of observations measured sequentially over time or only at specific times, usually spaced out (days, months, quarters, years, etc.) [91].

The method used to calculate future inflation and interest rates is called simple exponential smoothing. This method is the weighted combination of previous observations, where the most recent observations are given a greater "weight" than the older ones. This means that the more recent the observation, the greater its contribution to the forecast and, therefore, it can be said that the weighting decreases exponentially with the age of the observations (hence the name exponential smoothing method) [91].

The simple exponential smoothing method considers that the forecast for the following period $\hat{Y}_{T+1}$, is no more than the forecast for the current period, $\hat{Y}_T$, adjusted by the respective forecast error, $e_T = Y_T + \hat{Y}_T$, where $\alpha$ is the smoothing constant that varies between 0 and 1, represented in equation (5):

$$\hat{Y}_{T+1} = \hat{Y}_T + \alpha\left(Y_T - \hat{Y}_T\right) \tag{5}$$

If the value of the $\alpha$ is higher (closer to 1), a higher weight is given to the most recent observations, if $\alpha$ has a smaller value (closer to 0), it is the historical data that has more weight. Thus, the parameter $\alpha$ can be used to adjust the sensitivity of the forecast to changes in the level of the series [92].

### 5.1.4 Depreciation

The Life Cycle Investment (LCI) method considers expenses, and the depreciation variable must be added to this component, since as mentioned in chapter 3, depreciation is an expense that occurs naturally from the moment the physical asset is acquired. There are a variety of depreciation methods for calculating depreciation, but this study considers three different methods, namely the straight-line method, the exponential method and the sum-of-the-digits method.

#### 5.1.4.1 Straight Line Depreciation Method (SLDM)

The Straight Line Method of Depreciation (SLDM or SLMD) considers that the decline in the value of the equipment is constant over the years. This is the simplest method, in the sense that it is based on uniform distribution of depreciation over the asset's life cycle, and is calculated from the equation (6) and (7):

$$\mathrm{d}_n = \frac{II - VC_n}{N} \tag{6}$$

Therefore:

- $d_n$: Annual depreciation quota;
- $II$: Initial investment;
- $VC_n$: Residual value after $n$ periods of time;
- $N$: Useful life;
- $n$: Period in $n = 1,2,3 \ldots N$.

The value of the equipment, $V_n$ in a period $n$ least than $N$ is given by the equation (7):

$$V_n = II - n \times d_n \tag{7}$$

##### 5.1.4.1.1 Exponent Depreciation Method - EDM

The Exponent Depreciation Method (EMD or EDM) applies a decreasing annual depreciation charge over the life of the asset, based on the fact that a given asset produces more in the initial years of acquisition and its production capacity decreases with use [49]. That said, this method is the most accelerated and distributes depreciation exponentially over the years, providing a decreasing annual depreciation charge as the use of the asset decreases, contributing to most of the depreciation being recorded in the first years of use of the asset. This method is calculated using equation (8) and (9):

$$\mathrm{d}_n = 1 - \sqrt[N]{\frac{VC_n}{II}} \tag{8}$$

Therefore:

- $d_n$: Annual depreciation quota;
- $II$: Initial investment;
- $VC_n$: Residual value after $n$ periods of time;
- $N$: Useful life;
- $n$: Period in $n = 1,2,3 \ldots N$.

The value of the equipment, $V_n$ in a period $n$ least than $N$ is given by the (equation (9)):

$$V_n = II \times (1 - d_n)^n \tag{9}$$

#### 5.1.4.1.2 Sum-of-the-Digits Depreciation Method (SDM)

The Sum-of-the-Digits Depreciation Method (MSD or SDM) is faster than the straight-line method and, like the exponential method, considers that most of the depreciation occurs in the first few years of the asset's use, with a gradual decrease over the life of the asset. However, this decrease is slower than the exponential method. This value can be obtained by calculating the equation ((10) – ((12).

$$SD = \frac{N(N+1)}{2} \tag{10}$$

$$d_n = \frac{N - (n-1)}{SD} \times (II - VC_n) \tag{11}$$

Therefore:

- $SD$: Sum of the digits;
- $N$: Useful life;
- $d_n$: Annual depreciation quota;
- $II$: Initial investment;
- $VC_n$: Residual value after $n$ periods of time;
- $n$: Period in $n = 1,2,3 \ldots N$.

The value of the equipment, $V_n$ in a period $n$ least than $N$ is given by the (Equation (12)):

$$V_n = II - d_n \tag{12}$$

In order to calculate all the depreciation methods, it is necessary to know the residual value, which is difficult to find as it can depend on various factors, such as the company where the asset was acquired, which makes it difficult to obtain this value. To fill this gap, the residual value was set at 1. In this way, it is possible to draw the necessary conclusions, in addition to the fact that the value is probably zero in reality.

#### 5.1.4.2 Availability

Since the Key Performance Indicators (KPI'S) are of great importance, as discussed in chapter 4, it is also essential to include them in the LCI method.

Availability is calculated taking into account the Mean Time Between Failures (MTBF) (equation (13)), which is a calculation based on the perceived reliability of the asset, through the average time without failures [67]. In addition to this, the Mean Repair Time is also used (MTTR) and the Mean Waiting Time for Repair (MWT) [88] (equation (13) -(15)).

The MTBF is calculated using the equation (13:

$$MTBF = \frac{\sum_{i=1}^{n} TBFi}{n} \tag{13}$$

Therefore:

- $TBFi$: Average time between failures $i = 1,2,3 \ldots n$;
- $n$: Number of intervals in good working order.

The MTTR is calculated using the (equation (14)):

$$MTTR = \frac{\sum_{i=1}^{n} TTRi}{n} \quad (14)$$

Therefore:

- $TTRi$: Average repair time in between $i = 1,2,3 \dots n$;
- $n$: Number of interventions.

In turn, the MWT is calculated using the (equation (15)):

$$MWT = \frac{\sum_{i=1}^{n} WTi}{n} \quad (15)$$

Therefore:

- $WTi$: Average waiting time for repair $i = 1,2,3 \dots n$
- $n$: Number of interventions.

The availability (A) is then calculated by relating all these indicators (equation (16):

$$A = \frac{MTBF}{MTBF + MWT + MTTR} \quad (16)$$

### 5.1.4.3 Return On Investment - ROI

As explained in, Return on Investment (ROI) is a highly relevant metric for organizations to understand the financial impact of their assets. In this case, it will be applied to the study encompassing imaging assets. This calculation is made using cash flows, updated to present value, on the initial investment in the asset, represented in the equation (17).

$$ROI = \frac{\sum_{j=1}^{n} \frac{CF_j}{(1+ia)^j}}{II} \quad (17)$$

Therefore:

$CF_j$ –Cash flow $j = 1,2,3 \dots n$;

$II$ – Initial investment;

$ia$ – Apparent rate;

$j$ – Period in $j = 1, 2, 3 \dots n$.

In this sense, the ROI is calculated on all the imaging equipment, using the different cash flow values, i.e. the amounts generated and spent on the equipment, in order to understand what return the hospital has on each investment over the years. If the ROI calculations are positive, it means that the investment has produced benefits for the organization (total returns exceed total expenses), otherwise not (total expenses exceed total returns).

## 5.2 Case Study

In order to carry out the necessary Life Cycle Investment (LCI) calculations, using the different depreciation methods, the benefit value is taken to be the amount paid per medical consultation where each piece of equipment is used. In turn, the operating value in this case refers to the amount of energy consumed by the asset, which is estimated as a daily cycle, i.e. the time periods are the same every day, with no distinction between working days and weekends. It is considered that there is an annual increase in the operating value of 30% from 2026, since this is the deadline that indicates that this value is equal to the value of 2023.

As for the value of maintenance, it takes into account the years within the warranty and, after the warranty expires, the payment of a constant annual amount that can measure various types of maintenance. It should be noted that the value of maintenance in the future may change depending on the type of maintenance the asset requires. However, as there is little history on the asset, the maintenance value is considered to be constant over the coming years. In addition, as mentioned in chapter 3, each piece of equipment has different maintenance values due to its functionality, use and whether or not it depends on accessories to perform its function. In this sense, any accessory that is essential for correct operation is added to the maintenance value.

As far as availability is concerned, since these are assets acquired by the entity in a relatively recent period, this variable is also considered to be constant over time. In turn, the value of depreciation is obtained by calculating the different methods, which follows the line of reasoning presented above.

All the values considered relate to the respective assets up to the start date of this study. All depreciation methods have been calculated for each asset, however for a more in-depth explanation, the LCI of each asset will be explained according to a depreciation method. All the other tables and graphs can be found in the appendix for consultation.

It should be noted that the data presented has a variable offset from the real values, but it is in line with reality and market values. In this way, the lag applied does not compromise the objective of the study or its results.

### 5.2.1 Case Study - Ultrasound Scanner

The first physical asset under analysis is an ultrasound scanner, where the asset's useful life is initially calculated, followed by all the calculations needed to calculate the Life Cycle Investment (LCI). The characteristics of the ultrasound scanner are the same as those mentioned in chapter 2, however, this asset has a hospital function to assist in the diagnosis of mammograms, and its use is optional depending on the health professional. This asset was acquired in 2023 and is still under warranty.

The ultrasound scanner is a physical asset that requires changing probes with some frequency, obviously depending on a number of factors, such as frequency of use, characteristics of the materials, among others. In this case, the replacement of probes is not included in the maintenance value, so it was considered that the equipment requires the replacement of a probe every 3 years, adding this value of the probe to the maintenance value.

#### 5.2.1.1 Useful Life - Ultrasound Scanner

The Figure 10 shows the sum of the value of maintenance in the coming years, as well as the purchase price of equivalent new equipment. It can thus be seen that in the initial years of purchase, the maintenance value is constant, due to the warranty period. The sum of the maintenance costs exceeds the purchase price of equivalent new equipment in 2046.

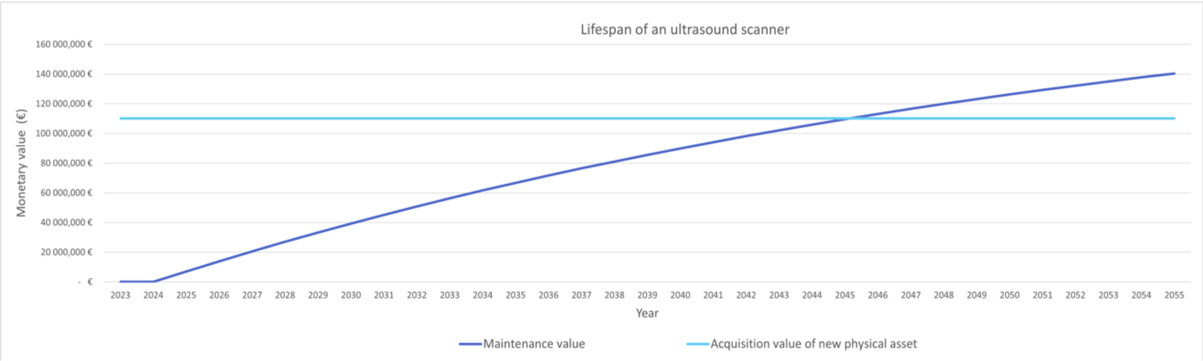


Figure 10 - Time when the ultrasound scanner reaches its useful life.

In this sense, it can be seen that the ultrasound scanner has a useful life of some 23 years after the year it was purchased.

#### 5.2.1.2 LCI by SLDM - Ultrasound Scanner

In Table 2 describes the annual amounts on which the ultrasound scanner's LCI is based, namely the initial investment, the operating and maintenance value, the value of an equivalent probe, the benefits obtained and the asset's availability. These values are updated to present value according to the respective calculated rate.

| Data | Prices incl. Tax (Yearly amount) |
|---|---|
| Initial Investment (II) | 104 796,00 € |
| | |
| Operation (O) | 264,15 € |
| Maintenance (M) | 7 603,20 € |
| Probe (Every 3 years) | 3 600,00 € |
| Benefits (B) | 25 536,00 € |
| | |
| Availability (A) | 0,96 |

Table 2 - Annual information taken into account to calculate the LCI of the ultrasound scanner.

According to the echograph's LCI method by SLDM, Figure 11 is obtained, which shows the overall result between expenses and benefits.

At first glance, it can be seen that the Figure 11 is represented by gradual values that give rise to a concise curve, with no sudden change in values, due to the influence of the depreciation method, which, as the name suggests, is a linear method. It is possible to see that the overall result of expenses and benefits starts at negative values in the year the asset is acquired, moving to positive values in 2026 and remaining positive until 2052, and then decreasing to visibly sharp negative values.

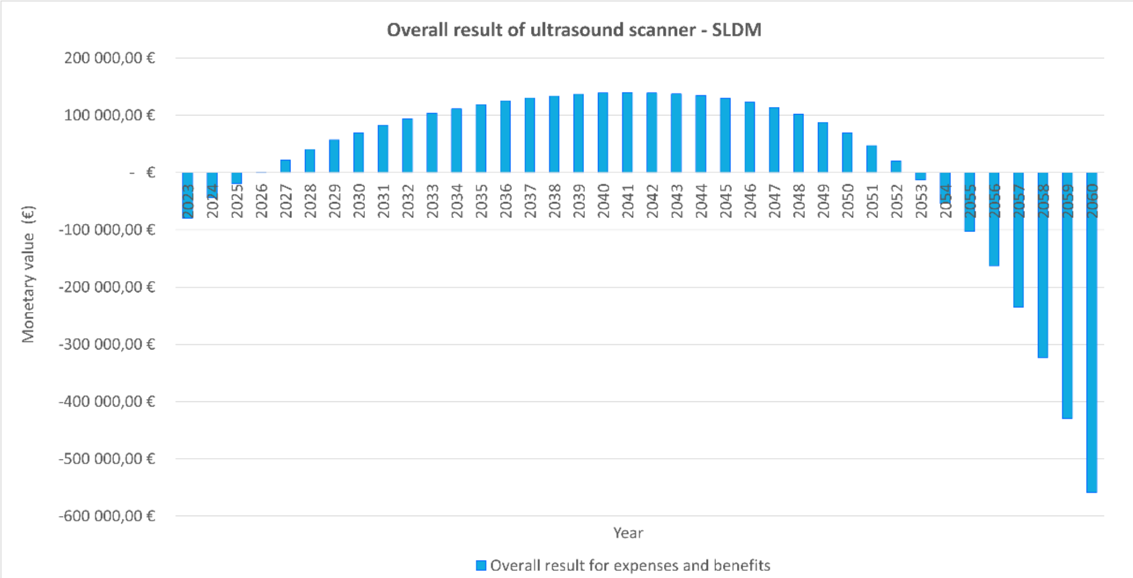


Figure 11 - Overall result of the ultrasound scanner's LCI using the SLDM method over time.

From 2023 to 2025, the overall result is negative, since it is in 2023 that the ultrasound scanner is purchased, which means that more money is spent than income generated until 2025. However, it is in 2026 that the overall result becomes positive (9,857.57 €), with 2027 being the year in which this figure is most significant, amounting to around 31,854.99 €, revealing that it is in this period, between 2026 and 2027, that the entity will have recovered the amount invested in the acquisition of the asset.

The positive figures continue until 2052, meaning that it is during this period of time that the asset generates more total benefits than total expenses. During this year, it is between 2037 and 2045 that the overall result is higher, 136 876.76 € and 130 269.69 € respectively, and in 2041 the highest value of total benefits in relation to total expenses is obtained, around 143 017.90 €.

After 2041, the overall result begins to gradually decrease, becoming negative in 2053 with a figure of -12 981.20 €, due to the increase in total expenditure in relation to total benefits. From this analysis, it can be concluded that it is in this period, between 2052 and 2053, when the difference in values begins, that the time is right for the company to consider replacing the equipment.

#### 5.2.1.3 ROI - Ultrasound Scanner

Turning to the ROI of the ultrasound scanner, this is calculated considering net values, insofar as depreciation values are disregarded. In this way, Figure 12 was obtained, which, at first glance, shows that there is an initial period in which the equipment generates more expense than benefit, reversing this value during a certain period and then returning to the initial trend.

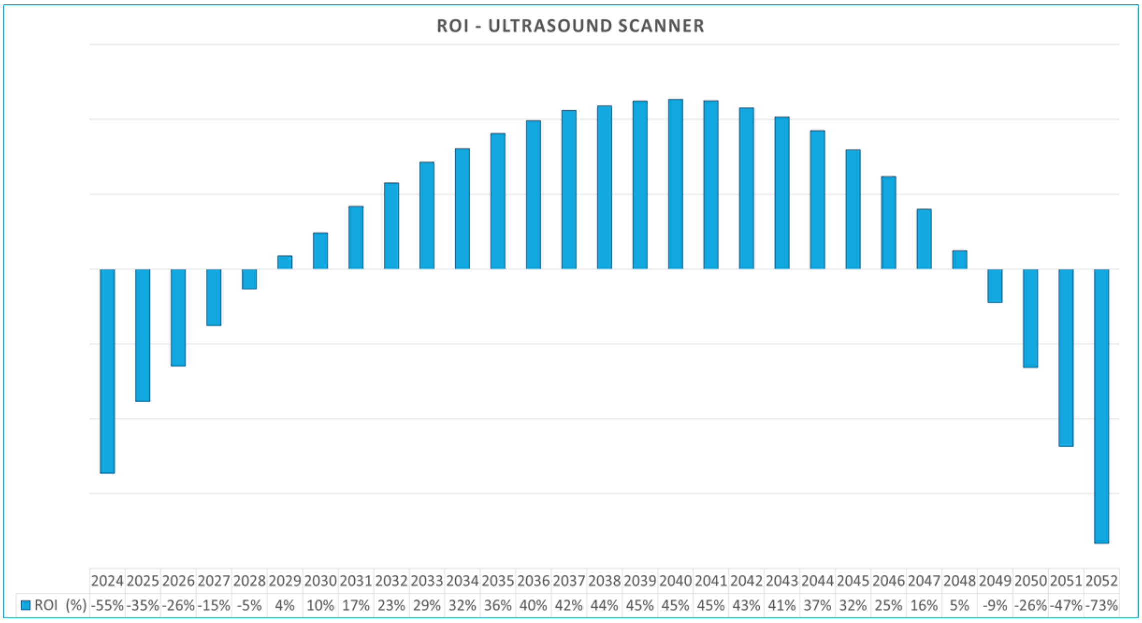


Figure 12 - ROI of the ultrasound scanner over time.

According to the ROI, the ultrasound scanner is not financially profitable until 2028, as this is the period in which the amount invested in the asset is recovered, and until that year the ROI value is negative. After this year, the asset effectively begins to make a profit, as total returns exceed total expenses, reaching an ROI of 45% between 2039 and 2041.

However, from 2049 onwards, the figures reverse, and the ROI is negative, because total expenses start to exceed total profits, which could be a warning that the asset is no longer financially advantageous.

In short, the amount spent on the ultrasound scanner is a financially reliable investment, but it is an asset that, under the conditions presented, takes a certain 5 years for the benefits to outweigh the expenses, however, these values are reversed, reaching values above 40% return.

### 5.2.2 Case Study - Mammography Equipment

The second physical imaging asset under study is a mammography machine, where the same line of reasoning as above was followed sequentially. Firstly, the useful life of the mammography equipment was calculated, following the entire line of reasoning according to the Life Cycle Investment (LCI) and the three depreciation methods.

#### 5.2.2.1 Useful Life – Mammography Equipment

In the Figure 13 shows the moment in time when the sum of the mammography equipment's maintenance value is constant, which is in the first two years after the asset's acquisition, in relation to the warranty period. After these years, the sum of the mammography equipment's maintenance exceeds the value of an equivalent new asset in 2032.

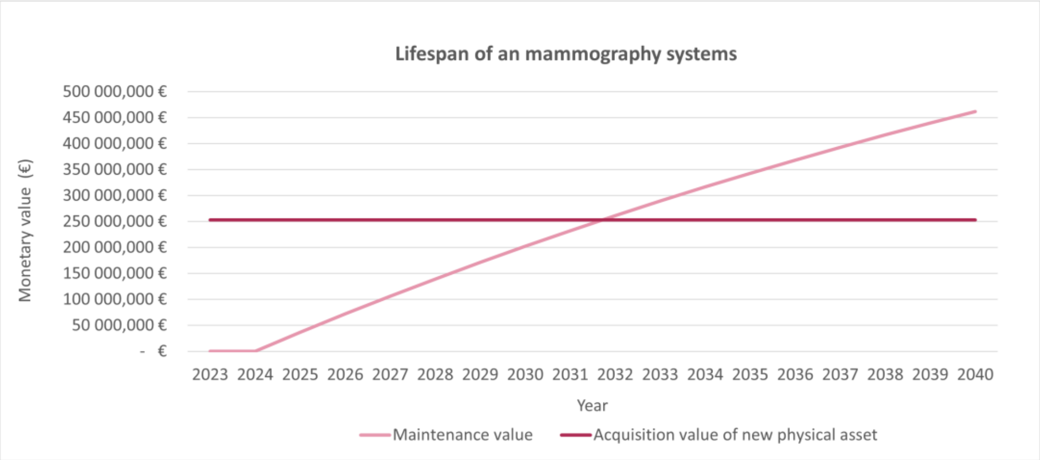


Figure 13 - The point in time when mammography systems reach their useful life.

It can therefore be concluded that the mammography equipment has a useful life of 9 years after the year it was purchased.

### 5.2.2.2 LCI by EDM – Mammography Equipment

The Table 3 below shows all the annual values considered when calculating the LCI of mammography equipment.

| Data | Prices incl. Tax (Yearly amount) |
|---|---|
| Initial Investment (II) | 247 230,00 € |
| | |
| Operation (O) | 2 201,28 € |
| Maintenance (M) | 39 067,20 € |
| Benefits (B) | 82 530,00 € |
| | |
| Availability (A) | 0,999 |

Table 3 - Annual information taken into account to calculate mammography systems' LCI.

The Life Cycle Investment (LCI) of mammography equipment according to the EDM results in an overall result of expenses and benefits shown in Figure 14 .

Firstly, the EDM, as the name implies, influences the LCI, in that it is translated into an exponential curve, i.e. the values increase rapidly from one year to the next, with a more gradual decrease starting at a certain point in the last few years of useful life. In Figure 14 shows that the LCI curve starts at a negative value, but quickly reaches positive and quite significant values, gradually decreasing after reaching the most profitable year, around 2036.

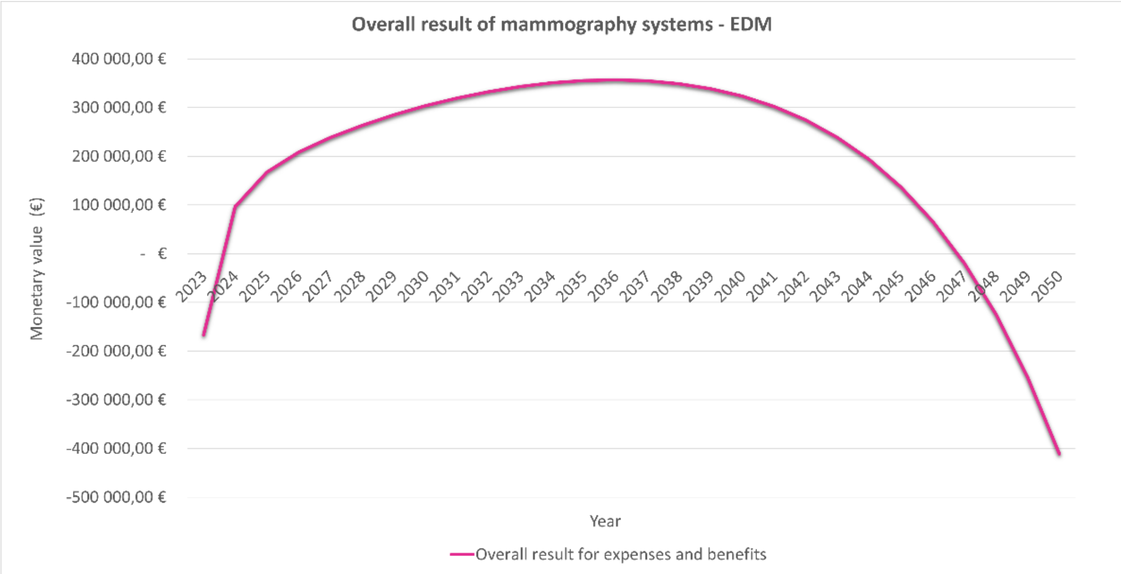


Figure 14 - Overall result of the LCI of mammography systems by the EDM method over time.

With this depreciation method, it is in the year 2024 that the entity obtains the highest total benefits generated, with around 96,694.47 €, increasing exponentially to around 167,530.37 € in 2025 and around 208,417.18 € in 2026.

This high value in the year 2025 is also due to the equipment's warranty years, in which maintenance values are not considered. However, even though the maintenance value is added in the following year, the overall result becomes higher over time, because the total benefits generated by the mammography machine outweigh the depreciated value of the asset.

The overall result of benefits and expenses remains positive until the year 2046, and between the years 2032 and 2040, the total benefits exceed the total expenses, resulting in values of between 332,802.61 € and 323,319.49 €, respectively. The highest value occurs in the year 2036 with values of around 356,849.60 €.

From the year 2046 onwards, the total expenses compared to the benefits will increase more and more, with the interval between 2046 and 2047 being the period in which the entity will consider replacing the asset.

#### 5.2.2.3 ROI – Mammography Equipment

In Figure 15 shows the ROI of the mammography equipment under the conditions presented, not considering depreciation over the years. Looking at Figure 15 , at first glance, it is possible to conclude that this asset is not financially profitable during the first two years, since it has negative ROI values, but the scenario reverses between 2026 and 2043, returning to negative in 2044.

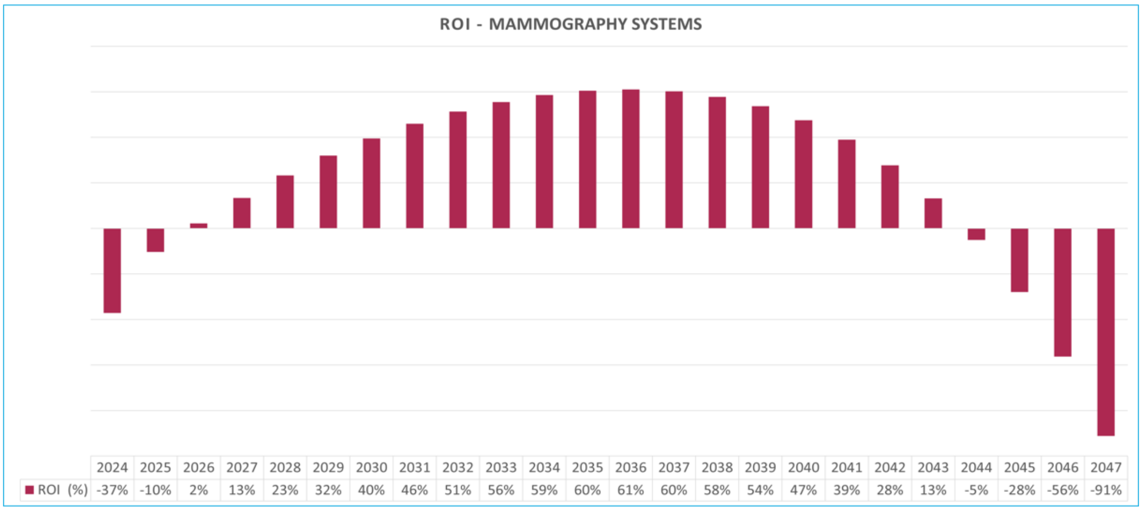


Figure 15 - ROI of mammography systems over time.

According to the study of the mammography equipment's ROI, it can be concluded that this asset is financially reliable in that, although between 2024 and 2025 it shows negative ROI values, in 2026 this value is reversed and total returns become higher than total expenses.

From 2026 to 2043, the ROI values are positive, reaching profits of between 60% and 61% between 2035 and 2037. The opposite occurs in 2044, when the equipment no longer becomes financially advantageous, and the total expenses outweigh the total expected benefits.

In short, the amount invested in the mammography equipment is a financially reliable investment, since, although it takes 2 years to recoup the amounts invested in the asset, it has a certainty of 18 years with an average ROI of 41%.

### 5.2.3 Case Study – X-ray

The last physical asset under study is the X-ray, which follows exactly the same line of reasoning explained above and developed for the previous assets. It should be noted that all depreciation methods were studied in the LCI, but in this chapter the Life Cycle Investment (LCI) will be described graphically considering the sum-of-the-digits depreciation model, with the remaining graphs attached.

#### 5.2.3.1 Useful Life – X-ray

Following the methodology described for obtaining the useful life of equipment, we obtain the Figure 16 , which shows the end of the X-ray's useful life in 2033.

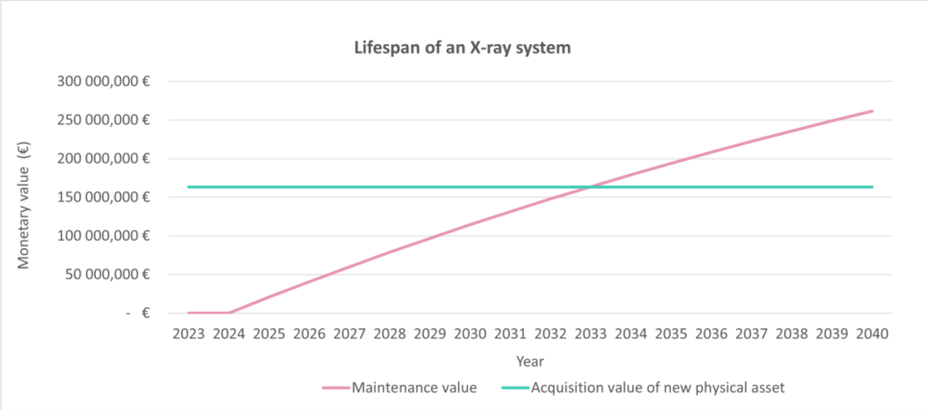


Figure 16 - Time when the X-ray reaches its useful life.

This means that, from the moment it is purchased, the X-ray has a useful life of 10 years.

#### 5.2.3.2 LCI by SDM – X-ray

The respective X-ray values for calculating the LCI are shown in the following table (Table 4):

| Data | Prices incl. Tax (Yearly amount) |
|---|---|
| Initial Investment (II) | 151 290,00 € |
| | |
| Operation (O) | 37 274,93 € |
| Maintenance (M) | 22 104,00 € |
| Benefits (B) | 278 100,00 € |
| | |
| Availability (A) | 0,661 |

Table 4: Annual information used to calculate X ray's LCI.

In Figure 17 shows the Life Cycle Investment (LCI), this time using the SDM, giving rise to a curve that reflects the behavior of the overall result of the expenses and benefits of X-ray over time.

At first glance, it is possible to see the influence of the SDM on the LCI, insofar as it is possible to identify the initial acceleration, indicating that depreciation occurs more in the first years of the asset's acquisition, with a gradual decrease in the last years of its useful life. Contrary to all the assets analyzed, the overall result of the expenses and benefits of the X-ray starts at positive values, and it is only in 2038 that this value rises to negative values.

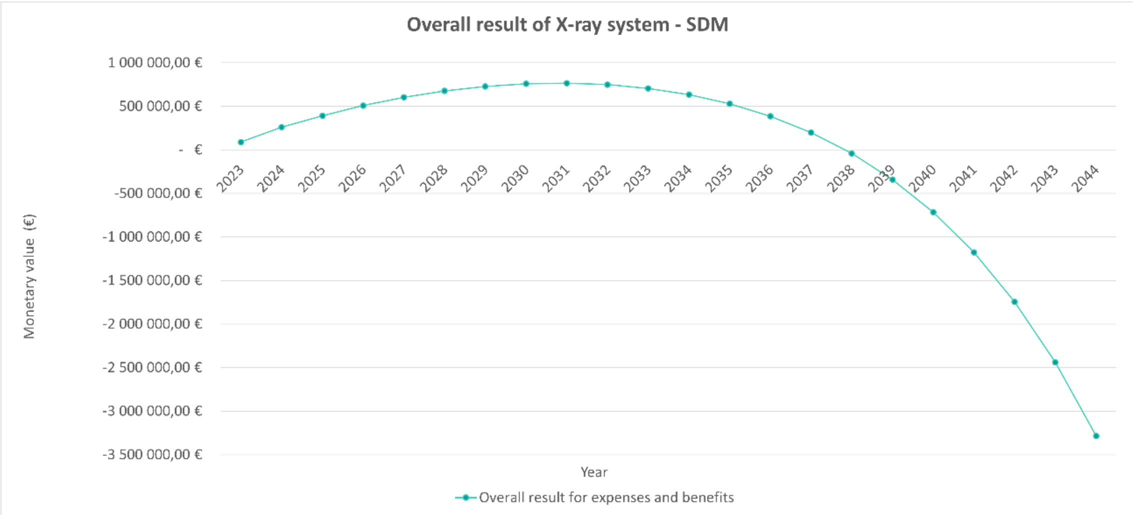


Figure 17 - Overall result of the X-ray LCI by the SDM method over time.

Immediately in the year 2023, the overall result of the X-ray's expenses and benefits is contrary to the other graphs analyzed for other equipment, in that it starts with positive values, around 89,535.07 €, which indicates that the amount invested in this asset, the entity recovers immediately at the end of the first year of operation.

In the remaining years, the overall result is always positive, reaching successively increasing values, meaning that total profits are greater than total expenses throughout the positive period. It is between 2027 and 2035 that the overall result is highest, reaching values between 603,469.48 € and 529,088.18 €, respectively. However, it is in the year 2031 that the maximum value is highest, with around 765,728.80 € in total profit in relation to expenses.

It is in the year 2038 that this scenario is reversed, i.e. the expenses start to outweigh the benefits and, consequently, the overall result is negative. It can therefore be concluded that the interval in which the entity should consider replacing the x-ray is between 2037 and 2038.

#### 5.2.3.3 ROI – X-ray

The X-ray ROI study was carried out exactly as mentioned above and in the same way as the previous assets. In this way, Figure 18 is obtained, where it can be seen immediately that the asset in 2024 shows positive ROI values, which means that the benefits compensate for the expenses of the first year, continuing in a constant growth, starting the reversal of ROI in 2034.

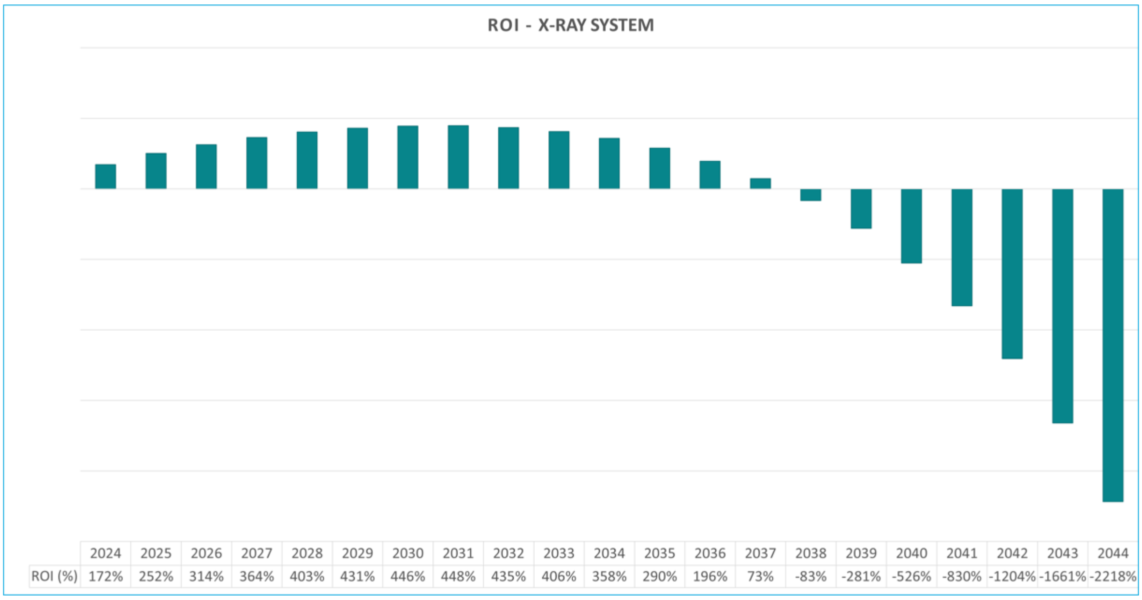


Figure 18 - ROI of X ray systems over time.

According to the ROI study of the X-ray, it can be concluded that this asset is financially quite profitable, in that the total returns generated by the asset exceed the total expenses for 14 years by more than 200%. It is between the years 2029 and 2033 that the ROI varies between 431% and 406% respectively, with the highest return in 2031 being a certain 448%. Subsequently, total expenditure begins to exceed total returns in 2038, and this reversal continues steeply.

In short, the amount invested in the X-ray is a highly profitable investment, since the return on the asset's investment is almost immediate and over 14 years it has an average ROI of 328%.

# 6 DISCUSSION OF RESULTS

The study of the Life Cycle Investment (LCI) of the three imaging assets, using the actual values of the organization, including the different depreciation methods, allows us to understand the real difference between the three depreciation methods and the direct impact on the overall results.

On the one hand, the LCI calculated, first with factual values, gives a broad perception of the future impact of the current condition of the assets present in the organization. On the other hand, the scenarios presented below make it possible to understand the real impact that the metrics considered have on the asset's life cycle, especially maintenance and availability.

## 6.1 Ultrasound Scanner

In summary, the following overall result was obtained for the LCI of the ultrasound scanner, using the depreciation methods:

**The LCI method with SLDM:**

Year of investment return: 2026

Period with the highest profit: 2037 to 2045

Year with the highest profits: 2041 (139 947,42 €)

Ideal replacement period: 2052 to 2053

**The LCI method with EDM:**

Year of investment return: 2025

Period with the highest profit: 2035 to 2044

Year with the highest profits: 2040 (144 446,44 €)

Ideal replacement period: 2052 to 2053

**The LCI method with SDM:**

Year of investment return: 2026

Period with the highest profit: 2037 to 2045;

Year with the highest profits: 2041 (143 017,90 €)

Ideal replacement period: 2052 to 2053

**Analysis of ROI:**

Period of positive financial return: 2029 to 2047 - average of 30% over 20 years.

Maximum financial return: 45%

**What impact does the value of maintenance and availability have on these results?**

Considering that the asset needs more maintenance interventions from the year 2030 onwards, this leads to an increase in the value of maintenance of around 1,500 € and, consequently, a decrease in availability from 96% to 85%. What is the impact on LCI and ROI?

Considering these changes, it can be concluded that:

**The LCI method with SLDM (Figure 19):**

Year of investment return: 2026

Period with the highest profit: 2037 to 2045

Year with the highest profits: 2041 (123 071,51 €)

Ideal replacement period: 2051 to 2052

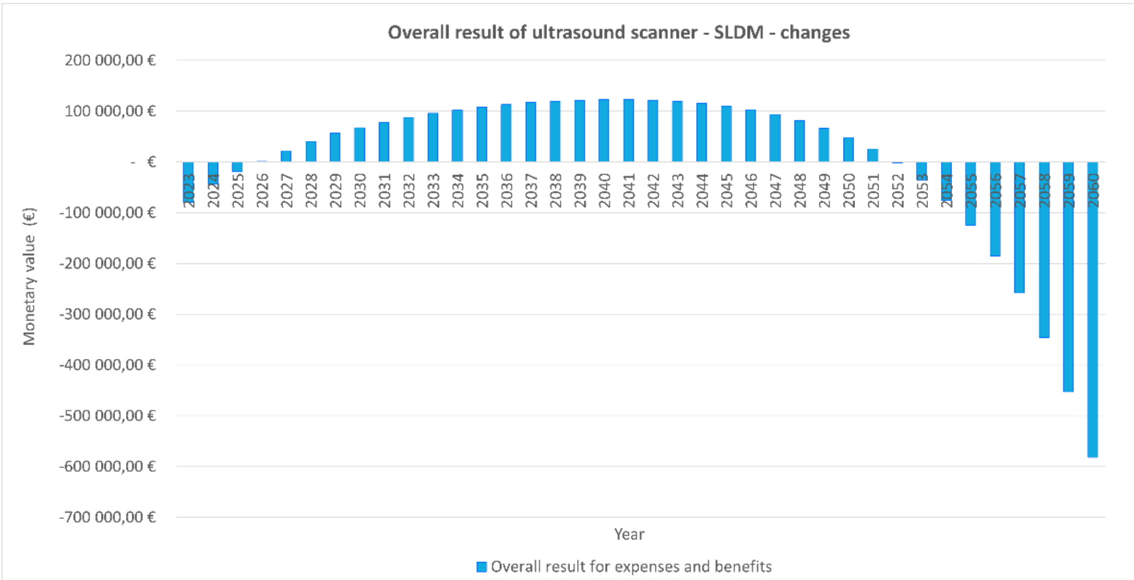


Figure 19 - Overall result of the ultrasound scanner LCI by the SLDM method over time with an increase in maintenance value and decrease in availability.

**The LCI method with EDM:**

Year of investment return: 2025

Period with the highest profit: 2036 to 2044

Year with the highest profits: 2040 (136 119,55€)

Ideal replacement period: 2052 to 2053

**The LCI method with SDM:**

Year of investment return: 2026

Period with the highest profit: 2036 a 2044;

Year with the highest profits: 2040 (126 787,03 €)

Ideal replacement period: 2051 to 2052

**Analysis of ROI (Figure 20):**

Period of positive financial return: 2029 to 2046 - average of 21% over 18 years.

Maximum financial return: 30% between 2037 and 2041

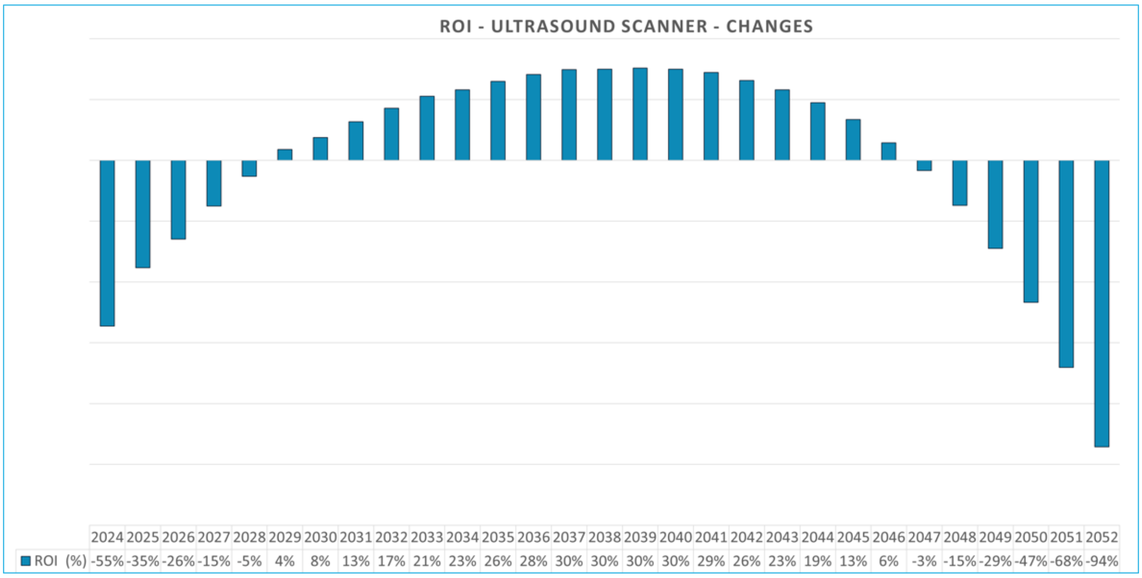


Figure 20 - ROI of the ultrasound scanner over time with an increase in maintenance value and decrease in availability.

According to the factual figures, it can be concluded that the amount invested in the asset will be recovered in benefits in 2026, considering the SLDM and SDM methods, and in 2025 according to the EDM method. It will take approximately 27 years for the total benefits to outweigh the total expenses, reaching maximum annual values of 139,947.42 € and 144,446.44 € between 2040 and 2041, depending on the depreciation methods. Furthermore, it can be concluded that the advisable replacement period, which cuts across all replacement methods, is between 2052 and 2053. As for the ROI, it shows 20 years with positive values, reaching a return of 45% between 2039 and 2040, reaching an average of 30% over 20 years.

However, considering an increase of 1,500 € per year in maintenance from 2030 and a decrease in availability from 96% to 85%, it is clear that there is a slight reduction in all the segments under analysis, reducing the maximum total benefits to 123,071.51 € and €136,119.55 €, using the depreciation methods. In addition, the indicated replacement period is brought forward by 1 year. As for ROI, there is a reduction in the number of years in which profit exceeds expenditure, from 20 to 18 years, and a decrease in the average ROI to 21%.

Thus, considering all the values presented in the hypothetical situation, it can be seen that there is a direct impact on the overall result of the asset, increasing total expenses slightly in relation to total benefits and causing a decrease in the asset's life cycle.

## 6.2 Mammography Equipment

With regard to the mammogram, the following information was obtained in the overall result:

**The LCI method with SLDM:**

Year of investment return: 2025

Period with the highest profit: 2033 to 2041

Year with the highest profits: 2037 (390 940,27 €)

Ideal replacement period: 2047 to 2048

**The LCI method with EDM:**

Year of investment return: 2024

Period with the highest profit: 2032 to 2040

Year with the highest profits: 2036 (356 849,60 €)

Ideal replacement period: 2046 to 2047

**The LCI method with SDM:**

Year of investment return: 2025

Period with the highest profit: 2031 to 2039

Year with the highest profits: 2035 (350 176,57 €)

Ideal replacement period: 2046 to 2047

**Analysis of ROI:**

Period of positive financial return: 2026 to 2043 - average of 41% over 18 years.

Maximum financial return: 61%

**What impact does availability have on these results?**

Considering that the mammography machine will need a few extra work orders four years after its acquisition, i.e. in 2027. This has led to a change from approximately 100% availability to 89% between 2017 and 2029 and 92% from 2030 onwards. What is the impact on LCI and ROI?

**The LCI method with SLDM:**

Year of investment return: 2025

Period with the highest profit: 2033 to 2041

Year with the highest profits: 2037 (353 397,37 €)

Ideal replacement period: 2046 to 2047

**The LCI method with EDM (Figure 21):**

Year of investment return: 2024

Period with the highest profit: 2031 to 2039

Year with the highest profits: 2035 (321 468,15 €)

Ideal replacement period: 2046 to 2047

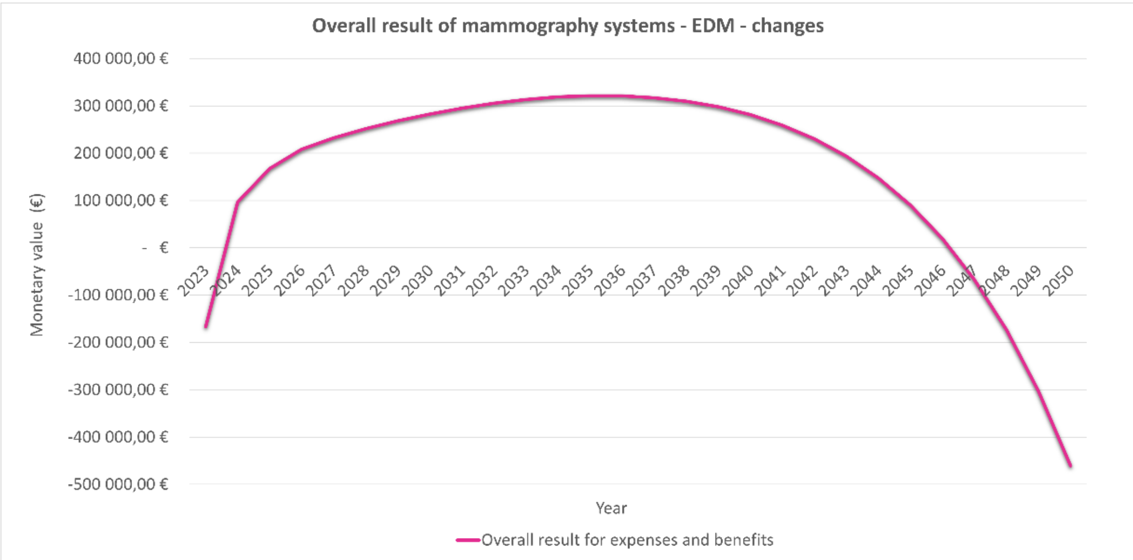


Figure 21 - Overall result of the LCI of mammography systems by the EDM method over time considering a decrease in availability.

**The LCI method with SDM:**

Year of investment return: 2025

Period with the highest profit: 2030 to 2038

Year with the highest profits: 2034 (316 998,98 €)

Ideal replacement period: 2045 to 2046

**Analysis of ROI (Figure 22):**

Period of positive financial return: 2026 to 2042 - average of 31% over 17 years.

Maximum financial return: 47

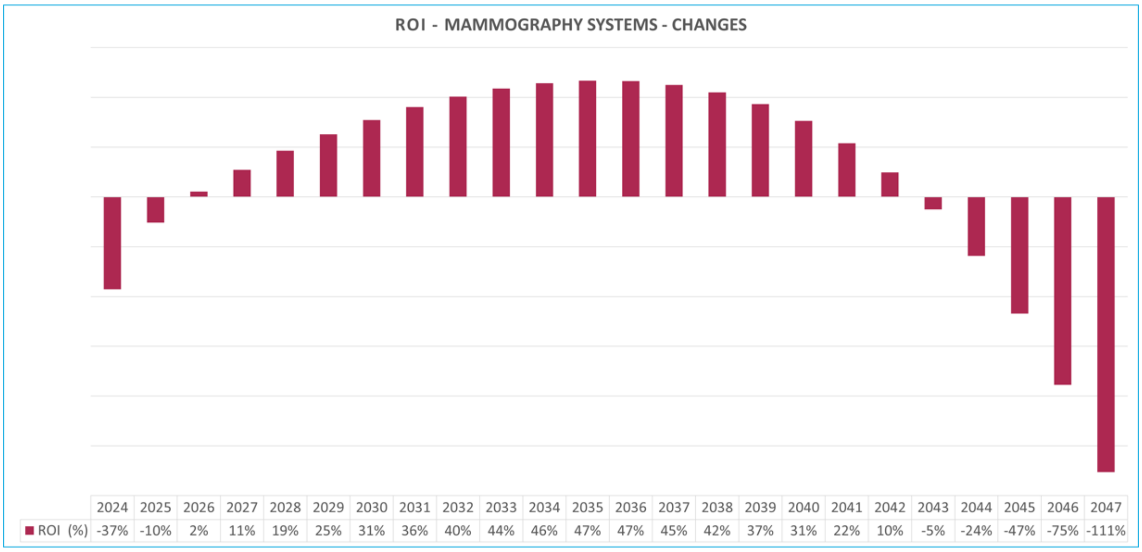


Figure 22 - ROI of mammography systems over time, considering a decrease in availability.

In the first mammography study, considering the factual values, it can be seen that the entity will have recovered the amount invested in 2025, considering the SLDM and SDM methods, and in 2024 according to the EDM method. In addition, the total benefits exceed the total profits for 23 years of the life cycle, reaching maximum annual values of between 350,176.57 € and 390,940.27 €, depending on the depreciation methods. The replacement period is between 2046 and 2047 under the SLDM and EDM methods and 2047 and 2048 under the SDM method. In terms of ROI, over 18 years total profits exceed total expenses by an average of 41%.

However, in order to understand the impact of availability on this asset, it was considered that from 2027 to 2029, there would be a decrease in availability from almost 100% to 89% and from 2030 onwards, availability would be 92%. This hypothetical situation causes a significant difference in the LCI, in that the maximum total benefits achieved fall to annual values of between 316,998.98 € and 353,397.37 €, bringing forward the replacement period by 1 year. As for ROI, the period in which total profits exceed total expenses is reduced by 1 year and the average goes from 41% (18 years) to 21% (17 years).

Depending on the situations presented, the impact that availability has on the life cycle of the mammography machine is clear: in this case, it reduces the life cycle by 1 year and causes a clear drop in the maximum total benefits by more than 33,000.00 €.

## 6.3 X-ray

Finally, from the overall result of the LCI X-ray, the following information was obtained:

**The LCI method with SLDM:**

Year of investment return: 2023

Period with the highest profit: 2027 to 2035

Year with the highest profits: 2031 (755 466,88 €)

Ideal replacement period: 2037 to 2038

**The LCI method with EDM:**

Year of investment return: 2024

Period with the highest profit: 2031 to 2038

Year with the highest profits: 3031 (769 572,42 €)

Ideal replacement period: 2037 to 2038

**The LCI method with SDM:**

Year of investment return: 2023

Period with the highest profit: 2027 to 2035

Year with the highest profits: 2031 (765 728,80 €)

Ideal replacement period: 2037 to 2038

**Analysis of ROI:**

Period of positive financial return: 2024 to 2037 - average of 328% over 14 years.

Maximum financial return: 448%

**What impact does the value of maintenance and availability have on these results?**

Hypothetically, disregarding the real value of 66% availability and considering that the availability of the X-ray is 90% until the year 2027 and from 2028 it goes to 83%, plus an annual increase of 1500 € in the maintenance value. What is the impact on the LCI and ROI?

**The LCI method with SLDM:**

Year of investment return: 2024

Period with the highest profit: 2028 to 2036

Year with the highest profits: 2032 (1 083 610,70 €)

**The LCI method with EDM:**

Year of investment return: 2024

Period with the highest profit: 2027 to 2035

Year with the highest profits: 3031 (1 090 055,66 €)

Ideal replacement period: 2039 to 2040

**The LCI method with SDM: (Figure 23):**

Year of investment return: 2024

Period with the highest profit: 2027 to 2035

Year with the highest profits: 2031 (1 086 212,04 €)

Ideal replacement period: 2039 to 2040

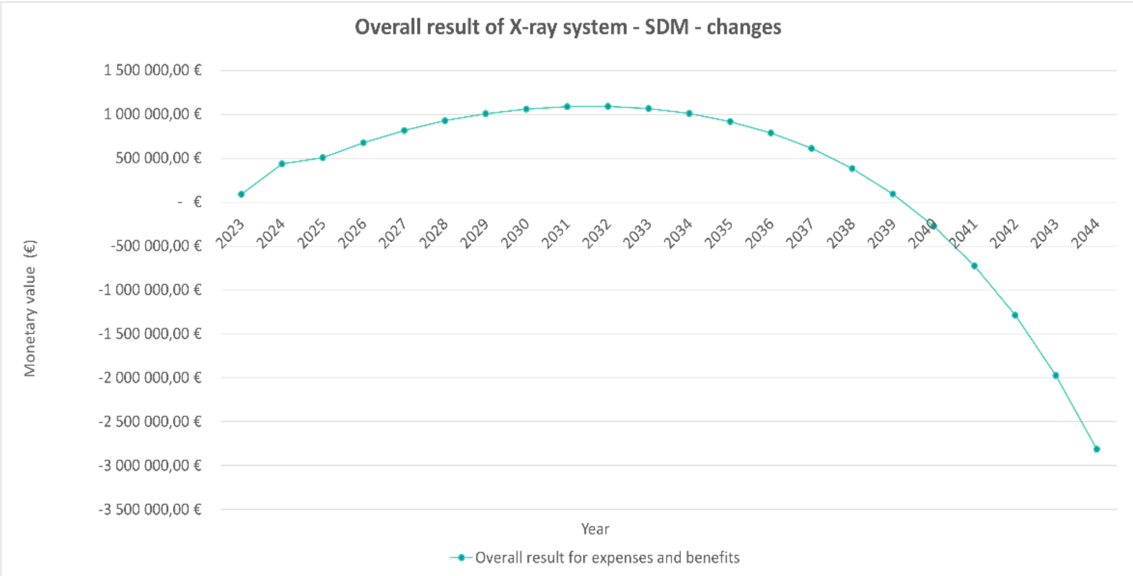


Figure 23 - Overall result of the X-ray LCI using the SDM method over time, considering an increase in maintenance value and an increase in availability.

**Analysis of ROI (Figure 24):**

Period of positive financial return: 2024 to - 2039 average of 515% over 16 years.

Maximum financial return: 660%.

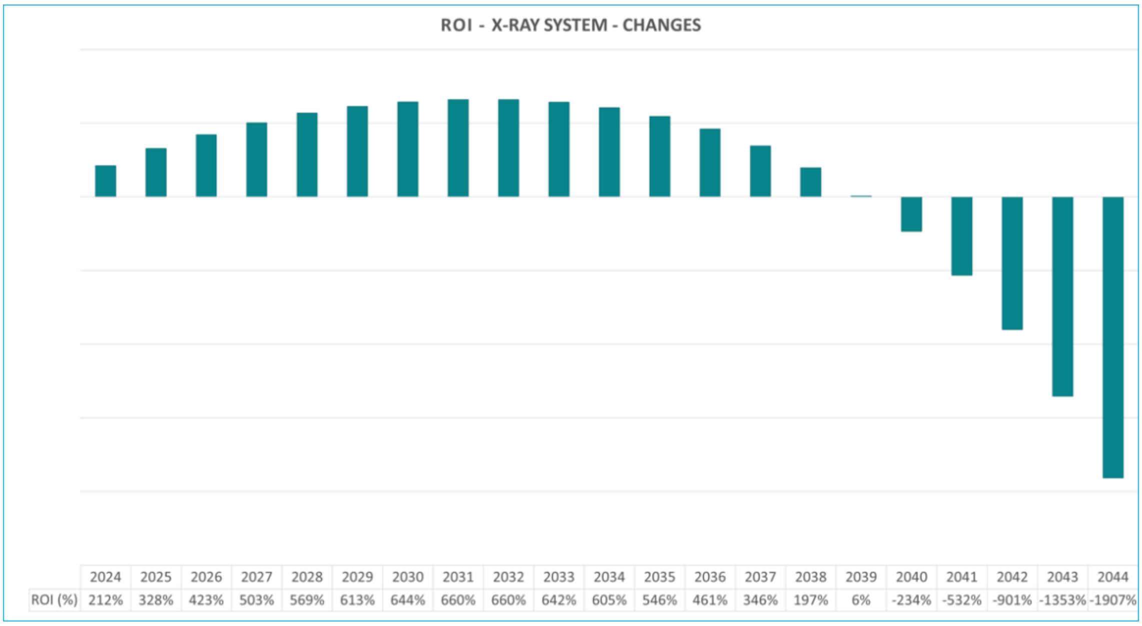


Figure 24 - ROI of X-ray over time considering increase in maintenance value and increase in availability.

The last asset under analysis is the X-ray where, considering the organization's real values, it will be recovered at the end of the first year in activity, considering all depreciation methods. Over 15 years, the total benefits exceed the total expenses, reaching annual values of between 755,466.88 € and 769,572.42 €, using depreciation methods. The ROI validates these figures, as it is always positive over 14 years, reaching an average ROI of around 328% in these years.

Similarly, the X-ray also considers a hypothetical situation in which a higher availability value and an increase in maintenance value are considered. In this sense, the maximum annual return can vary between 1 083 610.70 € and 1 090 055.66 €, depending on the depreciation methods. In addition, the life cycle is extended by two years, increasing the maximum total profit obtained by more than 320,000.00 €. In turn, the increase in ROI is notable, since over 16 years it reaches an average of 515%.

In fact, according to the situation presented, considering an increase in maintenance and availability over the years, there is an increase in the life cycle of the X-ray by two years, as well as a significant increase in total profits over total expenses and in ROI.

## 6.4 Final Thoughts on Discussing the Results

Throughout the study, the impact and influence of the variables considered in the LCI model on the three physical medical imaging assets is verified, insofar as the economic life cycle of the asset can be extended or reduced according to the amounts invested in it. The insertion of depreciation methods makes it possible to understand how each one works and what impact they have on the LCI, concluding that, in general, the difference between the different methods is not very pronounced.

The study is initially carried out considering factual values, in order to see what the economic life cycle of each physical asset looks like over the next few years, based on the organization's current values and conditions. Based on the organization's current values and conditions, the period of greatest profit, the optimum replacement period and the ROI of each asset. Of the three assets under study, it is clear that they are all economically profitable for the hospital, with the X-ray being the asset that can obtain the most total benefits over total expenses throughout its life cycle, compared to the other assets.  This aspect is presented in the initial result with factual values and also later when hypothetical situations are simulated.

On the other hand, when scenarios are introduced, influencing the variables, especially maintenance and availability, the impact of these metrics on the economic life cycle of the assets initially calculated can be seen, tunning the results. The hypothetical situations show the impact that maintenance and availability have on assets with different assets with different characteristics and conditions, in that they can decrease or increase the asset's economic life cycle and net return.

This approach of inserting hypothetical situations focused on changing the variables of maintenance and availability, since these are variables that are unpredictable and can vary over time. This is because these variables depend on various external factors, such as suppliers or maintenance technicians. Turning these factors to the LCI model, it is easy to see the underlying impact that these variables have on the total benefits that physical assets can produce.

Introducing a hypothetical situation into the initial LCI of the ultrasound scanner, where it is considered that there is an annual increase in the value of maintenance and with a decrease in availability, the recommended period for replacing the ultrasound scanner is brought forward by 1 year and there is a marked reduction in ROI, in relation to the overall result of the asset under current hospital conditions.

In the case of the mammography systems, by introducing a hypothetical situation into the initial LCI where there is a slight decrease in availability, compared to the initial years of the asset's functionality, there is an anticipation of the replacement period, a decrease in the total benefits over total expenses and also in the ROI, in relation to the overall result of the asset under current hospital conditions.

Considering a hypothetical situation introduced in the initial LCI of the X-ray, in which an increase in availability and an increase in the annual value of maintenance, there is an increase of 2 years in the recommended period in the life cycle, as well as a significant increase in total profits over total expenses and in ROI, in relation to the overall result of the asset under current hospital conditions.

Finally, all the assets presented are recent and so there are still a few values to insert into the respective variables, which can generate long life cycles. However, the recommended use of this model is to update it over the years, from the moment the asset was acquired. This aspect is highlighted since it is a model that needs continuous data analysis and as considered in this report, different values over time change the results, which allows for more reliable continuous monitoring.

# 7 CONCLUSION AND FUTURE WORKS

To conclude this report, this chapter highlights the conclusions drawn from the implementation of the LCI in physical medical imaging assets and the impact that all the variables considered have had throughout the life cycle. Finally, several suggestions for improvements are made for possible future work.

## 7.1 Conclusion

The internship in a hospital was extremely enriching, as it allowed me to get to know the reality of various complex assets, especially physical medical imaging assets, through the monitoring they require, the different functionalities and particularities that differ between them.

In addition, a variety of relevant content was covered during the internship, including a set of standards and criteria aimed at supporting the management of these assets. As well as the importance of studying relevant information in advance about the asset that is to be acquired, ranging from the value of the acquisition and ownership to the type of maintenance, monitoring and tracking of the medical images produced by the asset. It also covered continuous improvement methods and how these are effectively implemented in the hospital environment, as well as providing a brief understanding of the importance and influence that asset management has on sustainability.

The goal of create a Life Cycle Investment (LCI) model applied to physical assets (Imaging Equipment) was fulfilled, and the importance and impact that the life cycle analysis model on constant monitoring during the asset's economic life cycle was demonstrate. It also demonstrates the purpose of the LCI model in helping physical asset management to make informed and conscious decisions based on the values obtained and reimbursed throughout the asset's activity, which consequently has an impact on the entity's financial structure.

## 7.2 Future works

The objective of asset management should also focus on the knowledge of methods and techniques capable of facilitating the use of physical assets, to get the best out of them for the main purpose of organizations. Directing this evidence to the hospital environment, where the aim is for all assets to be functional and available effectively and efficiently, since they deal with the quality of life of all those involved, but also considering the constant investment on the part of the organization.

In order for asset management to advance and continue to flourish in an environment where asset management is highly relevant, it is necessary to increase the number of studies in the literature, such as:

- Extended study focusing on the specific characterization of the difference between medical devices and medical equipment;

- Study on the impact of disinfection on medical devices and equipment and what impact it has on the degradation of these assets over time;

- Survey in the hospital environment on the depreciation method used for medical equipment and how this method is calculated;

- The study of when an asset is considered technologically obsolete, i.e. when the effective time and conditions for the end of an asset's technological life occur;

- A study, for information purposes only, on the dismantling of physical assets, in particular medical imaging physical assets made up of various components, some of which are harmful to the environment.

In this sense, the improvements presented are merely suggestive, in the sense of promoting possible future work and subsequent debate, so that various concepts can be increased and improved in asset management and, consequently, support managers directly in the hospital reality.

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# ANNEXES

## LCI – Ultrasound Scanner

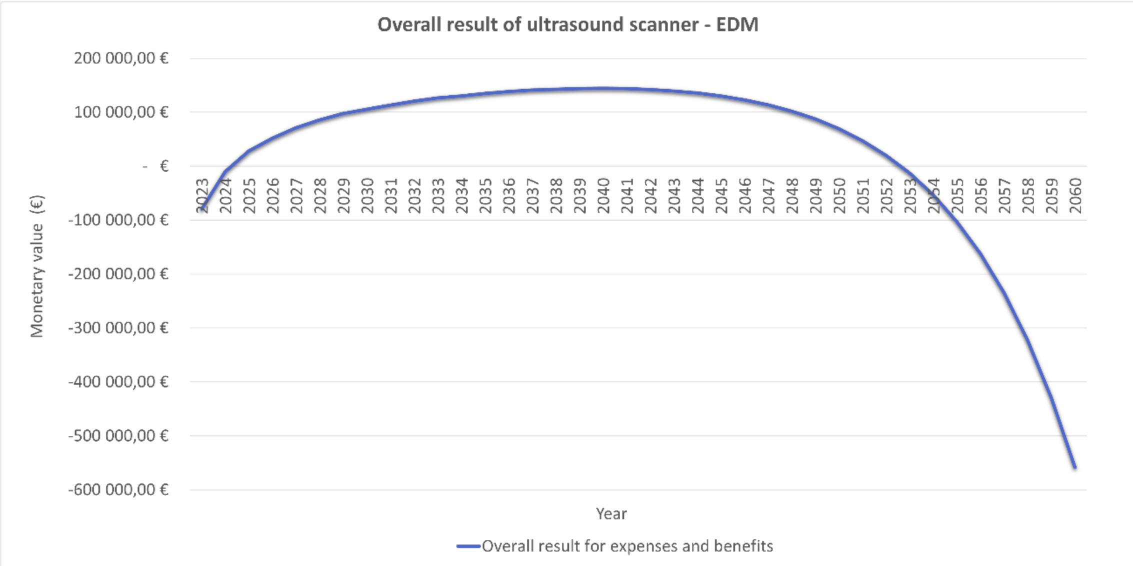


Figure 25 - Overall result of the ultrasound scanner's LCI using the EDM method over time.

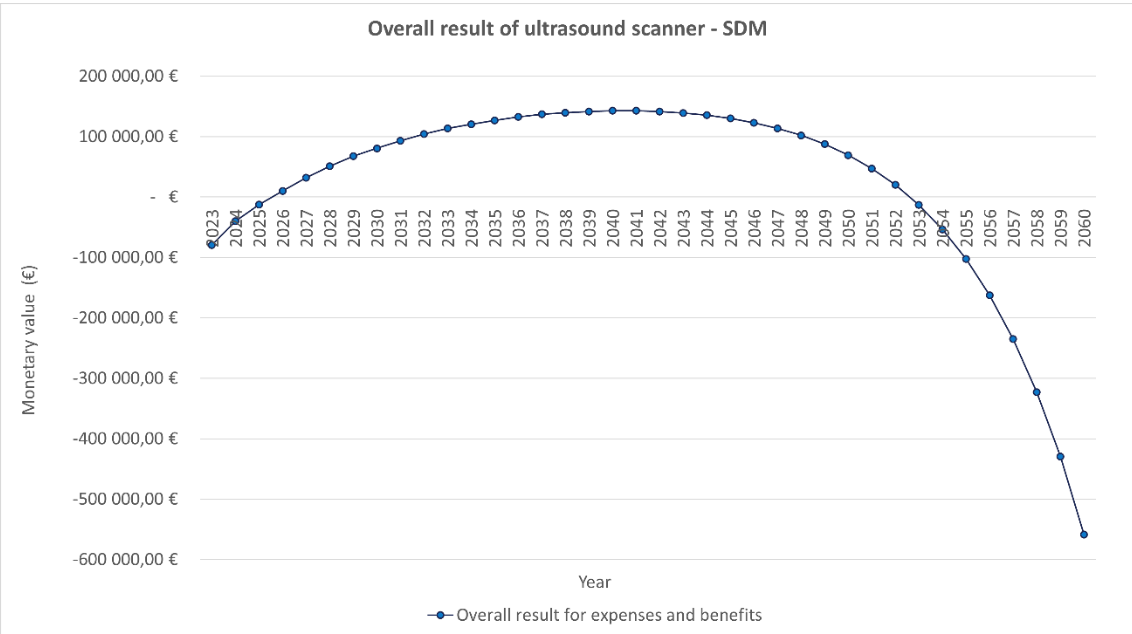


Figure 26 - Overall result of the ultrasound scanner's LCI using the SDM method over time.

LCI – Ultrasound Scanner: hypothetical situation in which there is an increase in the value of maintenance and a decrease in availability

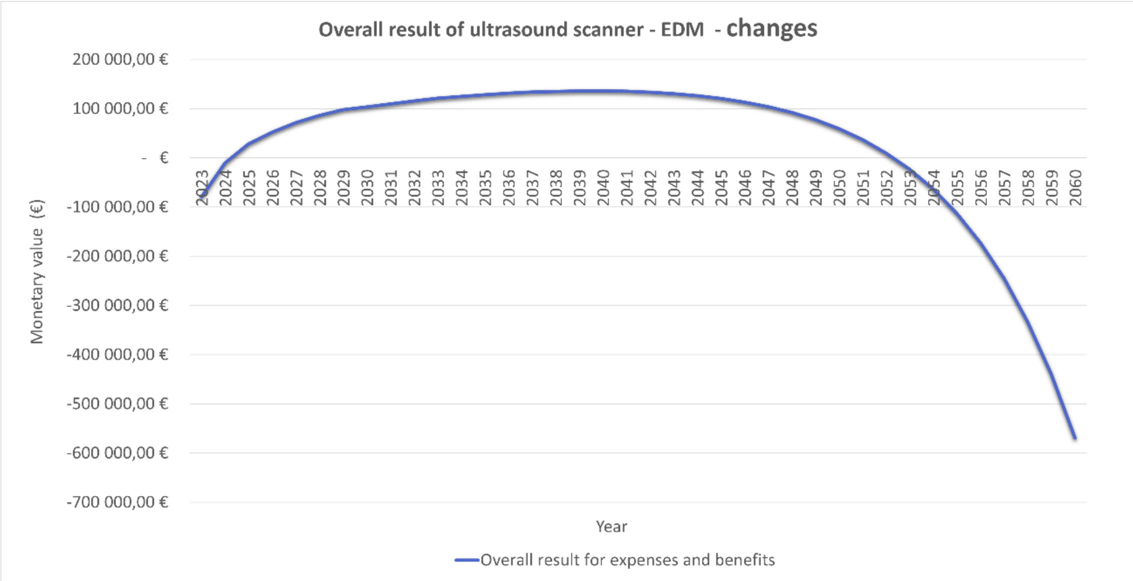


Figure 27 - Overall result of the LCI of the ultrasound scanner by the EDM method over time with an increase in maintenance value and decrease in availability.

LCI – Mammograpgy Systems

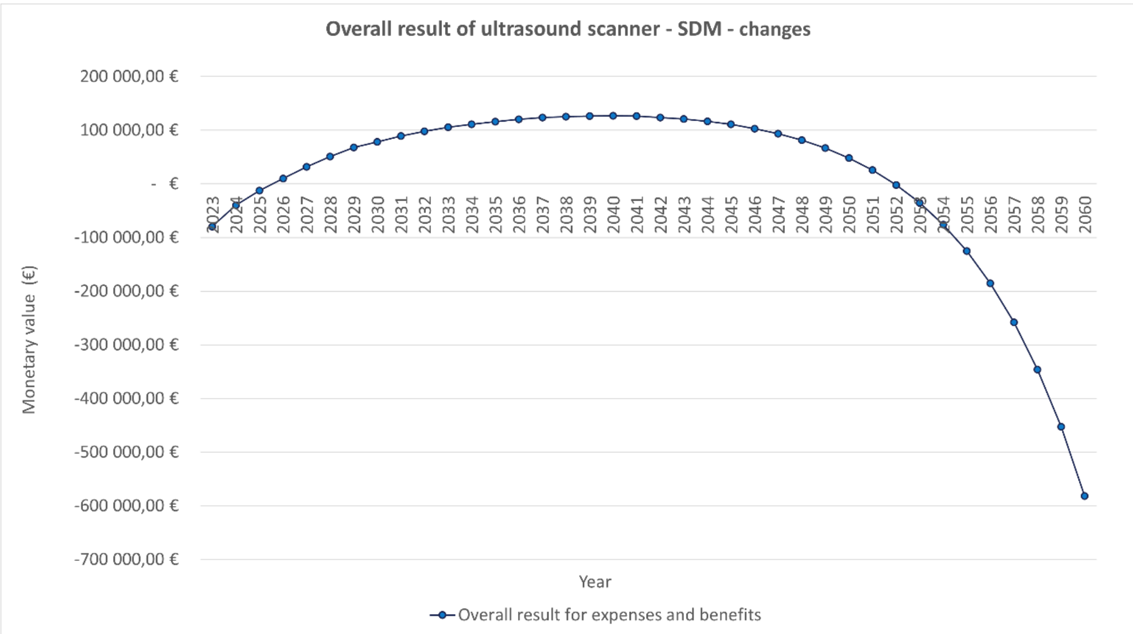


Figure 28 - Overall result of the LCI of the ultrasound scanner by the SDM method over time with an increase in maintenance value and decrease in availability.

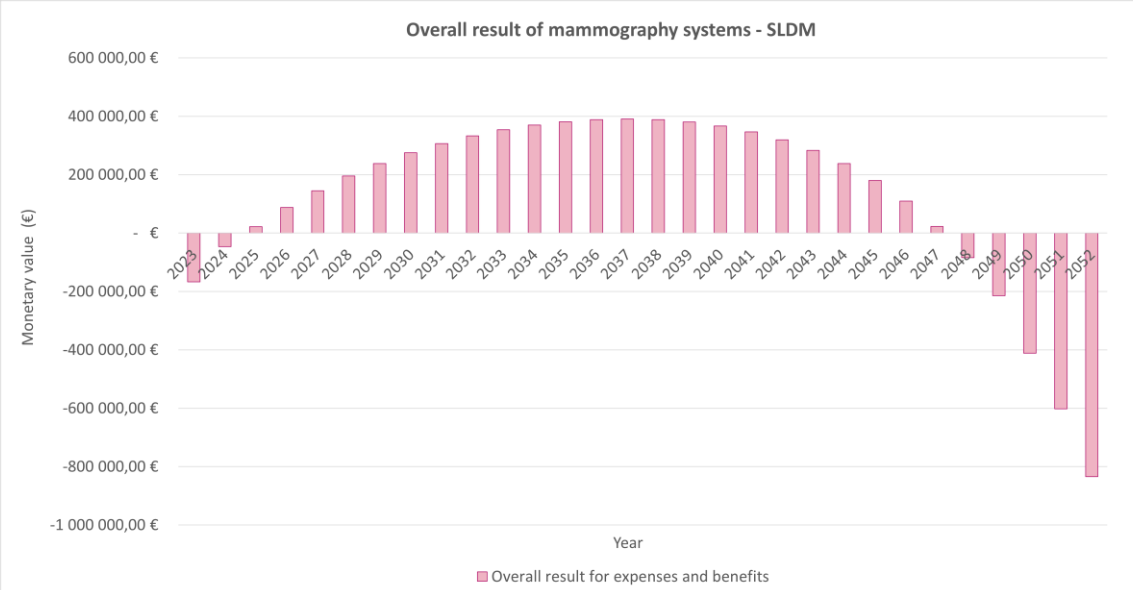


Figure 29 - Overall result of the LCI of mammography systems by the SLDM method over time.

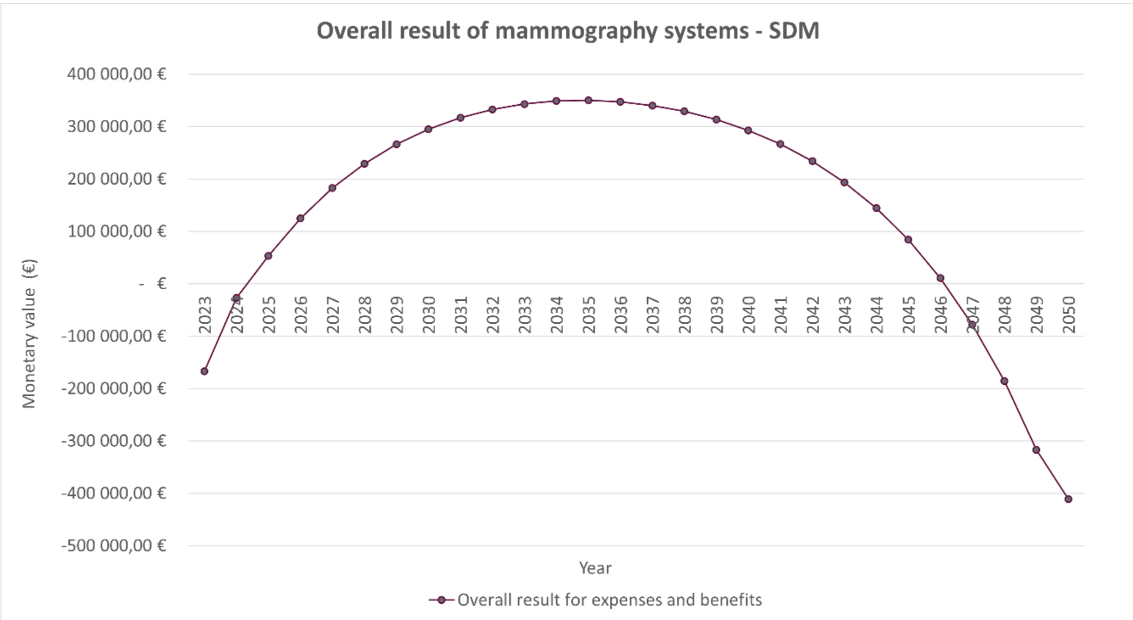


Figure 30 - Overall result of the LCI of mammography systems by the SDM method over time.

LCI – Mammography Systems: hypothetical situation in which a decrease in availability is considered.

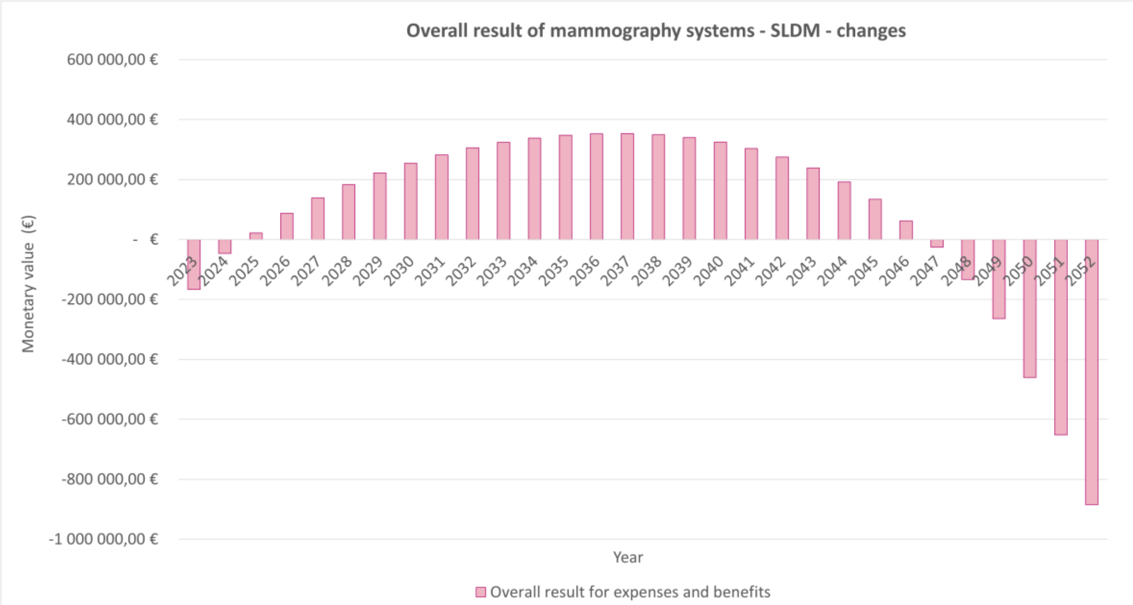


Figure 31 - Overall result of the LCI of mammography systems by the SLDM method over time considering a decrease in availability.

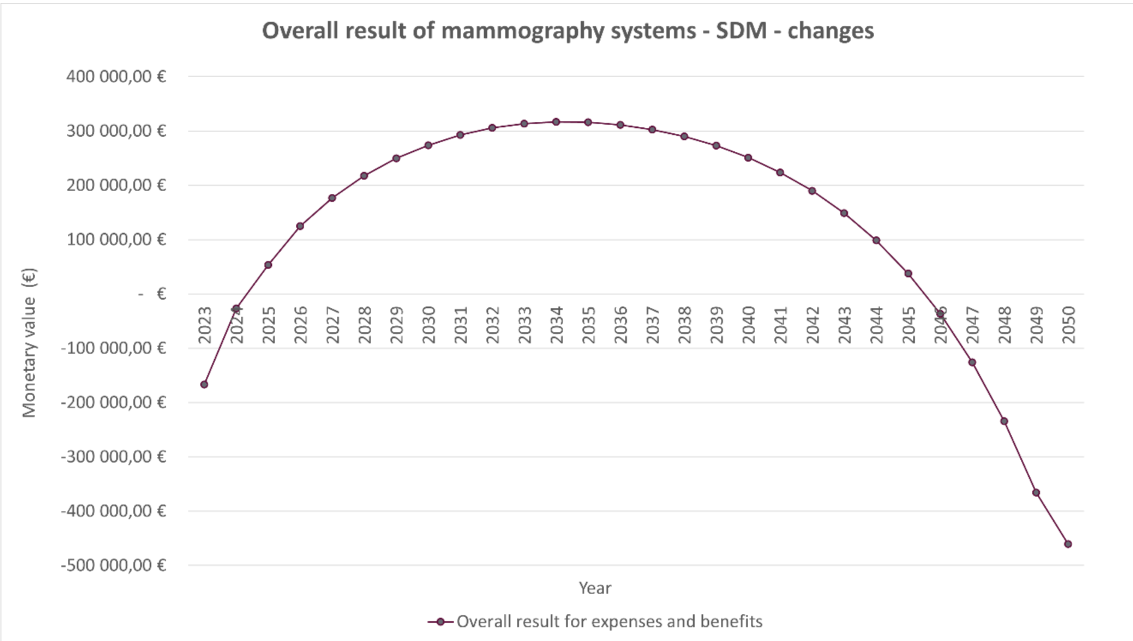


Figure 32 - Overall result of the LCI of mammography systems by the SLDM method over time considering a decrease in availability.

## LCI - X-ray

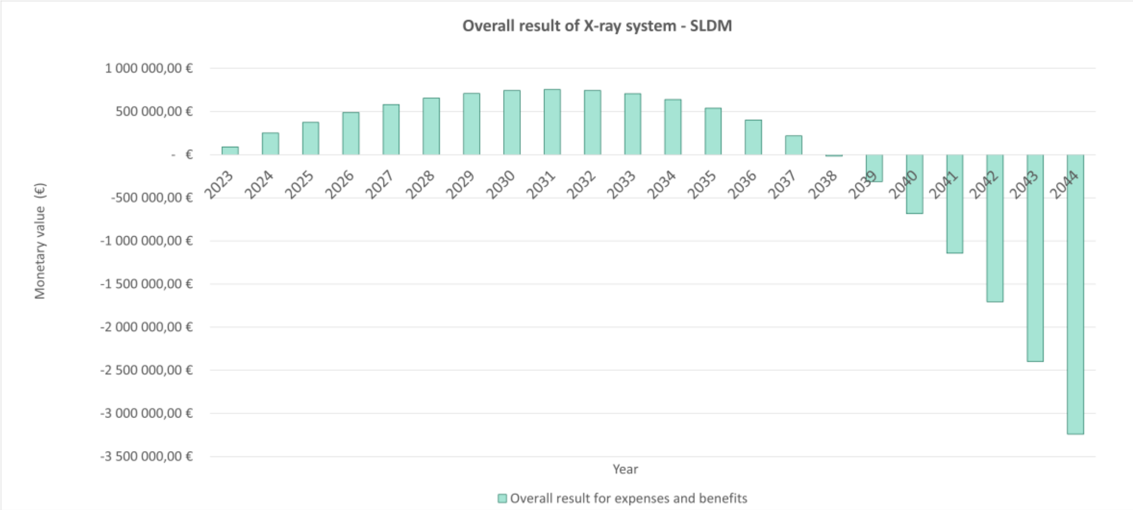


Figure 33 - Overall result of the X-ray LCI by the SLDM method over time.

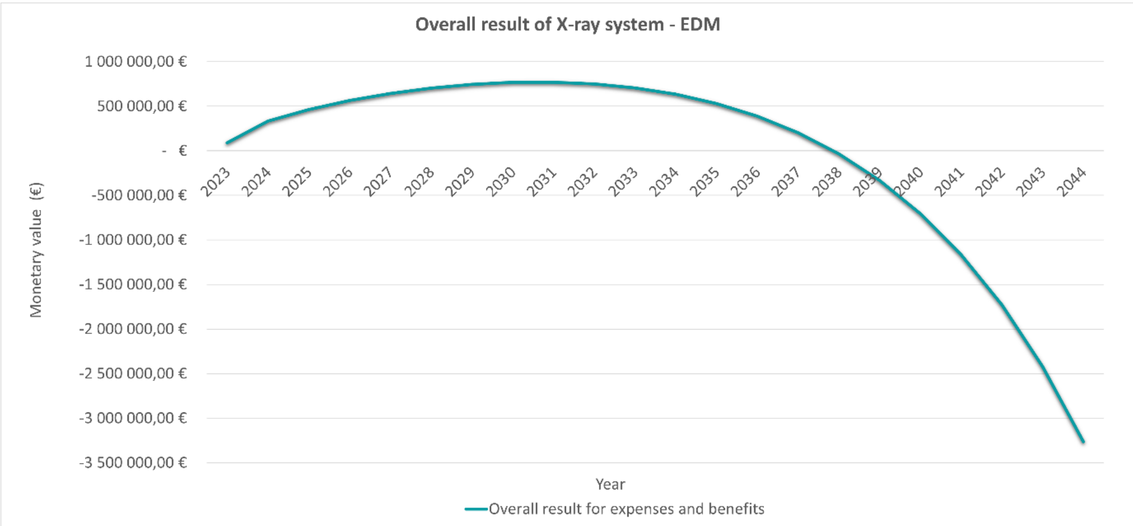


Figure 34 - Overall result of the X-ray LCI by the EDM method over time.

LCI – X-ray: hypothetical situation in which we consider an increase in the value of maintenance and an increase in availability.

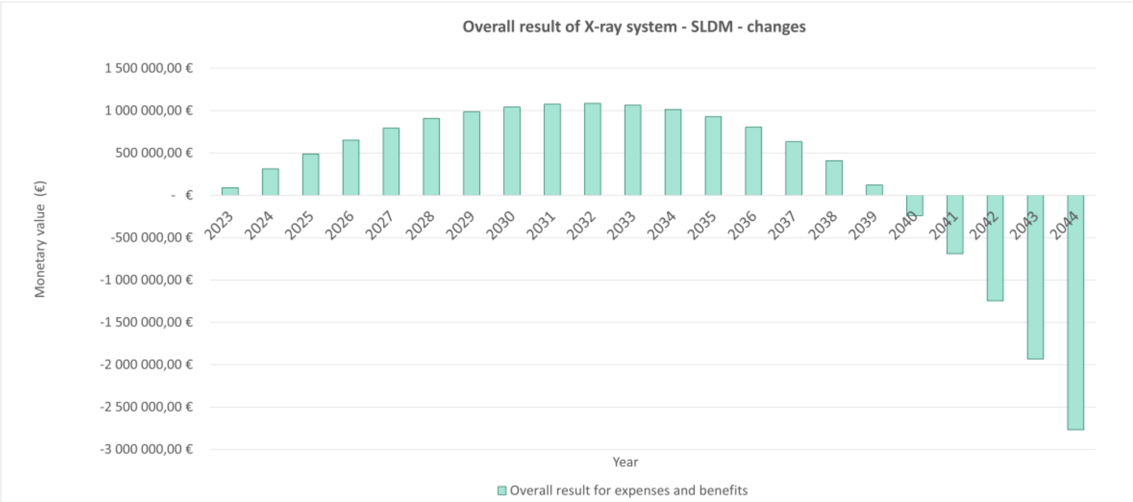


Figure 35 - Overall result of the X-ray LCI using the SLDM method over time, considering an increase in maintenance value and an increase in availability.

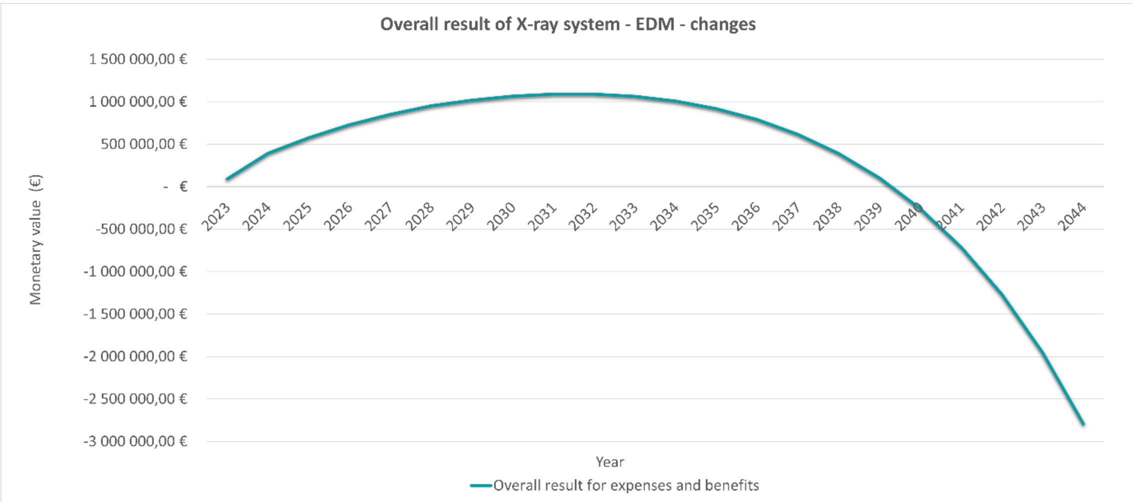


Figure 36 - Overall result of the X-ray LCI using the EDM method over time, considering an increase in maintenance value and an increase in availability.

## LCI – Ultrasound Scanner - tables

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 24 | 26 | 28 | 30 | 32 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 104 796,00 | | | | | | | | | | | | | | | | | |
| Present value of II | - | 86 600,06 | 71 563,52 | 59 137,80 | 48 869,59 | 40 384,26 | 33 372,26 | 27 577,77 | 22 789,39 | 18 832,42 | 10 627,39 | 8 782,13 | 7 257,28 | 5 997,18 | 4 955,88 | 4 095,38 | 3 722,90 | 3 384,29 |
| **O** | 264,15 | 264,15 | 351,60 | 622,95 | 1 103,69 | 1 955,45 | 3 464,52 | 6 138,19 | 10 875,21 | 19 267,93 | 107 158,52 | 189 855,84 | 336 373,07 | 595 961,86 | 1 055 882,80 | 1 870 737,98 | 2 490 070,19 | 3 314 440,40 |
| Present value of O | - | 218,29 | 240,10 | 351,54 | 514,69 | 753,55 | 1 103,28 | 1 615,31 | 2 364,97 | 3 462,55 | 10 866,97 | 15 910,34 | 23 294,32 | 34 105,22 | 49 933,45 | 73 107,56 | 88 460,15 | 107 036,78 |
| Accumulated O | | 722,57 | 1 161,11 | 1 803,17 | 2 743,22 | 4 119,54 | 6 134,62 | 9 084,89 | 13 404,38 | 19 728,54 | 62 392,11 | 91 451,49 | 133 997,32 | 196 288,66 | 287 489,43 | 421 016,47 | 509 476,62 | 616 513,40 |
| **M** | - | 7 603,20 | | | | | | | | | | | | | | | | |
| Present value of M | - | - | 5 192,10 | 4 290,59 | 3 545,61 | 2 929,97 | 2 421,24 | 2 000,83 | 1 653,42 | 1 366,34 | 771,04 | 637,16 | 526,53 | 435,11 | 359,56 | 297,13 | 398,00 | 245,54 |
| Accumulated M | - | - | 21 211,24 | 30 221,70 | 39 514,41 | 45 667,51 | 52 013,36 | 56 215,21 | 60 548,69 | 63 418,06 | 70 357,61 | 71 695,69 | 73 075,69 | 73 989,44 | 74 931,82 | 75 555,80 | 75 953,80 | 76 199,34 |
| **B** | 25 536,00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 20 325,11 | 16 796,02 | 13 879,69 | 11 469,73 | 9 478,22 | 7 832,50 | 6 472,53 | 5 348,69 | 4 419,98 | 2 494,26 | 2 061,17 | 1 703,29 | 1 407,54 | 1 163,15 | 961,19 | 873,77 | 794,30 |
| Accumulated B | | 68 219,78 | 103 492,29 | 132 640,37 | 156 727,41 | 176 632,16 | 193 080,82 | 206 673,46 | 217 905,98 | 227 188,18 | 246 435,42 | 250 764,00 | 254 340,99 | 257 296,91 | 259 739,58 | 261 758,13 | 262 631,89 | 263 426,19 |
| **Cash Flow** | | 20 106,82 | 11 363,81 | 9 237,56 | 7 409,44 | 5 794,69 | 4 307,98 | 2 856,39 | 1 330,29 | - 408,91 | - 9 143,76 | - 14 486,33 | - 22 117,57 | - 33 132,78 | - 49 129,86 | - 72 443,50 | - 87 984,38 | - 106 488,03 |
| **SLDM** | - | 95 683,39 | 86 570,78 | 77 458,17 | 68 345,57 | 59 232,96 | 50 120,35 | 41 007,74 | 31 895,13 | 22 782,52 | - | - | - | - | - | - | - | - |
| Present value of SLDM | - | 79 069,69 | 59 117,81 | 43 710,70 | 31 871,63 | 22 826,06 | 15 960,81 | 10 791,46 | 6 936,05 | 4 094,14 | - | - | - | - | - | - | - | - |
| **B** | - 79 260,00 | 68 219,78 | 103 492,29 | 132 640,37 | 156 727,41 | 176 632,16 | 193 080,82 | 206 673,46 | 217 905,98 | 227 188,18 | 246 435,42 | 250 764,00 | 254 340,99 | 257 296,91 | 259 739,58 | 261 758,13 | 262 631,89 | 263 426,19 |
| **Expenses (O + M + SLDM)** | 264,15 | 87 395,46 | 81 490,15 | 75 735,57 | 74 129,26 | 72 613,11 | 74 108,79 | 76 091,56 | 80 889,11 | 87 240,75 | 132 749,73 | 163 147,18 | 207 073,00 | 270 278,10 | 362 421,24 | 496 572,27 | 585 430,42 | 692 712,74 |
| **Overall result** | - 79 524,15 | - 19 175,68 | 22 002,14 | 56 904,80 | 82 598,14 | 104 019,05 | 118 972,03 | 130 581,90 | 137 016,86 | 139 947,42 | 113 685,70 | 87 616,82 | 47 267,99 | - 12 981,20 | - 102 681,67 | - 234 814,15 | - 322 798,53 | - 429 286,55 |
| **ROI (%)** | | -35% | -15% | 4% | 17% | 29% | 36% | 42% | 45% | 45% | 16% | -9% | -47% | -105% | -190% | -317% | -401% | -502% |

Table 5 - Table with all the ultrasound scanner values considered over time with the SLDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 104 796,00 € | | | | | | | | | | | | | | | | |
| Present value of II | - € | 86 600,06 € | 71 563,52 € | 59 137,80 € | 48 869,59 € | 40 384,26 € | 33 372,26 € | 27 577,77 € | 22 789,39 € | 18 832,42 € | 15 562,51 € | 12 860,36 € | 10 627,39 € | 8 782,13 € | 7 257,28 € | 5 997,18 € | 4 955,88 € |
| | | | | | | | | | | | | | | | | | |
| **O** | 264,15 € | 264,15 € | 351,60 € | 622,95 € | 1 103,69 € | 1 955,45 € | 3 464,52 € | 6 138,19 € | 10 875,21 € | 19 267,93 € | 34 137,54 € | 60 482,46 € | 107 158,52 € | 189 855,84 € | 336 373,07 € | 595 961,86 € | 1 055 882,80 € |
| Present value of O | - € | 218,29 € | 240,10 € | 351,54 € | 514,69 € | 753,55 € | 1 103,28 € | 1 615,31 € | 2 364,97 € | 3 462,55 € | 5 069,52 € | 7 422,29 € | 10 866,97 € | 15 910,34 € | 23 294,32 € | 34 105,22 € | 49 933,45 € |
| Accumulated O | | 722,57 € | 1 161,11 € | 1 803,17 € | 2 743,22 € | 4 119,54 € | 6 134,62 € | 9 084,89 € | 13 404,38 € | 19 728,54 € | 28 987,76 € | 42 544,17 € | 62 392,11 € | 91 451,49 € | 133 997,32 € | 196 288,66 € | 287 489,43 € |
| | | | | | | | | | | | | | | | | | |
| **M** | - € | 7 603,20 € | | | | | | | | | | | | | | | |
| Present value of M | - € | - € | 5 192,10 € | 4 290,59 € | 3 545,61 € | 2 929,97 € | 2 421,24 € | 2 000,83 € | 1 653,42 € | 1 366,34 € | 1 129,10 € | 933,05 € | 771,04 € | 637,16 € | 526,53 € | 435,11 € | 359,56 € |
| Accumulated M | - € | - € | 21 211,24 € | 30 221,70 € | 39 514,41 € | 45 667,51 € | 52 013,36 € | 56 215,21 € | 60 548,69 € | 63 418,06 € | 66 377,33 € | 68 336,78 € | 70 357,61 € | 71 695,69 € | 73 075,69 € | 73 989,44 € | 74 931,82 € |
| | | | | | | | | | | | | | | | | | |
| **B** | 25 536,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 20 325,11 € | 16 796,02 € | 13 879,69 € | 11 469,73 € | 9 478,22 € | 7 832,50 € | 6 472,53 € | 5 348,69 € | 4 419,98 € | 3 652,53 € | 3 018,34 € | 2 494,26 € | 2 061,17 € | 1 703,29 € | 1 407,54 € | 1 163,15 € |
| Accumulated B | | 68 219,78 € | 103 492,29 € | 132 640,37 € | 156 727,41 € | 176 632,16 € | 193 080,82 € | 206 673,46 € | 217 905,98 € | 227 188,18 € | 234 858,69 € | 241 197,35 € | 246 435,42 € | 250 764,00 € | 254 340,99 € | 257 296,91 € | 259 739,58 € |
| | | | | | | | | | | | | | | | | | |
| **EDM** | - € | 38 352,44 € | 14 035,93 € | 5 136,76 € | 1 879,91 € | 688,00 € | 251,79 € | 92,15 € | 33,72 € | 12,34 € | 4,52 € | 1,65 € | - € | - € | - € | - € | - € |
| Present value of EDM | - € | 31 693,23 € | 9 584,91 € | 2 898,75 € | 876,66 € | 265,13 € | 80,18 € | 24,25 € | 7,33 € | 2,22 € | 0,67 € | 0,20 € | - € | - € | - € | - € | - € |
| | | | | | | | | | | | | | | | | | |
| **Benefits (B)** | - 79 260,00 € | 68 219,78 € | 103 492,29 € | 132 640,37 € | 156 727,41 € | 176 632,16 € | 193 080,82 € | 206 673,46 € | 217 905,98 € | 227 188,18 € | 234 858,69 € | 241 197,35 € | 246 435,42 € | 250 764,00 € | 254 340,99 € | 257 296,91 € | 259 739,58 € |
| **Expenses (O+M+EMD)** | 264,15 € | 40 019,00 € | 31 957,26 € | 34 923,62 € | 43 134,29 € | 50 052,18 € | 58 228,15 € | 65 324,35 € | 73 960,40 € | 83 148,83 € | 95 365,75 € | 110 881,15 € | 132 749,73 € | 163 147,18 € | 207 073,00 € | 270 278,10 € | 362 421,24 € |
| | | | | | | | | | | | | | | | | | |
| **Overall result** | - 79 524,15 € | 28 200,79 € | 71 535,03 € | 97 716,75 € | 113 593,11 € | 126 579,98 € | 134 852,66 € | 141 349,11 € | 143 945,58 € | 144 039,35 € | 139 492,94 € | 130 316,20 € | 113 685,70 € | 87 616,82 € | 47 267,99 € | - 12 981,20 € | - 102 681,67 € |

Table 6 - Table with all the ultrasound scanner values considered over time with the EDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 104 796,00 | | | | | | | | | | | | | | | | | |
| Present value of II | - | 86 600,06 | 71 563,52 | 59 137,80 | 48 869,59 | 40 384,26 | 33 372,26 | 27 577,77 | 22 789,39 | 18 832,42 | 15 562,51 | 12 860,36 | 10 627,39 | 8 782,13 | 7 257,28 | 5 997,18 | 4 955,88 | 4 095,38 |
| | | | | | | | | | | | | | | | | | | |
| **O** | 264,15 | 264,15 | 351,60 | 622,95 | 1 103,69 | 1 955,45 | 3 464,52 | 6 138,19 | 10 875,21 | 19 267,93 | 34 137,54 | 60 482,46 | 107 158,52 | 189 855,84 | 336 373,07 | 595 961,86 | 1 055 882,80 | 1 870 737,98 |
| Present value of O | - | 218,29 | 240,10 | 351,54 | 514,69 | 753,55 | 1 103,28 | 1 615,31 | 2 364,97 | 3 462,55 | 5 069,52 | 7 422,29 | 10 866,97 | 15 910,34 | 23 294,32 | 34 105,22 | 49 933,45 | 73 107,56 |
| Accumulated O amounts spent | | 722,57 | 1 161,11 | 1 803,17 | 2 743,22 | 4 119,54 | 6 134,62 | 9 084,89 | 13 404,38 | 19 728,54 | 28 987,76 | 42 544,17 | 62 392,11 | 91 451,49 | 133 997,32 | 196 288,66 | 287 489,43 | 421 016,47 |
| | | | | | | | | | | | | | | | | | | |
| **M** | - | 7 603,20 | | | | | | | | | | | | | | | | |
| Present value of M | - | - | 5 192,10 | 4 290,59 | 3 545,61 | 2 929,97 | 2 421,24 | 2 000,83 | 1 653,42 | 1 366,34 | 1 129,10 | 933,05 | 771,04 | 637,16 | 526,53 | 435,11 | 359,56 | 297,13 |
| Accumulated M amounts spent | - | - | 21 211,24 | 30 221,70 | 39 514,41 | 45 667,51 | 52 013,36 | 56 215,21 | 60 548,69 | 63 418,06 | 66 377,33 | 68 336,78 | 70 357,61 | 71 695,69 | 73 075,69 | 73 989,44 | 74 931,82 | 75 555,80 |
| | | | | | | | | | | | | | | | | | | |
| **B** | 25 536,00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 20 325,11 | 16 796,02 | 13 879,69 | 11 469,73 | 9 478,22 | 7 832,50 | 6 472,53 | 5 348,69 | 4 419,98 | 3 652,53 | 3 018,34 | 2 494,26 | 2 061,17 | 1 703,29 | 1 407,54 | 1 163,15 | 961,19 |
| Accumulated B amounts spent | | 68 219,78 | 103 492,29 | 132 640,37 | 156 727,41 | 176 632,16 | 193 080,82 | 206 673,46 | 217 905,98 | 227 188,18 | 234 858,69 | 241 197,35 | 246 435,42 | 250 764,00 | 254 340,99 | 257 296,91 | 259 739,58 | 261 758,13 |
| | | | | | | | | | | | | | | | | | | |
| **SDM** | - | 87 709,86 | 72 142,49 | 58 093,88 | 45 564,04 | 34 552,97 | 25 060,67 | 17 087,14 | 10 632,38 | 5 696,38 | 2 279,15 | 380,69 | - | - | - | - | - | - |
| Present value of SDM | - | 72 480,62 | 49 264,95 | 32 783,16 | 21 247,91 | 13 315,36 | 7 980,57 | 4 496,60 | 2 312,16 | 1 023,67 | 338,46 | 46,72 | - | - | - | - | - | - |
| | | | | | | | | | | | | | | | | | | |
| **Benefits (B)** | - 79 260,00 | 68 219,78 | 103 492,29 | 132 640,37 | 156 727,41 | 176 632,16 | 193 080,82 | 206 673,46 | 217 905,98 | 227 188,18 | 234 858,69 | 241 197,35 | 246 435,42 | 250 764,00 | 254 340,99 | 257 296,91 | 259 739,58 | 261 758,13 |
| **Expenses (O + M + SDM)** | 264,15 | 80 806,39 | 71 637,30 | 64 808,03 | 63 505,54 | 63 102,41 | 66 128,54 | 69 796,69 | 76 265,23 | 84 170,28 | 95 703,54 | 110 927,67 | 132 749,73 | 163 147,18 | 207 073,00 | 270 278,10 | 362 421,24 | 496 572,27 |
| | | | | | | | | | | | | | | | | | | |
| **Overall result** | - 79 524,15 | - 12 586,61 | 31 854,99 | 67 832,34 | 93 221,87 | 113 529,75 | 126 952,28 | 136 876,76 | 141 640,75 | 143 017,90 | 139 155,15 | 130 269,69 | 113 685,70 | 87 616,82 | 47 267,99 | - 12 981,20 | - 102 681,67 | - 234 814,15 |

Table 7 - Table with all the ultrasound scanner values considered over time with the SDM method.

LCI – Ultrasound Scanner: hypothetical situation in which there is an increase in the value of maintenance and a decrease in availability - tables

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| **II** | 104 796,00 | | | | | | | | |
| Present value of II | - | 86 600,06 | 71 563,52 | 59 137,80 | 48 869,59 | 40 384,26 | 33 372,26 | 27 577,77 | 22 789,39 |
| **O** | 264,15 | 264,15 | 351,60 | 622,95 | 1 103,69 | 1 955,45 | 3 464,52 | 6 138,19 | 10 875,21 |
| Present value of O | - | 218,29 | 240,10 | 351,54 | 514,69 | 753,55 | 1 103,28 | 1 615,31 | 2 364,97 |
| Accumulated O amounts spent | | 722,57 | 1 161,11 | 1 803,17 | 2 743,22 | 4 119,54 | 6 134,62 | 9 084,89 | 13 404,38 |
| **M** | - | 7 603,20 | | | | | | | |
| Present value of M | - | - | 5 192,10 | 4 290,59 | 4 245,10 | 3 508,02 | 2 898,91 | 2 395,57 | 1 979,62 |
| Accumulated M amounts spent | - | - | 21 211,24 | 30 221,70 | 40 983,39 | 48 350,40 | 55 699,39 | 60 730,21 | 65 748,72 |
| **B** | 25 536,00 | - | - | - | - | - | - | - | - |
| Present value of B | - | 20 325,11 | 16 796,02 | 13 879,69 | 10 121,99 | 8 364,49 | 6 912,14 | 5 711,97 | 4 720,19 |
| Accumulated B amounts spent | | 68 219,78 | 103 492,29 | 132 640,37 | 153 897,07 | 171 462,92 | 185 978,79 | 197 974,23 | 207 886,88 |
| **Cash Flow** | | 20 106,82 | 11 363,81 | 9 237,56 | 5 362,20 | 4 102,92 | 2 909,96 | 1 701,10 | 375,60 |
| **SLDM** | - | 95 683,39 | 86 570,78 | 77 458,17 | 68 345,57 | 59 232,96 | 50 120,35 | 41 007,74 | 31 895,13 |
| Present value of SLDM | - | 79 069,69 | 59 117,81 | 43 710,70 | 31 871,63 | 22 826,06 | 15 960,81 | 10 791,46 | 6 936,05 |
| **Benefits (B)** | - 79 260,00 | 68 219,78 | 103 492,29 | 132 640,37 | 153 897,07 | 171 462,92 | 185 978,79 | 197 974,23 | 207 886,88 |
| **Expenses (O + M + SLDM)** | 264,15 | 87 395,46 | 81 490,15 | 75 735,57 | 75 598,24 | 75 296,00 | 77 794,82 | 80 606,56 | 86 089,14 |
| **Overall result** | - 79 524,15 | - 19 175,68 | 22 002,14 | 56 904,80 | 78 298,83 | 96 166,92 | 108 183,96 | 117 367,67 | 121 797,74 |
| **ROI (%)** | | -35% | -15% | 4% | 13% | 21% | 26% | 30% | 30% |

| Period | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|
| **II** | | | | | | | | | | |
| Present value of II | 18 832,42 | 15 562,51 | 12 860,36 | 10 627,39 | 8 782,13 | 7 257,28 | 5 997,18 | 4 955,88 | 4 095,38 | 3 384,29 |
| **O** | 19 267,93 | 34 137,54 | 60 482,46 | 107 158,52 | 189 855,84 | 336 373,07 | 595 961,86 | 1 055 882,80 | 1 870 737,98 | 3 314 440,40 |
| Present value of O | 3 462,55 | 5 069,52 | 7 422,29 | 10 866,97 | 15 910,34 | 23 294,32 | 34 105,22 | 49 933,45 | 73 107,56 | 107 036,78 |
| Accumulated O amounts spent | 19 728,54 | 28 987,76 | 42 544,17 | 62 392,11 | 91 451,49 | 133 997,32 | 196 288,66 | 287 489,43 | 421 016,47 | 616 513,40 |
| **M** | | | | | | | | | | |
| Present value of M | 1 635,90 | 1 351,85 | 1 117,13 | 923,16 | 762,87 | 630,41 | 520,95 | 430,50 | 355,75 | 293,98 |
| Accumulated M amounts spent | 69 184,18 | 72 611,24 | 74 957,26 | 77 297,55 | 78 899,61 | 80 497,75 | 81 591,78 | 82 683,12 | 83 430,21 | 84 175,47 |
| **B** | - | - | - | - | - | - | - | - | - | - |
| Present value of B | 3 900,62 | 3 223,34 | 2 663,67 | 2 201,17 | 1 818,98 | 1 503,14 | 1 242,15 | 1 026,47 | 848,24 | 700,96 |
| Accumulated B amounts spent | 216 078,38 | 222 847,57 | 228 441,41 | 233 063,98 | 236 883,93 | 240 040,61 | 242 649,19 | 244 804,84 | 246 586,20 | 248 058,25 |
| **Cash Flow** | - 1 197,83 | - 3 198,03 | - 5 875,75 | - 9 588,96 | - 14 854,23 | - 22 421,59 | - 33 384,02 | - 49 337,47 | - 72 615,07 | - 106 629,80 |
| **SLDM** | 22 782,52 | 13 669,91 | 4 557,30 | - | - | - | - | - | - | - |
| Present value of SLDM | 4 094,14 | 2 030,02 | 559,26 | - | - | - | - | - | - | - |
| **Benefits (B)** | 216 078,38 | 222 847,57 | 228 441,41 | 233 063,98 | 236 883,93 | 240 040,61 | 242 649,19 | 244 804,84 | 246 586,20 | 248 058,25 |
| **Expenses (O + M + SLDM)** | 93 006,87 | 103 629,02 | 118 060,70 | 139 689,66 | 170 351,10 | 214 495,07 | 277 880,44 | 370 172,55 | 504 446,68 | 700 688,88 |
| **Overall result** | 123 071,51 | 119 218,55 | 110 380,72 | 93 374,33 | 66 532,83 | 25 545,54 | - 35 231,25 | - 125 367,71 | - 257 860,48 | - 452 630,62 |
| **ROI (%)** | 29% | 23% | 13% | -3% | -29% | -68% | -126% | -212% | -339% | -524% |

Table 8 - Table with all the values considered, for the hypothetical situation, of the ultrasound scanner over time with the SLDM method

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 104 796,00 | | | | | | | | | |
| Present value of II | - | 86 600,06 | 71 563,52 | 59 137,80 | 48 869,59 | 40 384,26 | 33 372,26 | 27 577,77 | 22 789,39 | 18 832,42 |
| **O** | 264,15 | 264,15 | 351,60 | 622,95 | 1 103,69 | 1 955,45 | 3 464,52 | 6 138,19 | 10 875,21 | 19 267,93 |
| Present value of O | - | 218,29 | 240,10 | 351,54 | 514,69 | 753,55 | 1 103,28 | 1 615,31 | 2 364,97 | 3 462,55 |
| Accumulated O amounts spent | | 722,57 | 1 161,11 | 1 803,17 | 2 743,22 | 4 119,54 | 6 134,62 | 9 084,89 | 13 404,38 | 19 728,54 |
| **M** | - | 7 603,20 | | | | | | | | |
| Present value of M | - | - | 5 192,10 | 4 290,59 | 4 245,10 | 3 508,02 | 2 898,91 | 2 395,57 | 1 979,62 | 1 635,90 |
| Accumulated M amounts sper | - | - | 21 211,24 | 30 221,70 | 40 983,39 | 48 350,40 | 55 699,39 | 60 730,21 | 65 748,72 | 69 184,18 |
| **B** | 25 536,00 | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 20 325,11 | 16 796,02 | 13 879,69 | 10 121,99 | 9 478,22 | 7 832,50 | 6 472,53 | 5 348,69 | 4 419,98 |
| Accumulated B amounts spent | | 68 219,78 | 103 492,29 | 132 640,37 | 153 897,07 | 173 801,82 | 190 250,48 | 203 843,12 | 215 075,64 | 224 357,84 |
| **EDM** | - | 38 352,44 | 14 035,93 | 5 136,76 | 1 879,91 | 688,00 | 251,79 | 92,15 | 33,72 | 12,34 |
| Present value of EDM | - | 31 693,23 | 9 584,91 | 2 898,75 | 876,66 | 265,13 | 80,18 | 24,25 | 7,33 | 2,22 |
| **Benefits (B)** | - 79 260,00 | 68 219,78 | 103 492,29 | 132 640,37 | 153 897,07 | 173 801,82 | 190 250,48 | 203 843,12 | 215 075,64 | 224 357,84 |
| **Expenses (O + M + EDM)** | 264,15 | 40 019,00 | 31 957,26 | 34 923,62 | 44 603,27 | 52 735,07 | 61 914,19 | 69 839,35 | 79 160,43 | 88 914,94 |
| **Overall Result** | - 79 524,15 | 28 200,79 | 71 535,03 | 97 716,75 | 109 293,80 | 121 066,75 | 128 336,29 | 134 003,77 | 135 915,22 | 135 442,90 |

| Period | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 |
|---|---|---|---|---|---|---|---|---|---|
| **II** | | | | | | | | | |
| Present value of II | 15 562,51 | 12 860,36 | 10 627,39 | 8 782,13 | 7 257,28 | 5 997,18 | 4 955,88 | 4 095,38 | 3 384,29 |
| **O** | 34 137,54 | 60 482,46 | 107 158,52 | 189 855,84 | 336 373,07 | 595 961,86 | 1 055 882,80 | 1 870 737,98 | 3 314 440,40 |
| Present value of O | 5 069,52 | 7 422,29 | 10 866,97 | 15 910,34 | 23 294,32 | 34 105,22 | 49 933,45 | 73 107,56 | 107 036,78 |
| Accumulated O amounts spent | 28 987,76 | 42 544,17 | 62 392,11 | 91 451,49 | 133 997,32 | 196 288,66 | 287 489,43 | 421 016,47 | 616 513,40 |
| **M** | | | | | | | | | |
| Present value of M | 1 351,85 | 1 117,13 | 923,16 | 762,87 | 630,41 | 520,95 | 430,50 | 355,75 | 293,98 |
| Accumulated M amounts sper | 72 611,24 | 74 957,26 | 77 297,55 | 78 899,61 | 80 497,75 | 81 591,78 | 82 683,12 | 83 430,21 | 84 175,47 |
| **B** | - | - | - | - | - | - | - | - | - |
| Present value of B | 3 652,53 | 3 018,34 | 2 494,26 | 2 061,17 | 1 703,29 | 1 407,54 | 1 163,15 | 961,19 | 794,30 |
| Accumulated B amounts spent | 232 028,35 | 238 367,02 | 243 605,09 | 247 933,66 | 251 510,66 | 254 466,57 | 256 909,24 | 258 927,79 | 260 595,85 |
| **EDM** | 4,52 | 1,65 | - | - | - | - | - | - | - |
| Present value of EDM | 0,67 | 0,20 | - | - | - | - | - | - | - |
| **Benefits (B)** | 232 028,35 | 238 367,02 | 243 605,09 | 247 933,66 | 251 510,66 | 254 466,57 | 256 909,24 | 258 927,79 | 260 595,85 |
| **Expenses (O + M + EDM)** | 101 599,67 | 117 501,63 | 139 689,66 | 170 351,10 | 214 495,07 | 277 880,44 | 370 172,55 | 504 446,68 | 700 688,88 |
| **Overall Result** | 130 428,69 | 120 865,38 | 103 915,43 | 77 582,56 | 37 015,59 | - 23 413,87 | - 113 263,31 | - 245 518,89 | - 440 093,03 |

Table 9 - Table with all the values considered, for the hypothetical situation, of the ultrasound scanner over time with the EDM method

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 104 796,00 | | | | | | | | | | | | | | | | | | |
| Present value of II | - | 86 600,06 | 71 563,52 | 59 137,80 | 48 869,59 | 40 384,26 | 33 372,26 | 27 577,77 | 22 789,39 | 18 832,42 | 15 562,51 | 12 860,36 | 10 627,39 | 8 782,13 | 7 257,28 | 5 997,18 | 4 955,88 | 4 095,38 | 3 384,29 |
| | | | | | | | | | | | | | | | | | | | |
| **O** | 264,15 | 264,15 | 351,60 | 622,95 | 1 103,69 | 1 955,45 | 3 464,52 | 6 138,19 | 10 875,21 | 19 267,93 | 34 137,54 | 60 482,46 | 107 158,52 | 189 855,84 | 336 373,07 | 595 961,86 | 1 055 882,80 | 1 870 737,98 | 3 314 440,40 |
| Present value of O | - | 218,29 | 240,10 | 351,54 | 514,69 | 753,55 | 1 103,28 | 1 615,31 | 2 364,97 | 3 462,55 | 5 069,52 | 7 422,29 | 10 866,97 | 15 910,34 | 23 294,32 | 34 105,22 | 49 933,45 | 73 107,56 | 107 036,78 |
| Accumulated O amounts spent | | 722,57 | 1 161,11 | 1 803,17 | 2 743,22 | 4 119,54 | 6 134,62 | 9 084,89 | 13 404,38 | 19 728,54 | 28 987,76 | 42 544,17 | 62 392,11 | 91 451,49 | 133 997,32 | 196 288,66 | 287 489,43 | 421 016,47 | 616 513,40 |
| | | | | | | | | | | | | | | | | | | | |
| **M** | - | 7 603,20 | | | | | | | | | | | | | | | | | |
| Present value of M | - | - | 5 192,10 | 4 290,59 | 4 245,10 | 3 508,02 | 2 898,91 | 2 395,57 | 1 979,62 | 1 635,90 | 1 351,85 | 1 117,13 | 923,16 | 762,87 | 630,41 | 520,95 | 430,50 | 355,75 | 293,98 |
| Accumulated M amounts spent | - | - | 21 211,24 | 30 221,70 | 40 983,39 | 48 350,40 | 55 699,39 | 60 730,21 | 65 748,72 | 69 184,18 | 72 611,24 | 74 957,26 | 77 297,55 | 78 899,61 | 80 497,75 | 81 591,78 | 82 683,12 | 83 430,21 | 84 175,47 |
| | | | | | | | | | | | | | | | | | | | |
| **B** | 25 536,00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 20 325,11 | 16 796,02 | 13 879,69 | 10 121,99 | 8 364,49 | 6 912,14 | 5 711,97 | 4 720,19 | 3 900,62 | 3 223,34 | 2 663,67 | 2 201,17 | 1 818,98 | 1 503,14 | 1 242,15 | 1 026,47 | 848,24 | 700,96 |
| Accumulated B amounts spent | | 68 219,78 | 103 492,29 | 132 640,37 | 153 897,07 | 171 462,92 | 185 978,79 | 197 974,23 | 207 886,88 | 216 078,38 | 222 847,57 | 228 441,41 | 233 063,98 | 236 883,93 | 240 040,61 | 242 649,19 | 244 804,84 | 246 586,20 | 248 058,25 |
| | | | | | | | | | | | | | | | | | | | |
| **SDM** | - | 87 709,86 | 72 142,49 | 58 093,88 | 45 564,04 | 34 552,97 | 25 060,67 | 17 087,14 | 10 632,38 | 5 696,38 | 2 279,15 | 380,69 | - | - | - | - | - | - | - |
| Present value of SDM | - | 72 480,62 | 49 264,95 | 32 783,16 | 21 247,91 | 13 315,36 | 7 980,57 | 4 496,60 | 2 312,16 | 1 023,67 | 338,46 | 46,72 | - | - | - | - | - | - | - |
| | | | | | | | | | | | | | | | | | | | |
| **Benefits (B)** | - 79 260,00 | 68 219,78 | 103 492,29 | 132 640,37 | 153 897,07 | 171 462,92 | 185 978,79 | 197 974,23 | 207 886,88 | 216 078,38 | 222 847,57 | 228 441,41 | 233 063,98 | 236 883,93 | 240 040,61 | 242 649,19 | 244 804,84 | 246 586,20 | 248 058,25 |
| **Expenses (O + M + SDM)** | 264,15 | 80 806,39 | 71 637,30 | 64 808,03 | 64 974,52 | 65 785,31 | 69 814,57 | 74 311,69 | 81 465,26 | 89 936,40 | 101 937,46 | 117 548,15 | 139 689,66 | 170 351,10 | 214 495,07 | 277 880,44 | 370 172,55 | 504 446,68 | 700 688,88 |
| | | | | | | | | | | | | | | | | | | | |
| **Overall Result** | - 79 524,15 | - 12 586,61 | 31 854,99 | 67 832,34 | 88 922,55 | 105 677,62 | 116 164,21 | 123 662,54 | 126 421,62 | 126 141,98 | 120 910,11 | 110 893,26 | 93 374,33 | 66 532,83 | 25 545,54 | - 35 231,25 | - 125 367,71 | - 257 860,48 | - 452 630,62 |

Table 10 - Table with all the values considered, for the hypothetical situation, of the ultrasound scanner over time with the SDM method

# LCI – Mammograpgy Systems - tables

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 247 230,00 | | | | | | | | | | | | | | |
| Present value of II | - | 204 302,96 | 168 829,43 | 139 515,24 | 115 290,93 | 95 272,73 | 78 730,34 | 65 060,23 | 53 763,69 | 44 428,60 | 36 714,37 | 30 339,58 | 25 071,66 | 20 718,42 | 17 121,04 |
| | | | | | | | | | | | | | | | |
| **O** | 2 201,28 | 2 201,28 | 2 930,04 | 5 191,23 | 9 197,45 | 16 295,39 | 28 871,01 | 51 151,60 | 90 626,76 | 160 566,05 | 284 479,50 | 504 020,52 | 892 987,69 | 1 582 132,02 | 2 803 108,90 |
| Present value of O | - | 1 819,06 | 2 000,87 | 2 929,48 | 4 289,05 | 6 279,60 | 9 193,97 | 13 460,89 | 19 708,08 | 28 854,61 | 42 246,03 | 61 852,41 | 90 558,11 | 132 586,13 | 194 119,36 |
| Accumulated O amounts spent | | 6 021,40 | 9 675,89 | 15 026,43 | 22 860,16 | 34 329,52 | 51 121,80 | 75 707,39 | 111 703,14 | 164 404,53 | 241 564,63 | 354 534,74 | 519 934,27 | 762 095,71 | 1 116 644,29 |
| | | | | | | | | | | | | | | | |
| **M** | - | 39 067,20 | | | | | | | | | | | | | |
| Present value of M | - | - | 26 678,37 | 22 046,15 | 18 218,23 | 15 054,96 | 12 440,94 | 10 280,80 | 8 495,72 | 7 020,59 | 5 801,59 | 4 794,25 | 3 961,81 | 3 273,92 | 2 705,46 |
| Accumulated M amounts spent | - | 39 067,20 | 95 093,16 | 141 391,23 | 179 650,47 | 211 266,68 | 237 393,30 | 258 983,51 | 276 824,96 | 291 568,57 | 303 752,22 | 313 820,39 | 322 140,41 | 329 015,81 | 334 697,41 |
| | | | | | | | | | | | | | | | |
| **B** | 82 530,00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 68 105,55 | 56 280,25 | 46 508,19 | 38 432,88 | 31 759,70 | 26 245,20 | 21 688,20 | 17 922,43 | 14 810,52 | 12 238,94 | 10 113,87 | 8 357,78 | 6 906,60 | 5 707,39 |
| Accumulated B amounts spent | | 225 555,20 | 343 746,65 | 441 416,28 | 522 127,33 | 588 824,37 | 643 940,66 | 689 487,01 | 727 125,05 | 758 227,92 | 783 930,34 | 805 169,99 | 822 721,76 | 837 225,99 | 849 211,81 |
| | | | | | | | | | | | | | | | |
| **Cash Flow** | | 66 286,48 | 27 601,00 | 21 532,56 | 15 925,60 | 10 425,14 | 4 610,30 | - 2 053,49 | - 10 281,37 | - 21 064,67 | - 35 808,68 | - 56 532,79 | - 86 162,15 | - 128 953,45 | - 191 117,42 |
| | | | | | | | | | | | | | | | |
| **SLDM** | - | 192 290,22 | 137 350,44 | 82 410,67 | 27 470,89 | - 27 468,89 | - 82 408,67 | - 137 348,44 | - 192 288,22 | - 247 228,00 | - 302 167,78 | - 357 107,56 | - 412 047,33 | - 466 987,11 | - |
| Present value of SLDM | - | 158 902,49 | 93 794,43 | 46 505,46 | 12 810,52 | - 10 585,43 | - 26 243,02 | - 36 144,16 | - 41 815,82 | - 44 428,24 | - 44 872,79 | - 43 823,54 | - 41 785,83 | - 39 134,54 | - |
| | | | | | | | | | | | | | | | |
| **Benefits (B)** | - 164 700,00 | 225 555,20 | 343 746,65 | 441 416,28 | 522 127,33 | 588 824,37 | 643 940,66 | 689 487,01 | 727 125,05 | 758 227,92 | 783 930,34 | 805 169,99 | 822 721,76 | 837 225,99 | 849 211,81 |
| **Expenses (O + M + SLDM)** | 2 201,28 | 203 991,09 | 198 563,49 | 202 923,12 | 215 321,14 | 235 010,76 | 262 272,08 | 298 546,73 | 346 712,29 | 411 544,87 | 500 444,06 | 624 531,59 | 800 288,85 | 1 051 976,98 | 1 451 341,71 |
| | | | | | | | | | | | | | | | |
| **Overall Result** | - 166 901,28 | 21 564,11 | 145 183,16 | 238 493,16 | 306 806,19 | 353 813,61 | 381 668,58 | 390 940,27 | 380 412,76 | 346 683,05 | 283 486,28 | 180 638,40 | 22 432,92 | - 214 750,99 | - 602 129,90 |
| | | | | | | | | | | | | | | | |
| **ROI (%)** | | -10% | 13% | 32% | 46% | 56% | 60% | 60% | 54% | 39% | 13% | -28% | -91% | -186% | -390% |

Table 11 - Table with all the considered values of the mammography systems over time with the SLDM method.

| Period | 0 | 1 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 247 230,00 € | | | | | | | | | | | | | | |
| Present value of II | - € | 224 743,90 € | 204 302,96 € | 168 829,43 € | 139 515,24 € | 115 290,93 € | 95 272,73 € | 78 730,34 € | 65 060,23 € | 53 763,69 € | 44 428,60 € | 36 714,37 € | 30 339,58 € | 25 071,66 € | 20 718,42 € |
| | | | | | | | | | | | | | | | |
| **O** | 2 201,28 € | 2 201,28 € | 2 201,28 € | 2 930,04 € | 5 191,23 € | 9 197,45 € | 16 295,39 € | 28 871,01 € | 51 151,60 € | 90 626,76 € | 160 566,05 € | 284 479,50 € | 504 020,52 € | 892 987,69 € | 1 582 132,02 € |
| Present value of O | - € | 2 001,06 € | 1 819,06 € | 2 000,87 € | 2 929,48 € | 4 289,05 € | 6 279,60 € | 9 193,97 € | 13 460,89 € | 19 708,08 € | 28 854,61 € | 42 246,03 € | 61 852,41 € | 90 558,11 € | 132 586,13 € |
| Accumulated O amounts spent | | 4 202,34 € | 6 021,40 € | 9 675,89 € | 15 026,43 € | 22 860,16 € | 34 329,52 € | 51 121,80 € | 75 707,39 € | 111 703,14 € | 164 404,53 € | 241 564,63 € | 354 534,74 € | 519 934,27 € | 762 095,71 € |
| | | | | | | | | | | | | | | | |
| **M** | - € | - € | 39 067,20 € | | | | | | | | | | | | |
| Present value of M | - € | - € | - € | 26 678,37 € | 22 046,15 € | 18 218,23 € | 15 054,96 € | 12 440,94 € | 10 280,80 € | 8 495,72 € | 7 020,59 € | 5 801,59 € | 4 794,25 € | 3 961,81 € | 3 273,92 € |
| Accumulated M amounts spent | - € | - € | 39 067,20 € | 95 093,16 € | 141 391,23 € | 179 650,47 € | 211 266,68 € | 237 393,30 € | 258 983,51 € | 276 824,96 € | 291 568,57 € | 303 752,22 € | 313 820,39 € | 322 140,41 € | 329 015,81 € |
| | | | | | | | | | | | | | | | |
| **B** | 82 530,00 € | | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 74 919,65 € | 68 105,55 € | 56 280,25 € | 46 508,19 € | 38 432,88 € | 31 759,70 € | 26 245,20 € | 21 688,20 € | 17 922,43 € | 14 810,52 € | 12 238,94 € | 10 113,87 € | 8 357,78 € | 6 906,60 € |
| Accumulated B amounts spent | | 157 449,65 € | 225 555,20 € | 343 746,65 € | 441 416,28 € | 522 127,33 € | 588 824,37 € | 643 940,66 € | 689 487,01 € | 727 125,05 € | 758 227,92 € | 783 930,34 € | 805 169,99 € | 822 721,76 € | 837 225,99 € |
| | | | | | | | | | | | | | | | |
| **EDM** | - € | 62 211,07 € | 15 654,32 € | 991,21 € | 62,76 € | 3,97 € | 0,25 € | 0,02 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| Present value of EDM | - € | 56 552,84 € | 12 936,23 € | 676,88 € | 35,42 € | 1,85 € | 0,10 € | 0,01 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| | | | | | | | | | | | | | | | |
| **Benefits (B)** | - 164 700,00 € | 157 449,65 € | 225 555,20 € | 343 746,65 € | 441 416,28 € | 522 127,33 € | 588 824,37 € | 643 940,66 € | 689 487,01 € | 727 125,05 € | 758 227,92 € | 783 930,34 € | 805 169,99 € | 822 721,76 € | 837 225,99 € |
| **Expenses (O + M + EDM)** | 2 201,28 € | 60 755,18 € | 58 024,83 € | 105 445,94 € | 156 453,08 € | 202 512,48 € | 245 596,29 € | 288 515,11 € | 334 690,90 € | 388 528,11 € | 455 973,10 € | 545 316,85 € | 668 355,13 € | 842 074,67 € | 1 091 111,52 € |
| | | | | | | | | | | | | | | | |
| **Overall Result** | - 166 901,28 € | 96 694,47 € | 167 530,37 € | 238 300,70 € | 284 963,20 € | 319 614,86 € | 343 228,08 € | 355 425,56 € | 354 796,11 € | 338 596,94 € | 302 254,82 € | 238 613,49 € | 136 814,86 € | - 19 352,91 € | - 253 885,53 € |

Table 12 - Table with all the considered values of the mammography systems over time with the EDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| II | 247 230,00 € | | | | | | | | | | | | | |
| Present value of II | - € | 204 302,96 € | 168 829,43 € | 139 515,24 € | 115 290,93 € | 95 272,73 € | 78 730,34 € | 65 060,23 € | 53 763,69 € | 44 428,60 € | 36 714,37 € | 30 339,58 € | 25 071,66 € | 20 718,42 € |
| | | | | | | | | | | | | | | |
| O | 2 201,28 € | 2 201,28 € | 2 930,04 € | 5 191,23 € | 9 197,45 € | 16 295,39 € | 28 871,01 € | 51 151,60 € | 90 626,76 € | 160 566,05 € | 284 479,50 € | 504 020,52 € | 892 987,69 € | 1 582 132,02 € |
| Present value of O | - € | 1 819,06 € | 2 000,87 € | 2 929,48 € | 4 289,05 € | 6 279,60 € | 9 193,97 € | 13 460,89 € | 19 708,08 € | 28 854,61 € | 42 246,03 € | 61 852,41 € | 90 558,11 € | 132 586,13 € |
| Accumulated O amounts spent | | 6 021,40 € | 9 675,89 € | 15 026,43 € | 22 860,16 € | 34 329,52 € | 51 121,80 € | 75 707,39 € | 111 703,14 € | 164 404,53 € | 241 564,63 € | 354 534,74 € | 519 934,27 € | 762 095,71 € |
| | | | | | | | | | | | | | | |
| M | - € | 39 067,20 € | | | | | | | | | | | | |
| Present value of M | - € | - € | 26 678,37 € | 22 046,15 € | 18 218,23 € | 15 054,96 € | 12 440,94 € | 10 280,80 € | 8 495,72 € | 7 020,59 € | 5 801,59 € | 4 794,25 € | 3 961,81 € | 3 273,92 € |
| Accumulated M amounts spent | - € | 39 067,20 € | 95 093,16 € | 141 391,23 € | 179 650,47 € | 211 266,68 € | 237 393,30 € | 258 983,51 € | 276 824,96 € | 291 568,57 € | 303 752,22 € | 313 820,39 € | 322 140,41 € | 329 015,81 € |
| | | | | | | | | | | | | | | |
| B | 82 530,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 68 105,55 € | 56 280,25 € | 46 508,19 € | 38 432,88 € | 31 759,70 € | 26 245,20 € | 21 688,20 € | 17 922,43 € | 14 810,52 € | 12 238,94 € | 10 113,87 € | 8 357,78 € | 6 906,60 € |
| Accumulated B amounts spent | | 225 555,20 € | 343 746,65 € | 441 416,28 € | 522 127,33 € | 588 824,37 € | 643 940,66 € | 689 487,01 € | 727 125,05 € | 758 227,92 € | 783 930,34 € | 805 169,99 € | 822 721,76 € | 837 225,99 € |
| | | | | | | | | | | | | | | |
| SDM | - € | 153 832,38 € | 82 410,67 € | 32 964,87 € | 5 494,98 € | 1,00 € | 16 482,93 € | 54 940,78 € | 115 374,53 € | 197 784,20 € | 302 169,78 € | 428 531,27 € | 576 868,36 € | 747 179,93 € |
| Present value of SDM | - € | 127 122,15 € | 56 276,93 € | 18 602,52 € | 2 562,48 € | 0,39 € | 5 248,99 € | 14 458,03 € | 25 089,84 € | 35 542,91 € | 44 873,09 € | 52 588,52 € | 58 500,37 € | 62 615,32 € |
| | | | | | | | | | | | | | | |
| Benefits (B) | - 164 700,00 € | 225 555,20 € | 343 746,65 € | 441 416,28 € | 522 127,33 € | 588 824,37 € | 643 940,66 € | 689 487,01 € | 727 125,05 € | 758 227,92 € | 783 930,34 € | 805 169,99 € | 822 721,76 € | 837 225,99 € |
| Expenses (O + M + SDM) | 2 201,28 € | 172 210,76 € | 161 045,99 € | 175 020,18 € | 205 073,10 € | 245 596,58 € | 293 764,09 € | 349 148,93 € | 413 617,95 € | 491 516,02 € | 590 189,94 € | 720 943,64 € | 900 575,04 € | 1 153 726,84 € |
| | | | | | | | | | | | | | | |
| Overall Result | - 166 901,28 € | 53 344,44 € | 182 700,66 € | 266 396,09 € | 317 054,23 € | 343 227,79 € | 350 176,57 € | 340 338,08 € | 313 507,10 € | 266 711,90 € | 193 740,40 € | 84 226,35 € | - 77 853,28 € | - 316 500,85 € |

Table 13 - Table with all the considered values of the mammography systems over time with the SDM method.

LCI – Mammography Systems: hypothetical situation in which a decrease in availability is considered – tables

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 247 230,00 | | | | | | | | | | | | | | |
| Present value of II | - | 204 302,96 | 168 829,43 | 139 515,24 | 115 290,93 | 95 272,73 | 78 730,34 | 65 060,23 | 53 763,69 | 44 428,60 | 36 714,37 | 30 339,58 | 25 071,66 | 20 718,42 | 17 121,04 |
| **O** | 2 201,28 | 2 201,28 | 2 930,04 | 5 191,23 | 9 197,45 | 16 295,39 | 28 871,01 | 51 151,60 | 90 626,76 | 160 566,05 | 284 479,50 | 504 020,52 | 892 987,69 | 1 582 132,02 | 2 803 108,90 |
| Present value of O | - | 1 819,06 | 2 000,87 | 2 929,48 | 4 289,05 | 6 279,60 | 9 193,97 | 13 460,89 | 19 708,08 | 28 854,61 | 42 246,03 | 61 852,41 | 90 558,11 | 132 586,13 | 194 119,36 |
| Accumulated O amounts spent | | 6 021,40 | 9 675,89 | 15 026,43 | 22 860,16 | 34 329,52 | 51 121,80 | 75 707,39 | 111 703,14 | 164 404,53 | 241 564,63 | 354 534,74 | 519 934,27 | 762 095,71 | 1 116 644,29 |
| **M** | - | 39 067,20 | | | | | | | | | | | | | |
| Present value of M | - | - | 26 678,37 | 22 046,15 | 18 218,23 | 15 054,96 | 12 440,94 | 10 280,80 | 8 495,72 | 7 020,59 | 5 801,59 | 4 794,25 | 3 961,81 | 3 273,92 | 2 705,46 |
| Accumulated M amounts spent | - | 39 067,20 | 95 093,16 | 141 391,23 | 179 650,47 | 211 266,68 | 237 393,30 | 258 983,51 | 276 824,96 | 291 568,57 | 303 752,22 | 313 820,39 | 322 140,41 | 329 015,81 | 334 697,41 |
| **B** | 82 530,00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 68 105,55 | 50 159,00 | 41 449,79 | 35 407,37 | 29 259,52 | 24 179,13 | 19 980,86 | 16 511,54 | 13 644,61 | 11 275,47 | 9 317,69 | 7 699,84 | 6 362,90 | 5 258,10 |
| Accumulated B amounts spent | | 225 555,20 | 337 625,40 | 424 672,11 | 497 759,32 | 559 205,83 | 609 983,26 | 651 944,10 | 686 619,19 | 715 273,58 | 738 952,65 | 758 520,28 | 774 690,34 | 788 052,76 | 799 095,04 |
| **Cash Flow** | | 66 286,48 | 21 479,75 | 16 474,16 | 12 900,08 | 7 924,95 | 2 544,22 | - 3 760,83 | - 11 692,26 | - 22 230,59 | - 36 772,15 | - 57 328,97 | - 86 820,09 | - 129 497,15 | - 191 566,72 |
| **SLDM** | - | 192 290,22 | 137 350,44 | 82 410,67 | 27 470,89 | - 27 468,89 | - 82 408,67 | - 137 348,44 | - 192 288,22 | - 247 228,00 | - 302 167,78 | - 357 107,56 | - 412 047,33 | - 466 987,11 | - |
| Present value of SLDM | - | 158 902,49 | 93 794,43 | 46 505,46 | 12 810,52 | - 10 585,43 | - 26 243,02 | - 36 144,16 | - 41 815,82 | - 44 428,24 | - 44 872,79 | - 43 823,54 | - 41 785,83 | - 39 134,54 | - |
| **Benefits (B)** | - 164 700,00 | 225 555,20 | 337 625,40 | 424 672,11 | 497 759,32 | 559 205,83 | 609 983,26 | 651 944,10 | 686 619,19 | 715 273,58 | 738 952,65 | 758 520,28 | 774 690,34 | 788 052,76 | 799 095,04 |
| **Expenses (O + M +SLDM)** | 2 201,28 | 203 991,09 | 198 563,49 | 202 923,12 | 215 321,14 | 235 010,76 | 262 272,08 | 298 546,73 | 346 712,29 | 411 544,87 | 500 444,06 | 624 531,59 | 800 288,85 | 1 051 976,98 | 1 451 341,71 |
| **Overall Result** | - 166 901,28 | 21 564,11 | 139 061,91 | 221 749,00 | 282 438,18 | 324 195,07 | 347 711,17 | 353 397,37 | 339 906,90 | 303 728,72 | 238 508,59 | 133 988,69 | - 25 598,51 | - 263 924,22 | - 652 246,67 |
| **ROI (%)** | | -10% | 11% | 25% | 36% | 44% | 47% | 45% | 37% | 22% | -5% | -47% | -111% | -206% | -410% |

Table 14 - Table with all the values considered, for the hypothetical situation, of the mammography systems over time with the SLDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 247 230,00 € | | | | | | | | | | | | | |
| Present value of II | - € | 204 302,96 € | 168 829,43 € | 139 515,24 € | 115 290,93 € | 95 272,73 € | 78 730,34 € | 65 060,23 € | 53 763,69 € | 44 428,60 € | 36 714,37 € | 30 339,58 € | 25 071,66 € | 20 718,42 € |
| | | | | | | | | | | | | | | |
| **O** | 2 201,28 € | 2 201,28 € | 2 930,04 € | 5 191,23 € | 9 197,45 € | 16 295,39 € | 28 871,01 € | 51 151,60 € | 90 626,76 € | 160 566,05 € | 284 479,50 € | 504 020,52 € | 892 987,69 € | 1 582 132,02 € |
| Present value of O | - € | 1 819,06 € | 2 000,87 € | 2 929,48 € | 4 289,05 € | 6 279,60 € | 9 193,97 € | 13 460,89 € | 19 708,08 € | 28 854,61 € | 42 246,03 € | 61 852,41 € | 90 558,11 € | 132 586,13 € |
| Accumulated O amounts spent | | 6 021,40 € | 9 675,89 € | 15 026,43 € | 22 860,16 € | 34 329,52 € | 51 121,80 € | 75 707,39 € | 111 703,14 € | 164 404,53 € | 241 564,63 € | 354 534,74 € | 519 934,27 € | 762 095,71 € |
| | | | | | | | | | | | | | | |
| **M** | - € | 39 067,20 € | | | | | | | | | | | | |
| Present value of M | - € | - € | 26 678,37 € | 22 046,15 € | 18 218,23 € | 15 054,96 € | 12 440,94 € | 10 280,80 € | 8 495,72 € | 7 020,59 € | 5 801,59 € | 4 794,25 € | 3 961,81 € | 3 273,92 € |
| Accumulated M amounts spent | - € | 39 067,20 € | 95 093,16 € | 141 391,23 € | 179 650,47 € | 211 266,68 € | 237 393,30 € | 258 983,51 € | 276 824,96 € | 291 568,57 € | 303 752,22 € | 313 820,39 € | 322 140,41 € | 329 015,81 € |
| | | | | | | | | | | | | | | |
| **B** | 82 530,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 68 105,55 € | 50 159,00 € | 41 449,79 € | 35 407,37 € | 29 259,52 € | 24 179,13 € | 19 980,86 € | 16 511,54 € | 13 644,61 € | 11 275,47 € | 9 317,69 € | 7 699,84 € | 6 362,90 € |
| Accumulated B amounts spent | | 225 555,20 € | 337 625,40 € | 424 672,11 € | 497 759,32 € | 559 205,83 € | 609 983,26 € | 651 944,10 € | 686 619,19 € | 715 273,58 € | 738 952,65 € | 758 520,28 € | 774 690,34 € | 788 052,76 € |
| | | | | | | | | | | | | | | |
| **EDM** | - € | 15 654,32 € | 991,21 € | 62,76 € | 3,97 € | 0,25 € | 0,02 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| Present value of EDM | - € | 12 936,23 € | 676,88 € | 35,42 € | 1,85 € | 0,10 € | 0,01 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| | | | | | | | | | | | | | | |
| **Benefits (B)** | - 164 700,00 € | 225 555,20 € | 337 625,40 € | 424 672,11 € | 497 759,32 € | 559 205,83 € | 609 983,26 € | 651 944,10 € | 686 619,19 € | 715 273,58 € | 738 952,65 € | 758 520,28 € | 774 690,34 € | 788 052,76 € |
| **Expenses (O + M + EDM)** | 2 201,28 € | 58 024,83 € | 105 445,94 € | 156 453,08 € | 202 512,48 € | 245 596,29 € | 288 515,11 € | 334 690,90 € | 388 528,11 € | 455 973,10 € | 545 316,85 € | 668 355,13 € | 842 074,67 € | 1 091 111,52 € |
| | | | | | | | | | | | | | | |
| **Overall Result** | - 166 901,28 € | 167 530,37 € | 232 179,46 € | 268 219,03 € | 295 246,84 € | 313 609,54 € | 321 468,15 € | 317 253,20 € | 298 091,09 € | 259 300,48 € | 193 635,80 € | 90 165,15 € | - 67 384,33 € | - 303 058,76 € |

Table 15 - Table with all the values considered, for the hypothetical situation, of the mammography systems over time with the EDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 247 230,00 € | | | | | | | | | | | | | |
| Present value of II | - € | 204 302,96 € | 168 829,43 € | 139 515,24 € | 115 290,93 € | 95 272,73 € | 78 730,34 € | 65 060,23 € | 53 763,69 € | 44 428,60 € | 36 714,37 € | 30 339,58 € | 25 071,66 € | 20 718,42 € |
| | | | | | | | | | | | | | | |
| **O** | 2 201,28 € | 2 201,28 € | 2 930,04 € | 5 191,23 € | 9 197,45 € | 16 295,39 € | 28 871,01 € | 51 151,60 € | 90 626,76 € | 160 566,05 € | 284 479,50 € | 504 020,52 € | 892 987,69 € | 1 582 132,02 € |
| Present value of O | - € | 1 819,06 € | 2 000,87 € | 2 929,48 € | 4 289,05 € | 6 279,60 € | 9 193,97 € | 13 460,89 € | 19 708,08 € | 28 854,61 € | 42 246,03 € | 61 852,41 € | 90 558,11 € | 132 586,13 € |
| Accumulated O amounts spent | | 6 021,40 € | 9 675,89 € | 15 026,43 € | 22 860,16 € | 34 329,52 € | 51 121,80 € | 75 707,39 € | 111 703,14 € | 164 404,53 € | 241 564,63 € | 354 534,74 € | 519 934,27 € | 762 095,71 € |
| | | | | | | | | | | | | | | |
| **M** | - € | 39 067,20 € | | | | | | | | | | | | |
| Present value of M | - € | - € | 26 678,37 € | 22 046,15 € | 18 218,23 € | 15 054,96 € | 12 440,94 € | 10 280,80 € | 8 495,72 € | 7 020,59 € | 5 801,59 € | 4 794,25 € | 3 961,81 € | 3 273,92 € |
| Accumulated M amounts spent | - € | 39 067,20 € | 95 093,16 € | 141 391,23 € | 179 650,47 € | 211 266,68 € | 237 393,30 € | 258 983,51 € | 276 824,96 € | 291 568,57 € | 303 752,22 € | 313 820,39 € | 322 140,41 € | 329 015,81 € |
| | | | | | | | | | | | | | | |
| **B** | 82 530,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 68 105,55 € | 50 159,00 € | 41 449,79 € | 35 407,37 € | 29 259,52 € | 24 179,13 € | 19 980,86 € | 16 511,54 € | 13 644,61 € | 11 275,47 € | 9 317,69 € | 7 699,84 € | 6 362,90 € |
| Accumulated B amounts spent | | 225 555,20 € | 337 625,40 € | 424 672,11 € | 497 759,32 € | 559 205,83 € | 609 983,26 € | 651 944,10 € | 686 619,19 € | 715 273,58 € | 738 952,65 € | 758 520,28 € | 774 690,34 € | 788 052,76 € |
| | | | | | | | | | | | | | | |
| **SDM** | - € | 153 832,38 € | 82 410,67 € | 32 964,87 € | 5 494,98 € | 1,00 € | 16 482,93 € | 54 940,78 € | 115 374,53 € | 197 784,20 € | 302 169,78 € | 428 531,27 € | 576 868,36 € | 747 179,93 € |
| Present value of SDM | - € | 127 122,15 € | 56 276,93 € | 18 602,52 € | 2 562,48 € | 0,39 € | 5 248,99 € | 14 458,03 € | 25 089,84 € | 35 542,91 € | 44 873,09 € | 52 588,52 € | 58 500,37 € | 62 615,32 € |
| | | | | | | | | | | | | | | |
| **Benefits (B)** | - 164 700,00 € | 225 555,20 € | 337 625,40 € | 424 672,11 € | 497 759,32 € | 559 205,83 € | 609 983,26 € | 651 944,10 € | 686 619,19 € | 715 273,58 € | 738 952,65 € | 758 520,28 € | 774 690,34 € | 788 052,76 € |
| **Expenses (O + M + SDM)** | 2 201,28 € | 172 210,76 € | 161 045,99 € | 175 020,18 € | 205 073,10 € | 245 596,58 € | 293 764,09 € | 349 148,93 € | 413 617,95 € | 491 516,02 € | 590 189,94 € | 720 943,64 € | 900 575,04 € | 1 153 726,84 € |
| | | | | | | | | | | | | | | |
| **Overall Result** | - 166 901,28 € | 53 344,44 € | 176 579,41 € | 249 651,93 € | 292 686,22 € | 313 609,25 € | 316 219,17 € | 302 795,17 € | 273 001,25 € | 223 757,57 € | 148 762,72 € | 37 576,64 € | - 125 884,70 € | - 365 674,08 € |

Table 16 - Table with all the values considered, for the hypothetical situation, of the mammography systems over time with the SDM method.

## LCI – X-Ray – tables

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| II | 151 290,00 | | | | | | | | | | |
| Present value of II | - | 125 021,21 | 103 313,53 | 85 375,00 | 70 551,16 | 58 301,22 | 48 178,27 | 39 812,98 | 32 900,17 | 27 187,65 | 22 467,00 |
| O | 37 274,93 | 37 274,93 | 49 615,28 | 87 904,82 | 155 743,50 | 275 935,25 | 488 882,43 | 866 167,09 | 1 534 613,20 | 2 718 918,44 | 4 817 186,15 |
| Present value of O | - | 30 802,81 | 33 881,48 | 49 605,88 | 72 627,97 | 106 334,61 | 155 684,50 | 227 937,68 | 333 723,55 | 488 604,65 | 715 366,07 |
| Accumulated O amounts spent | | 101 962,43 | 163 845,14 | 254 447,61 | 387 098,69 | 581 313,15 | 865 662,52 | 1 281 978,45 | 1 891 506,59 | 2 783 916,74 | 4 090 494,45 |
| M | - | 22 104,00 | | | | | | | | | |
| Present value of M | - | - | 15 094,47 | 12 473,59 | 10 307,77 | 8 518,01 | 7 039,01 | 5 816,82 | 4 806,83 | 3 972,21 | 3 282,51 |
| Accumulated M amounts spent | - | 22 104,00 | 53 803,17 | 79 998,35 | 101 645,21 | 119 533,49 | 134 315,78 | 146 531,40 | 156 625,99 | 164 967,84 | 171 861,28 |
| B | 278 100,00 | - | - | - | - | - | - | - | - | - | - |
| Present value of B | - | 151 862,88 | 125 494,62 | 103 704,74 | 85 698,28 | 70 818,31 | 58 521,99 | 48 360,70 | 39 963,73 | 33 024,75 | 27 290,60 |
| Accumulated B amounts spent | | 597 019,95 | 860 565,19 | 1 078 350,55 | 1 258 321,39 | 1 407 043,54 | 1 529 942,77 | 1 631 502,76 | 1 715 428,68 | 1 784 782,38 | 1 842 094,05 |
| Cash Flow | | 121 060,07 | 76 518,67 | 41 625,27 | 2 762,54 | - 44 034,31 | - 104 201,53 | - 185 393,79 | - 298 566,65 | - 459 552,11 | - 691 357,99 |
| SLDM | - | 121 032,20 | 90 774,40 | 60 516,60 | 30 258,80 | 1,00 | - 30 256,80 | - 60 514,60 | - 90 772,40 | - 121 030,20 | - 151 288,00 |
| Present value of SLDM | - | 100 017,14 | 61 988,39 | 34 150,34 | 14 110,61 | 0,39 | - 9 635,27 | - 15 924,82 | - 19 739,75 | - 21 749,80 | - 22 466,71 |
| Benefits (B) | 126 810,00 | 597 019,95 | 860 565,19 | 1 078 350,55 | 1 258 321,39 | 1 407 043,54 | 1 529 942,77 | 1 631 502,76 | 1 715 428,68 | 1 784 782,38 | 1 842 094,05 |
| Expenses (O + M + SLDM) | 37 274,93 | 224 083,56 | 279 636,70 | 368 596,30 | 502 854,51 | 700 847,02 | 990 343,03 | 1 412 585,02 | 2 028 392,83 | 2 927 134,79 | 4 239 889,02 |
| Overall Result | 89 535,07 | 372 936,39 | 580 928,49 | 709 754,24 | 755 466,88 | 706 196,53 | 539 599,74 | 218 917,73 | - 312 964,15 | - 1 142 352,41 | - 2 397 794,97 |
| ROI (%) | | 252% | 364% | 431% | 448% | 406% | 290% | 73% | -281% | -830% | -1661% |

Table 17 - Table with all the X-ray values considered over time with the SLDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 151 290,00 € | | | | | | | | | | | |
| Present value of II | - € | 125 021,21 € | 103 313,53 € | 85 375,00 € | 70 551,16 € | 58 301,22 € | 48 178,27 € | 39 812,98 € | 32 900,17 € | 27 187,65 € | 20 423,58 € | 18 566,01 € |
| | | | | | | | | | | | | |
| **O** | 37 274,93 € | 37 274,93 € | 49 615,28 € | 87 904,82 € | 155 743,50 € | 275 935,25 € | 488 882,43 € | 866 167,09 € | 1 534 613,20 € | 2 718 918,44 € | 6 411 978,45 € | 8 534 747,53 € |
| Present value of O | - € | 30 802,81 € | 33 881,48 € | 49 605,88 € | 72 627,97 € | 106 334,61 € | 155 684,50 € | 227 937,68 € | 333 723,55 € | 488 604,65 € | 865 592,95 € | 1 047 367,47 € |
| Accumulated O amounts spent | | 101 962,43 € | 163 845,14 € | 254 447,61 € | 387 098,69 € | 581 313,15 € | 865 662,52 € | 1 281 978,45 € | 1 891 506,59 € | 2 783 916,74 € | 4 956 087,40 € | 6 003 454,87 € |
| | | | | | | | | | | | | |
| **M** | - € | 22 104,00 € | | | | | | | | | | |
| Present value of M | - € | - € | 15 094,47 € | 12 473,59 € | 10 307,77 € | 8 518,01 € | 7 039,01 € | 5 816,82 € | 4 806,83 € | 3 972,21 € | 2 983,96 € | 2 712,56 € |
| Accumulated M amounts spent | - € | 22 104,00 € | 53 803,17 € | 79 998,35 € | 101 645,21 € | 119 533,49 € | 134 315,78 € | 146 531,40 € | 156 625,99 € | 164 967,84 € | 174 845,24 € | 177 557,80 € |
| | | | | | | | | | | | | |
| **B** | 278 100,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 151 862,88 € | 125 494,62 € | 103 704,74 € | 85 698,28 € | 70 818,31 € | 58 521,99 € | 48 360,70 € | 39 963,73 € | 33 024,75 € | 24 808,46 € | 22 552,08 € |
| Accumulated B amounts spent | | 597 019,95 € | 860 565,19 € | 1 078 350,55 € | 1 258 321,39 € | 1 407 043,54 € | 1 529 942,77 € | 1 631 502,76 € | 1 715 428,68 € | 1 784 782,38 € | 1 866 902,51 € | 1 889 454,59 € |
| | | | | | | | | | | | | |
| **EDM** | - € | 13 926,70 € | 1 281,99 € | 118,01 € | 10,86 € | 1,00 € | 0,09 € | 0,01 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| Present value of EDM | - € | 11 508,58 € | 875,45 € | 66,60 € | 5,07 € | 0,39 € | 0,03 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| | | | | | | | | | | | | |
| **Benefits (B)** | 126 810,00 € | 597 019,95 € | 860 565,19 € | 1 078 350,55 € | 1 258 321,39 € | 1 407 043,54 € | 1 529 942,77 € | 1 631 502,76 € | 1 715 428,68 € | 1 784 782,38 € | 1 866 902,51 € | 1 889 454,59 € |
| **Expenses (O + M + EDM)** | 37 274,93 € | 135 575,01 € | 218 523,76 € | 334 512,56 € | 488 748,97 € | 700 847,02 € | 999 978,33 € | 1 428 509,85 € | 2 048 132,58 € | 2 948 884,58 € | 5 130 932,64 € | 6 181 012,67 € |
| | | | | | | | | | | | | |
| **Overall Result** | 89 535,07 € | 461 444,95 € | 642 041,43 € | 743 837,99 € | 769 572,42 € | 706 196,53 € | 529 964,44 € | 202 992,91 € | - 332 703,90 € | - 1 164 102,21 € | - 3 264 030,13 € | - 4 291 558,08 € |

Table 18 - Table with all the X-ray values considered over time with the EDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| II | 151 290,00 € | | | | | | | | | | |
| Present value of II | - € | 125 021,21 € | 103 313,53 € | 85 375,00 € | 70 551,16 € | 58 301,22 € | 48 178,27 € | 39 812,98 € | 32 900,17 € | 24 714,87 € | 22 467,00 € |
| | | | | | | | | | | | |
| O | 37 274,93 € | 37 274,93 € | 49 615,28 € | 87 904,82 € | 155 743,50 € | 275 935,25 € | 488 882,43 € | 866 167,09 € | 1 534 613,20 € | 3 619 051,84 € | 4 817 186,15 € |
| Present value of O | - € | 30 802,81 € | 33 881,48 € | 49 605,88 € | 72 627,97 € | 106 334,61 € | 155 684,50 € | 227 937,68 € | 333 723,55 € | 591 211,63 € | 715 366,07 € |
| Accumulated O amounts spent | | 101 962,43 € | 163 845,14 € | 254 447,61 € | 387 098,69 € | 581 313,15 € | 865 662,52 € | 1 281 978,45 € | 1 891 506,59 € | 3 375 128,37 € | 4 090 494,45 € |
| | | | | | | | | | | | |
| M | - € | 22 104,00 € | | | | | | | | | |
| Present value of M | - € | - € | 15 094,47 € | 12 473,59 € | 10 307,77 € | 8 518,01 € | 7 039,01 € | 5 816,82 € | 4 806,83 € | 3 610,93 € | 3 282,51 € |
| Accumulated M amounts spent | - € | 22 104,00 € | 53 803,17 € | 79 998,35 € | 101 645,21 € | 119 533,49 € | 134 315,78 € | 146 531,40 € | 156 625,99 € | 168 578,77 € | 171 861,28 € |
| | | | | | | | | | | | |
| B | 278 100,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 151 862,88 € | 125 494,62 € | 103 704,74 € | 85 698,28 € | 70 818,31 € | 58 521,99 € | 48 360,70 € | 39 963,73 € | 30 021,08 € | 27 290,60 € |
| Accumulated B amounts spent | | 597 019,95 € | 860 565,19 € | 1 078 350,55 € | 1 258 321,39 € | 1 407 043,54 € | 1 529 942,77 € | 1 631 502,76 € | 1 715 428,68 € | 1 814 803,45 € | 1 842 094,05 € |
| | | | | | | | | | | | |
| SDM | - € | 99 026,53 € | 57 765,89 € | 27 508,09 € | 8 253,13 € | 1,00 € | 2 751,71 € | 16 505,25 € | 41 261,64 € | 99 026,53 € | 123 782,91 € |
| Present value of SDM | - € | 81 832,35 € | 39 447,41 € | 15 523,19 € | 3 848,69 € | 0,39 € | 876,28 € | 4 343,47 € | 8 972,93 € | 16 177,06 € | 18 382,12 € |
| | | | | | | | | | | | |
| Benefits (B) | 126 810,00 € | 597 019,95 € | 860 565,19 € | 1 078 350,55 € | 1 258 321,39 € | 1 407 043,54 € | 1 529 942,77 € | 1 631 502,76 € | 1 715 428,68 € | 1 814 803,45 € | 1 842 094,05 € |
| Expenses (O + M + SDM) | 37 274,93 € | 205 898,78 € | 257 095,72 € | 349 969,15 € | 492 592,59 € | 700 847,02 € | 1 000 854,59 € | 1 432 853,31 € | 2 057 105,51 € | 3 559 884,21 € | 4 280 737,85 € |
| | | | | | | | | | | | |
| Overall Result | 89 535,07 € | 391 121,17 € | 603 469,48 € | 728 381,39 € | 765 728,80 € | 706 196,53 € | 529 088,18 € | 198 649,44 € | - 341 676,83 € | - 1 745 080,76 € | - 2 438 643,80 € |

Table 19 - Table with all the X-ray values considered over time with the SDM method.

LCI – X-ray: hypothetical situation in which there is an increase in maintenance value and an increase in availability - tables

| **Period** | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 151 290,00 € | | | | | | | | | | |
| Present value of II | - € | 125 021,21 € | 103 313,53 € | 85 375,00 € | 70 551,16 € | 58 301,22 € | 48 178,27 € | 39 812,98 € | 32 900,17 € | 27 187,65 € | 22 467,00 € |
| | | | | | | | | | | | |
| **O** | 37 274,93 € | 37 274,93 € | 49 615,28 € | 87 904,82 € | 155 743,50 € | 275 935,25 € | 488 882,43 € | 866 167,09 € | 1 534 613,20 € | 2 718 918,44 € | 4 817 186,15 € |
| Present value of O | - € | 30 802,81 € | 33 881,48 € | 49 605,88 € | 72 627,97 € | 106 334,61 € | 155 684,50 € | 227 937,68 € | 333 723,55 € | 488 604,65 € | 715 366,07 € |
| Accumulated O amounts spent | | 101 962,43 € | 163 845,14 € | 254 447,61 € | 387 098,69 € | 581 313,15 € | 865 662,52 € | 1 281 978,45 € | 1 891 506,59 € | 2 783 916,74 € | 4 090 494,45 € |
| | | | | | | | | | | | |
| **M** | - € | 22 104,00 € | | | | | | | | | |
| Present value of M | - € | - € | 16 118,80 € | 13 320,06 € | 11 007,27 € | 9 096,05 € | 7 516,69 € | 6 211,55 € | 5 133,03 € | 4 241,77 € | 3 505,26 € |
| Accumulated M amounts spent | - € | 22 104,00 € | 54 827,50 € | 82 800,31 € | 105 916,15 € | 125 018,34 € | 140 803,78 € | 153 848,36 € | 164 627,98 € | 173 535,92 € | 180 897,15 € |
| | | | | | | | | | | | |
| **B** | 278 100,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 206 831,65 € | 170 919,05 € | 130 256,55 € | 107 639,84 € | 88 950,12 € | 73 505,53 € | 60 742,62 € | 50 195,76 € | 41 480,17 € | 34 277,88 € |
| Accumulated B amounts spent | | 712 457,23 € | 1 071 396,15 € | 1 357 026,30 € | 1 583 075,57 € | 1 769 875,46 € | 1 924 240,90 € | 2 051 803,57 € | 2 157 217,27 € | 2 244 327,79 € | 2 316 313,13 € |
| | | | | | | | | | | | |
| **Cash Flow** | | 176 028,84 € | 120 918,78 € | 67 330,61 € | 24 004,60 € | - 26 480,54 € | - 89 695,66 € | - 173 406,61 € | - 288 660,82 € | - 451 366,26 € | - 684 593,45 € |
| | | | | | | | | | | | |
| **SLDM** | - € | 121 032,20 € | 90 774,40 € | 60 516,60 € | 30 258,80 € | 1,00 € | - 30 256,80 € | - 60 514,60 € | - 90 772,40 € | - 121 030,20 € | - 151 288,00 € |
| Present value of SLDM | - € | 100 017,14 € | 61 988,39 € | 34 150,34 € | 14 110,61 € | 0,39 € | - 9 635,27 € | - 15 924,82 € | - 19 739,75 € | - 21 749,80 € | - 22 466,71 € |
| | | | | | | | | | | | |
| **Benefits (B)** | 126 810,00 € | 712 457,23 € | 1 071 396,15 € | 1 357 026,30 € | 1 583 075,57 € | 1 769 875,46 € | 1 924 240,90 € | 2 051 803,57 € | 2 157 217,27 € | 2 244 327,79 € | 2 316 313,13 € |
| **Expenses (O + M + SLDM)** | 37 274,93 € | 224 083,56 € | 280 661,03 € | 371 398,26 € | 507 125,45 € | 706 331,87 € | 996 831,03 € | 1 419 901,98 € | 2 036 394,81 € | 2 935 702,86 € | 4 248 924,89 € |
| | | | | | | | | | | | |
| **Overall Result** | 89 535,07 € | 488 373,67 € | 790 735,12 € | 985 628,04 € | 1 075 950,12 € | 1 063 543,59 € | 927 409,88 € | 631 901,59 € | 120 822,46 € | - 691 375,08 € | - 1 932 611,77 € |
| | | | | | | | | | | | |
| **ROI (%)** | | 328% | 503% | 613% | 660% | 642% | 546% | 346% | 6% | -532% | -1353% |

Table 20 - Table with all the values considered, for the hypothetical situation, of the X-ray over time with the SLDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 151 290,00 € | | | | | | | | | | | |
| Present value of II | - € | 125 021,21 € | 103 313,53 € | 85 375,00 € | 70 551,16 € | 58 301,22 € | 48 178,27 € | 39 812,98 € | 32 900,17 € | 27 187,65 € | 22 467,00 € | 18 566,01 € |
| | | | | | | | | | | | | |
| **O** | 37 274,93 € | 37 274,93 € | 49 615,28 € | 87 904,82 € | 155 743,50 € | 275 935,25 € | 488 882,43 € | 866 167,09 € | 1 534 613,20 € | 2 718 918,44 € | 4 817 186,15 € | 8 534 747,53 € |
| Present value of O | - € | 30 802,81 € | 33 881,48 € | 49 605,88 € | 72 627,97 € | 106 334,61 € | 155 684,50 € | 227 937,68 € | 333 723,55 € | 488 604,65 € | 715 366,07 € | 1 047 367,47 € |
| Accumulated O amounts spent | | 101 962,43 € | 163 845,14 € | 254 447,61 € | 387 098,69 € | 581 313,15 € | 865 662,52 € | 1 281 978,45 € | 1 891 506,59 € | 2 783 916,74 € | 4 090 494,45 € | 6 003 454,87 € |
| | | | | | | | | | | | | |
| **M** | - € | 22 104,00 € | | | | | | | | | | |
| Present value of M | - € | - € | 16 118,80 € | 13 320,06 € | 11 007,27 € | 9 096,05 € | 7 516,69 € | 6 211,55 € | 5 133,03 € | 4 241,77 € | 3 505,26 € | 2 896,64 € |
| Accumulated M amounts spent | - € | 22 104,00 € | 54 827,50 € | 82 800,31 € | 105 916,15 € | 125 018,34 € | 140 803,78 € | 153 848,36 € | 164 627,98 € | 173 535,92 € | 180 897,15 € | 186 980,24 € |
| | | | | | | | | | | | | |
| **B** | 278 100,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 206 831,65 € | 170 919,05 € | 130 256,55 € | 107 639,84 € | 88 950,12 € | 73 505,53 € | 60 742,62 € | 50 195,76 € | 41 480,17 € | 34 277,88 € | 28 326,15 € |
| Accumulated B amounts spent | | 712 457,23 € | 1 071 396,15 € | 1 357 026,30 € | 1 583 075,57 € | 1 769 875,46 € | 1 924 240,90 € | 2 051 803,57 € | 2 157 217,27 € | 2 244 327,79 € | 2 316 313,13 € | 2 375 799,51 € |
| | | | | | | | | | | | | |
| **SDM** | - € | 99 026,53 € | 57 765,89 € | 27 508,09 € | 8 253,13 € | 1,00 € | 2 751,71 € | 16 505,25 € | 41 261,64 € | 77 020,85 € | 123 782,91 € | 181 547,80 € |
| Present value of SDM | - € | 81 832,35 € | 39 447,41 € | 15 523,19 € | 3 848,69 € | 0,39 € | 876,28 € | 4 343,47 € | 8 972,93 € | 13 841,07 € | 18 382,12 € | 22 279,19 € |
| | | | | | | | | | | | | |
| **Benefits (B)** | 126 810,00 € | 712 457,23 € | 1 071 396,15 € | 1 357 026,30 € | 1 583 075,57 € | 1 769 875,46 € | 1 924 240,90 € | 2 051 803,57 € | 2 157 217,27 € | 2 244 327,79 € | 2 316 313,13 € | 2 375 799,51 € |
| **Expenses (O + M + SDM)** | 37 274,93 € | 205 898,78 € | 258 120,04 € | 352 771,11 € | 496 863,53 € | 706 331,87 € | 1 007 342,58 € | 1 440 170,27 € | 2 065 107,50 € | 2 971 293,73 € | 4 289 773,72 € | 6 212 714,30 € |
| | | | | | | | | | | | | |
| **Overall Result** | 89 535,07 € | 506 558,45 € | 813 276,11 € | 1 004 255,18 € | 1 086 212,04 € | 1 063 543,59 € | 916 898,32 € | 611 633,30 € | 92 109,77 € | - 726 965,94 € | - 1 973 460,59 € | - 3 836 914,79 € |

Table 21 - Table with all the values considered, for the hypothetical situation, of the X-ray over time with the EDM method.

| Period | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **II** | 151 290,00 € | | | | | | | | | | |
| Present value of II | - € | 125 021,21 € | 103 313,53 € | 85 375,00 € | 70 551,16 € | 58 301,22 € | 48 178,27 € | 39 812,98 € | 32 900,17 € | 27 187,65 € | 22 467,00 € |
| **O** | 37 274,93 € | 37 274,93 € | 49 615,28 € | 87 904,82 € | 155 743,50 € | 275 935,25 € | 488 882,43 € | 866 167,09 € | 1 534 613,20 € | 2 718 918,44 € | 4 817 186,15 € |
| Present value of O | - € | 30 802,81 € | 33 881,48 € | 49 605,88 € | 72 627,97 € | 106 334,61 € | 155 684,50 € | 227 937,68 € | 333 723,55 € | 488 604,65 € | 715 366,07 € |
| Accumulated O amounts spent | | 101 962,43 € | 163 845,14 € | 254 447,61 € | 387 098,69 € | 581 313,15 € | 865 662,52 € | 1 281 978,45 € | 1 891 506,59 € | 2 783 916,74 € | 4 090 494,45 € |
| **M** | - € | 22 104,00 € | | | | | | | | | |
| Present value of M | - € | - € | 16 118,80 € | 13 320,06 € | 11 007,27 € | 9 096,05 € | 7 516,69 € | 6 211,55 € | 5 133,03 € | 4 241,77 € | 3 505,26 € |
| Accumulated M amounts spent | - € | 22 104,00 € | 54 827,50 € | 82 800,31 € | 105 916,15 € | 125 018,34 € | 140 803,78 € | 153 848,36 € | 164 627,98 € | 173 535,92 € | 180 897,15 € |
| **B** | 278 100,00 € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| Present value of B | - € | 206 831,65 € | 170 919,05 € | 130 256,55 € | 107 639,84 € | 88 950,12 € | 73 505,53 € | 60 742,62 € | 50 195,76 € | 41 480,17 € | 34 277,88 € |
| Accumulated B amounts spent | | 712 457,23 € | 1 071 396,15 € | 1 357 026,30 € | 1 583 075,57 € | 1 769 875,46 € | 1 924 240,90 € | 2 051 803,57 € | 2 157 217,27 € | 2 244 327,79 € | 2 316 313,13 € |
| **EDM** | - € | 13 926,70 € | 1 281,99 € | 118,01 € | 10,86 € | 1,00 € | 0,09 € | 0,01 € | 0,00 € | 0,00 € | 0,00 € |
| Present value of EDM | - € | 11 508,58 € | 875,45 € | 66,60 € | 5,07 € | 0,39 € | 0,03 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| **Benefits (B)** | 126 810,00 € | 712 457,23 € | 1 071 396,15 € | 1 357 026,30 € | 1 583 075,57 € | 1 769 875,46 € | 1 924 240,90 € | 2 051 803,57 € | 2 157 217,27 € | 2 244 327,79 € | 2 316 313,13 € |
| **Expenses (O + M + EDM)** | 37 274,93 € | 135 575,01 € | 219 548,09 € | 337 314,52 € | 493 019,91 € | 706 331,87 € | 1 006 466,33 € | 1 435 826,80 € | 2 056 134,57 € | 2 957 452,66 € | 4 271 391,60 € |
| **Overall Result** | 89 535,07 € | 576 882,23 € | 851 848,06 € | 1 019 711,78 € | 1 090 055,66 € | 1 063 543,59 € | 917 774,58 € | 615 976,77 € | 101 082,71 € | - 713 124,87 € | - 1 955 078,47 € |

Table 22 - Table with all the values considered, for the hypothetical situation, of the X-ray over time with the SDM metho