INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

Medical Equipment Replacement: Economic Analysis under Deterministic and Uncertain Environments

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Dissertation submitted to obtain the Master Degree in

Biomedical Engineering

Jury

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June 2012

Acknowledgments

I would like to express my gratitude to:

Professor João Zambujal de Oliveira, for the supervision and all the support provided during this work. Thank you also for the persistence. Without it, I wouldn't be able to finish this work.

Eng. Durão de Carvalho, SIE and Accounting Department members, that provide me necessary data to accomplish my work. Without them this work wouldn't be possible.

Lígia, for her contribution with her work.

Carmen Isabel Silva, for all the comprehension and support during the final part of this work.

Cristina Lopes Santos, for the support.

Resumo

Uma das decisões mais comuns na gestão de activos é a substituição de uma infra-estrutura ou equipamento. Decisões de substituição têm extensas consequências no desenvolvimento de um negócio, sendo particularmente complexas de modelar no que se refere á substituição de equipamento médico. Instituições de saúde lidam constantemente com este problema. Encontrar o tempo óptimo de substituição, do ponto de vista dos custos de Manutenção e de Operação, é de crucial importância para conseguir uma eficiente gestão orçamental. O estudo considera um medida de penalidade, criada com o objectivo de quantificar os custos indirectos gerados pelo tempo de paragem dos equipamentos, devido a avaria.

Este documento desenvolveu uma metodologia para auxiliar o processo de tomada de decisão no Hospital de Santa Maria, no que respeita á substituição de equipamento médico. Dois modelos são propostos para abordar o problema. Um modelo determinístico, baseado em técnicas tradicionais de avaliação de investimentos e um modelo com incerteza associada, baseado numa abordagem de Opções Reais. Uma análise de custos é realizada, sem esquecer os custos de penalidade, como uma forma de quantificar os prejuízos decorrentes do tempo de paragem dos equipamentos

Os modelos são aplicados aos Aceleradores Lineares a operar no Serviço de Radioterapia. Os resultados demonstram que os tempos óptimos de substituição obtidos pelo modelo de Opções Reais são, em média, superiores aos obtidos para o modelo Determinístico. Os resultados demonstram também que os custos de penalidade desempenham um papel mais preponderante, no processo de substituição, do que os custos de Operação e de Manutenção. O estudo sobre o efeito dos impostos, revelou que estes têm pouca influência sobre os resultados da análise.

Palavras Chave: Equipamento Médico, Substituição, Opções Reais, Defensor, Desafiante, Fluxos Descontados, Métodos Económicos.

Abstract

One of the most common capital budgeting decisions is the replacement of a plant or equipment. Replacement decisions have far reaching consequences on the ongoing life of a business, being particularly complex to model when it comes to medical equipment replacement. Health care institutions constantly deal with this problem. Finding the optimum timing to replace, regarding maintenance and operating costs, is of crucial importance to achieve an efficient budget management. The study considers a penalty measure, created with the objective to quantify the indirect costs incurred by the equipment downtime due to malfunction.

This document has developed a methodology to aid the decision-making process in Hospital de Santa Maria for medical equipment replacement. Two models are proposed to address this problem. A deterministic model, based on traditional investment evaluation tools and a model with uncertainty, based on the Real Options approach. A cost analysis is performed, not forgetting the penalty costs, as a measure to quantify the losses induced by equipment downtime.

The models were applied to the Linear Accelerators operating at the Radiotherapy Department. The results show that the optimum replacement timings obtained by the Real Options Model are, in average, longer than the ones obtained with the Deterministic Model. They also demonstrate that Penalty Costs play, in the replacement process, a more significant role than the Operating and Maintenance costs. The investigation on the effect of taxes, revealed that these have little influence over the analysis results.

Keywords: Medical Equipment, Replacement, Real Options, Defender, Challenger, Discounted Cash Flows, Economic Methods.

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List of Abbreviations

HSM	Hospital de Santa Maria
CDTT	Complementary Diagnostic and Therapeutic Techniques
SIE	Serviço de Instalações e Equipamentos
MARR	Minimum Accpetable Rate of Return
NPV	Net Present Value
EAA	Equivalent Annual Annuities
EAC	Equivalent Annual Cost
WACC	Weighted Average Cost of Capital
CAPM	Capital Asset Pricing Model
MV	Market Value
PV	Present Value
PDE	Partial Diferential Equation
LA	Linear Accelerator
GBM	Geometric Brownian Motion
CT	Computed Tomography
CHNL	Centro Hospitalar Lisboa Norte

1 Introduction

1.1 Motivation and Relevance

One of the most common capital budgeting decisions is the replacement of a plant or equipment (Lee & Petruzzi, 1984). Actually, all capital budgeting decisions can be viewed as replacement decisions. Expansion decisions are merely replacement decisions in which all cash flows from the old asset are zero (Guitman, 2003). Replacement decisions are ever-present in economic life, having far reaching consequences on the ongoing life of a business. Therefore companies have a growing need to develop and adopt efficient and reliable strategies to optimize, as far as possible, this process (Kierulff, 2007). A growing competitive market, in constant change and fast technological evolution, a constant pressure to reduce costs in order to remain competitive, aggravated by a difficult economic scenario created by a global crisis, are all factors that exacerbate this need for efficiency. Finding the optimal timing to invest, or to replace, is therefore the objective. Invest with an incorrect timing can prove to be a very expensive decision (Christer & Scarf, 1994).

Equipment replacement is particularly relevant in the medical field. Medical equipment replacement is a particularly complex problem to model since it embraces a high number of considerations from many different natures. Some of these natures have subjective backgrounds. Improvements in quality of service brought by a more advanced equipment or risk for patients and staff are considerations difficult to quantify, but nevertheless, have a significant influence in the decision-making process. In addition, hospital equipment is often of a high-tech and fast developing nature, representing investments in the order of millions of euro, with the annual maintenance cost frequently ascending to 10% of the replacement value (Christer & Scarf, 1994).

The practice in modern medicine has been increasingly dominated by technology, with all medical specialties depending, at some level, on technology to achieve their goals. The numbers of such equipments inside hospital facilities, as well as the number of procedures delivered by them, have been growing in a generalized way. Between 19982 and 2002, the average number of medical devices assigned by bed, in a group of three large Hospitals in Houston, USA, with a combined capacity of 1400 beds, has increased from 4 to over 17 devices per bed (Jahnke & David, 2005). As so, it is not uncommon that even a medium sized hospital (200-400 beds) possesses more than 2.000 medical devices. As a consequence an increasing of costs associated with medical equipment, especially replacement costs, has been observed (Fennigkoh, 1992). This increasing complexity in hospital's logistics brings the necessity for institutions to develop and adopt methodologies that allow an efficient hospital’s inventory management, in order to provide practitioners the adequate tools and environment to assure patients a medical service with the expected quality and safety.(Jahnke & David, 2005).

High-tech equipments are responsible today for the higher expenses in the healthcare system, whether regarding investment or maintenance costs (Antunes, 2002). Such medical devices can have an acquisition cost that can range from 20.000 euro, for small items such as ecographs or x-rays machines, to over 3 million euro, for heavy pieces of equipments such as the Linear Accelerator or the

Magnetic Resonance Imaging (MRI) machine. These technology delivery devices can provide millions of diagnostic exams and therapeutic treatments every year, within a medium-sized Hospital, representing an indispensable tool to aid practitioners in their mission of providing a quality healthcare service. This means that medical devices represent a great deal of expenses, but on the other hand they also represent a source of revenues, associated to the fees paid to Hospital for the provision of such services. It is therefore, of vital importance that Health Institutions manage to keep these expenses under control, and by consequence, it is important to define strategies to extract the full potential brought by such devices (Antunes, 2002).

1.2 Problem Definition

The concepts of capital investment planning are well established. However, they haven't found yet a widespread use within healthcare, especially when concerning the replacement planning of medical devices. Very few hospitals have any formal mechanisms for determining medical equipment replacement in which, the lack of usable models tend to encourage equipment purchases that may be premature, inappropriate, or simply not needed (Fennigkoh, 1992). This is also the reality in Hospital de Santa Maria (Lisbon, Portugal), where this work has been developed. The replacement policy at this Hospital mainly consists on the usage of medical equipment until the end of its physical life. Such process is not based on any methodology or systematic procedure, constituting still a source of inefficiency in the Hospital management.

1.3 Objective

Considering the motivations above, the objective of this work is to create a model to aid the replacement decision-making in Hospital de Santa Maria (HSM). The work will focus on the economical and financial aspects of the replacement problem, trying to identify the optimal replacement timing and the consequences of alternative decisions. The aim is to find the least-cost replacement interval, in order to achieve an equipment usage at the lowest possible cost. The model is intended to be general to all kinds of medical equipments, but for practicability reasons only a high budget equipment was selected to be evaluated in this work. The selected equipment was intended to be representative of the most expensive items offered by the medical equipment market. As so, the Linear Accelerator was selected, as it is the most expensive medical device acquired by HSM in a recent past.

The pretention is to create a definite replacement model to actually quantify the economic value of a decision, allowing the decision-makers in HSM to have a perspective on the financial impact of their choices, allowing for an overhaul expenditures reduction in the Hospital. The present work is structured into 6 Chapters, each representing a different stage of the work construction until the final result - a model to aid medical equipment replacement in HSM. In section 2 a contextualization of the problem is provided. The reasons that motivate the replacement process as well as some of the issues involved in this process are analyzed. A description is made of the Hospital de Santa Maria and its current procedures and policies in what equipment management is concerned. The problems and limitations generated by such policies are discussed. Section 3 will present the state of the art, based on the literature available, of the current methods used in the management of capital assets. A review is made of several articles proposing models to approach this problem either considering equipment management in general and considering the specific case of medical equipment replacement. In section 4 a medical equipment replacement methodology will be proposed. The model's mathematical formulation and two distinct approaches for future cash flows estimation will be defined and subsequently applied to the HSM data. Finally, the obtained results is will be presented and discussed in section 5, emphasizing the level of success on accomplishing the proposed objectives. The conclusions of this work are then presented in section 6.

2 Context

In this section a contextualization of the problem will be presented. An analyses will be made on the reasons that motivate the development of techniques to manage Hospitals patrimony, and the objectives that these techniques aim to achieve. The reasons that lead to equipment replacement, as well as some of the criteria used to manage this replacement process will be explained. A description of Hospital de Santa Maria, where this work was developed, will be provided, with special attention being given to the financial aspects of the Hospital management. Finally, the replacement process at HSM is analyzed and some of the limitations and risks associated with such method are exposed.

2.1 Reasons for Health equipment management

In order to achieve an efficient management of resources Healthcare Institutions need to elaborate strategic plans (Figueiredo, 2009). Such plans allow to bind organizations to the strategies and objectives defined on them, establish programs and courses of action, prioritize options and allocate resources (HSM, 2006). Hospitals have been allocating significant portion of their resources to acquire and managing capital assets. They are continuously faced with demands for new medical equipment and are asked to manage existing inventory for which they are not well prepared (Jahnke & David, 2005). It is necessary to recognize when an asset is no longer employed efficiently, what equipments should be considered for replacement and when replacement is economically feasible (Tarquin & Blank, 2004). Long range planning involves tree managerial functions: identifying and forecasting a set of objectives, developing a formal plan and committing the required resources to achieve plans objectives (Cassimatis, 1988). There are three reasons that generate the necessity for replacing an asset. These reasons are the following:

Deterioration: The deterioration process arises from the natural wear induced by usage and passage of time. As a result, system components start failing or working in a less efficient way (Katz, 1998). It manifests trough excessive operating costs, increased maintenance costs and higher failure rates (Tarquin & Blank, 2004). The simple ageing of equipment is not a signal of deterioration; hence the equipment performance can actually improve with time due to the modernization of replacing components. To actual verify the state of deterioration of an asset it is necessary to compare the performance of the same machine in different ages, regarding factors such as production rate, failure rate, average downtime, average cost per failure and average maintenance cost for period (Katz, 1998).

Obsolescence: Each new development or refinement of an older asset makes the previous way of accomplishing an objective less appealing (Tarquin & Blank, 2004). The existing equipment maintains a good performance, but the new alternatives coming up to the market, would provide better results. Obsolescence is frequently the reason why an equipment is replaced before its estimated economic life expires (Pilão & Hummel, 2003).

Inadequacy: New performance requirements such as production speed or technical specifications, may motivate an early replacement of an asset. In this case, the decision may fall over a technical upgrade or the complete replacement (Pilão & Hummel, 2003).

These reasons have different importance in the decision according with the business context in which the replacement is being made. This work will use cost analyses as a replacement criteria. It won't try to neglect the subjective aspects inherent to the medical equipment replacement decision, but instead it tries to quantify them as an economic value in order that these can be considered in an accountable way. It has to be taken into consideration that today replacements will affect the foreseeable future chain of replacements. Future replacement decisions should not be independent from today's actions. However the significance of present actions over future events becomes smaller as the time gap between them grows wider (Katz, 1998).

2.2 Hospital de Santa Maria

Hospital de Santa Maria is the main assistance centre in the metropolitan area of Lisbon, providing direct services to over 350.000 inhabitants in the country's capital. Due to the wide range of medical specialties provided, it became a reference Hospital in the treatment of complex and rare diseases, extending its influence to a national level. It was built in 1954, according to the typical model at the time, to renew and modernize the structure and functionality of the healthcare institutions. However the same structural and functional characteristics represent today an obstacle to the actualization and modernization of the hospital (HSM, 2008).

The change of the juridical status for Public Enterprise in 2005 brought to the Hospital an opportunity to begin the modernization process. This change allowed for a new management model, with a special concern being given to measures with impact in the financial sustainability, whether by reducing costs or improving revenues. Action was taken in areas such as logistics, purchases, financial management, human resources and equipment and facilities. The economic-financial measures adopted allowed for a progressive gain of efficiency, both in costs and revenues, and are expected to bring even more benefits in a proximal future (HSM, 2008).

The HSM is a 984 beds Hospital with an annual budget of over 300 million euro. In the economic year of 2007 it had a total revenues value of 319,182 million euros against a total value of costs of 311.651 million euro, which represented a result before taxes of 8.1 million euros and an operating income of 2.8 million euros. Approximately half of the total costs are due to personal payroll. However a significant part of these costs is attributable to operating and maintenance costs, associated with medical equipment. In what investment is concerned, medical equipment play a significant role. The HSM investment plan for the three first years as a Public Enterprise is represented in Table 1. It demonstrates that medical equipment roughly represents 30% of the Hospital annual investment, totalizing an amount of 13.3 million euros, during that period. The investment in medical equipment has been growing, along with the overall investment, 20-to-30%, every year. The reason for presenting values from the HSM 2007 Report and Accounts (HSM (2008)), has to due with fact that in 2008, HSM was incorporated in Centro Hospitalar Lisboa Norte (CHLN). Therefore, the subsequent Report and Accounts of this institution reflect financial information from all of its constitutive Hospitals. Thus, HSM (2008) represents the last Report and Accounts that provides information exclusively from HSM.

Table 1. Equipment and Building Investments (Values in thousand of euros) (HSM, 2008).

Investment Program	2005	2006	2007	Total
Buildings/Facilities	3,468	3,611	6,239	13,318
Medical Equipment	3,304	4,124	5,900	13,328
Transportation Equipment	0	85	0	85
Administrative Equipment	230	311	828	1,369
Hardware/Software	2,373	2,542	2,706	7,621
Other Investments	433	265	0	698
Total	9,808	10,938	15,673	36,419

The growing significance of the investment is perceptible in Table 2., which represents the evolution of the total investment. In 2007, the relation of the Hospital income with the investment achieved 4.9%.

Table 2. Execution of Investment Plan (HSM, 2008).

Execution of Investment Plan	2005	2006	2007
Investment (millions of euros)	9.8	10.9	15.6
Total Revenues (millions of euros)	382.2	317.7	319.8
Investments/Total Revenues (%)	2.6	3.4	4.9

Notice the fact that the biggest share of the investment in medical equipment was dedicated to the acquisition of a new Linear Accelerator for the Radiotherapy Department, with an approximate value of 2 million euro (HSM, 2008). Another considerable investment was made later in 2009 with the acquisition of two similar equipments. This time the total investment overcame the 6 million euro, distributed by the two linear accelerators and the necessary reconstruction of facilities to accommodate such equipments. Due to the huge financial effort necessary to replace it, and being one the most expensive items a hospital can purchase (Table 3.), the Linear Accelerator was the selected equipment to analyze in this work.

Table 3. Approximated acquisition costs of some of the medical equipments in operation in HSM (Figueiredo, 2009).

Equipment	Acquisition Cost (euros)
Linear Accelerator	2,000,000
Magnetic Resonance (MRI)	1,500,000
CT	880,000
Monoplane Angiography	750,000
Biplane Angiography	950,000
X-Ray Machine	120,000
Gama Chamber	400,000
Ecocardiograph	80,000
Perfusion Pump	1,500

Most of the HSM's revenues come from the fees attributed by the Ministery of Health for the Complementary Diagnostic and Therapeutic Techniques (CDTT) performed by the Hospital. The Hospital is paid according to a standardized table, that settles the value of these fees for each different diagnostic or therapeutic technique available in Portuguese Hospitals. Examples of these procedures are presented in Attachment 1. These values are given as weight factor, relative to a reference value of the standard procedure in a given medical specialty, and can range from a small amount to more than one thousand euros per procedure.

Considering the number of CDTT performed in HSM, represented in Table 4., it is easy to realize that CDTTs represent a considerable income source to the Hospital. Hence the importance of having an efficient inventory management, in a way that, every impossibility of performing such procedures originate a loss of revenues.

Table 4. Number of Complementary Diagnostic and Therapeutic Techniques (CDTT) by department in HSM (HSM, 2008).

CCDT's	2005	2006	Δ % 06/05	2007	Δ % 07/06
Department of Medicine	139,007	151,770	9.18%	185,740	22.38%
Department of Surgery	36,207	29,387	-18.84%	24,629	-16.19%
Department of Neurosciences	65,236	77,302	18.50%	93,598	21.08%
Department of Child and Family	51,587	51,992	0.79%	58,637	12.78%
Department of Gynecology	36,508	40,510	10.96%	34,786	-14.13%
Department of Oncology	130,573	130,878	0.23%	74,395	-43.16%
Department of Otorrinolaringology	9,408	10,244	8.89%	18,100	76.69%
Department of Torax	166,107	162,022	-2.46%	161,301	-0.45%
Department of Urgency and Intensive Care	64,356	62,769	-2.47%	46,628	-25.71%
Other Clinical Services	5,986,759	6,310,725	5.41%	5,684,172	-9.93%
Total	6,621,392	6,964,830	5.19%	6,381,986	-8.37%

The department responsible for the management of equipments and facilities in HSM is the so called Serviço de Instalações e Equipamentos (SIE). It is composed by a team of engineers and technicians that work every day to maintain Hospital's inventory working properly. They are also responsible for maintaining facilities in adequate conditions for the healthcare service, as well as implementing the necessary restructuration implied in the modernization of the HSM infrastructure. The model proposed in this work is intended to be used in SIE, helping the professionals in this department obtaining a precise knowledge of the financial impact of the several options presented to them every day, allowing for a more informed decision.

2.3 Problem Definition

After an interview with the management of SIE, it was possible to draw a picture of the reality of the equipment replacement process existing today in HSM. The methodologies used and their limitations, as well as the adversities generated by the several factors associated with the Hospital logistics were noted. The description of such process provided by Figueiredo (2009) was also analyzed. The main conclusions, extracted from both sources of information, are presented next.

The present replacement policy in HSM basically consists on the use of equipment until the end of its physical life. There is no specific methodology to determine when an equipment should be replaced and when the replacement does happen, it does not happen in a previously planned way. The decision is mostly based on the good sense and work experience of practitioners, who work directly with the equipment, and SIE personnel, who are responsible for the management of the Hospital patrimony. This is a reactive process, which is triggered by an equipment malfunction, and only then, a replacement analyses is considered. The malfunction which can be a complete breakdown of the equipment or a series of small failures is usually detected by the practitioners in the Medical Department where the item is being used.

Once a malfunction is detected the origin department submits a repair order to SIE to be analyzed. SIE will then determine if it is worthwhile to repair the equipment, according to its record of failures. If a repair is possible, the equipment is usually repaired. However, if the equipment is showing a high rate of failures or a major failure occurred, which will require an extensive and expensive repair, it will most likely be proposed for replacement. The proposition will then be submitted to the Administration Board, which has the final word in this process. In case of approval, a public examination is launched, for the acquisition of an equipment with the required features. Such features are previously determined by SIE in cooperation with the targeted Medical Department. A flowchart that describes the replacement process in HSM is presented in Attachment 2.

From the instant the equipment breaks down until the moment it is repaired or replaced a considerable period of time might pass. When a long stand-by period is predictable, due to a more extensive repair, and in order to comply with the commitment to provide an healthcare service of excellence, it is the HSM policy to outsource the impaired services. Whether they are diagnostic exams or therapeutic treatments, the Hospital pays to a third party institution, usually of private management, to assure these services. This process is always associated with a delay of service delivery, with an extra inconvenience for patients that have to be dislocated to the delivery institution.

Ultimately, the decision taken by the executive board is fundamentally administrative. For this reason it's important that any replacement methodology to be implemented in HSM be able to provide plausible and applicable results, within the reality of HSM's functionality and budget. It's also important that these results are simple enough to be analyzed and understood by the deciders, who don't necessarily work directly with the equipments, in order to prevent spending of time and resources developing a tool that ultimately will have little or no influence in the actual decision.

In its current application, the replacement policy in HSM is not in conformity with the directives from the Strategic Plan 2006-2008, not contributing for the achievement of the Hospital's own settled objectives. Considering these objectives the replacement planning in HSM is one of the management exercises that still needs revision and modernization.

As described, the replacement process in HSM is flawed, in a way that it's not based in any model or pre-determined criteria. As so, a previous planning of when to replace an equipment, in a proactive fashion, based on a definite methodology applied in systematic and standardized way to all Hospital inventory, is not in practice (Figueiredo, 2009). Instead, decision is mostly determined by subjective personal motivations which can be easily biased by several factors, removing objectivity from the process, and often disregarding some of the most important aspects of medical equipment replacement.

This is an inefficient process that can compromise the correct execution of the budget plan. The lack of a systematic planning of whether an item should be replaced introduces a large amount of uncertainty in the Hospital activities. As a consequence, unexpected expenses may appear, generated by equipments that should have been replaced already. Replacing equipments in the correct timing would prevent these extraordinary expenses, contributing for a generalized reduction in maintenance, repair and operating costs, releasing capital to be applied in other areas. Therefore a more efficient budget application would be possible and, as a result, the provided medical service would improve.

The delay of treatment due to equipment downtime, even for short periods, can have very serious implications in the quality of healthcare services provided. Not having an appropriate treatment in the correct timing can reduce the success rate of the treatment or reduce life expectancy after it. As well, a late diagnostic can compromise the treatment success, and so, downtime periods can ultimately result in human losses. Therefore, in addition to the economical advantages, an efficient replacement policy can actually save lives.

Downtime periods are also costly in a financial point view. There is always a loss of revenues due to the exams or treatments not made. In addition when a long downtime period occurs, an extra cost is incurred. The amount paid by HSM to third party institutions for the outsourcing of such services. This situation can represent a huge annual expense to the Hospital. Also during replacement processes this policy is applied, and in this case the costs are much higher as a result of the long periods of time the whole replacement procedure can endure. Considering the two Linear Accelerators replacement from the Radiotherapy Department, occurred in 2009, an average value of approximately 2000 radiotherapy treatments were outsourced every month, during the 10 months elapsed from the moment the old equipments were deactivated until the moment the new equipments started working. The usual outsourcing cost paid by HSM is about 102€. Hence, this operation represented an approximate expenditure of 2 million euro to the HSM. To this, additional costs must be added in order to consider the expenses and time losses associated with the bureaucratic process of transferring patients to other institutions, as well as the consequent logistics associated with their transport.

As a result, downtime periods due to equipment failure, represent one of the biggest problems in medical equipment management, being of vital importance, whether for economical or for medical reasons, to develop and implement strategies to reduce them to a minimum.

3 Literature Review

In this Chapter an analyses will be made to the current approaches used to manage capital assets, based on the existing literature. Focuses will be given to the various problems of asset replacement and the methods currently used by organizations in making replacement decisions, with special attention being given to the application of such methods to the specific case of medical equipment management. Different approaches to this problem employ different tools and methodologies to achieve a solution. In the same way, different business fields require different analyses according to the project specifications. The inherent concepts to these different approaches will be described and the advantages and limitations associated with each one of them will be discussed.

3.1 Definition of Concepts

First, a definition must be made of the concepts and terms associated with capital asset management. Such definitions are important for the fully understanding of the next sections of this work. The following terms are widely used in economics engineering literature.

Time Value of Money: One of the most important factors regarding investment analyses is the time value of money concept. It refers to the idea that money will have different values over time, due to existence of interest rates. The same amount of money today does not have the same value one year from now. In other words, the time value of money deals with the equivalence relationships between cash flows that occurs in different instants of time (DeFusco, 2004).

Minimum Acceptable Rate of Return (MARR): Also known as required rate of return, discount rate or cost of capital, is the rate after which an investment can start being considered profitable (Paplona & Montevechi, 2006). It encompass factors as the time value of money, the risks associated with an investment and may also include the desired profit return of the investment (Cassimatis, 1988).

Present Value: Is the value on a given date of a future payment or series of future payments, discounted to reflect the time value of money and other factors such as investment risk or inflation. Present Value calculations are widely used on business and economics to provide means to compare cash flows occurring in different times on a homogeneous time basis (Tarquin & Blank, 2004).

Economic Life: Is defined as the optimal period of time, in an economic perspective, during which an equipment should be used before it is disposed or replaced by a new model (Clapham, 1957).

Physical Life: Is the period of time after which an asset can no longer be repaired or refurbished so that it can perform an useful function (Pilão & Hummel, 2003).

Service Life: Is the period of time after which an asset cannot perform its intended function without a major overhaul. Such an overhaul is an investment for which a new economic life has to be determined (Cassimatis, 1988).

Useful Life: Is the length of time an asset might reasonably be expected to be useful in the production of income (Cassimatis, 1988).

Defender: It is the name given to existing equipment when its replacement is being considered. It may or may not be at the end of its economic life (Pilão & Hummel, 2003).

Challenger: It is the name given to each one of the currently available alternatives to the existing equipment. It may or may not perform the function of the *defender* in the same way (Pilão & Hummel, 2003).

3.2 Discounted Cash Flows Methods

In order to choose the best capital investment, organizations must evaluate a number of available alternative investments by means of an appropriate method of comparison. Since capital projects have differences in terms of costs, benefits and timing the basis of comparison must take into account these differences as well as the time value of the money (Cassimatis, 1988). A number of methods have been developed throughout the years to evaluate investments and the four most widely used will be described here.

3.2.1 Net Present Value

The Net Present Value (NPV) method requires that all cash flows be discounted to their present value, using the minimum acceptable rate of return established for the project, and it can expressed as

$$NPV = \sum_{t=0}^{n} \frac{A_t}{(1+i)^t} - C_0 \tag{1}$$

where A_t is the flow for period t and C_0 is the initial cost of the project. Considering that most projects have its costs spread over a number of years, the net present value expression must be rearranged as

$$NPV = \sum_{t=0}^{n} \frac{A_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{2}$$

After the reconversion of all cash flows to the present time, the project is rated as attractive if its NPV is positive. That means that project is profitable and therefore it should be implemented. As higher the NPV as higher the attractiveness of the project and when dealing with concurrent projects it should be selected the project with the higher NPV (Cassimatis, 1988). For projects based on cost minimization, therefore exhibiting negative NPV, the more attractive alternative will be one with the lower absolute NPV.

3.2.2 Internal Rate of Return

The Internal Rate of Return (IRR) is probably the most widely used by engineers and business managers in evaluating capital projects (Cassimatis, 1988). It is defined as the interest rate that generates a NPV of zero(Paplona & Montevechi, 2006). In other words, the IRR is the rate of return that makes of the cash flows equal to the cost of the investment. The mathematical representation is precisely obtained by making the NPV equal to zero in equation (2), and is given by

$$C_0 = \sum_{t=0}^{n} \left[\frac{A_t}{(1+r)^t} \right] \tag{3}$$

where C_0 is the initial capital outlay, A_t is the cash flow period t, and r is the internal rate of return of the investment. When the cash flows are not a uniform series, the IRR must be calculated by trial and error or using an iterative computational method(Cassimatis, 1988).

3.2.3 Equivalent Annual Annuities

The Equivalent Annual Annuities (EAA) method consists on the transformation of all the project's cash flows on a uniform series of payments, representing the benefit per period of the investment project (Paplona & Montevechi, 2006). As so, the annualized cost of the capital project must be subtracted from the expected annual cash flow. It can be expressed as

$$EAA = A - C_0(A/P\,, i, n) \tag{4}$$

where A is the annual cash flow, C_0 is the initial investment and $(A/P, i, n)$ is the *capital recovery factor of a uniform series.* It represents the factor that converts the present value of an investment P, in a series of n annuities that will be generated over the life of the investment at a given interest rate i. Mathematically, it is expressed by

$$\frac{A}{P} = \frac{i(1+i)^n}{(1+i)^n - 1} = (A/P\,, i, n) \tag{5}$$

The project will only be attractive if it possess a positive EAA, and within a pool of projects, the one with the higher EAA will be the most profitable per period, and so it should be the preferred investment (Cassimatis, 1988). When dealing only with the costs the method is referred as *Equivalent Annual Cost* (EAC), and the most attractive project will be the one with the lower EAC (Tarquin & Blank, 2004).

An important advantage of this method is that it allows to solve the dilemma faced by organizations when having to decide between several investment alternatives with unequal planning horizons. Solving this problem using the other mentioned methods, requires that all consequences of the different investment projects must be transported to a common time horizon. Then an assumption must be made that the alternative with shorter life can be replaced by a similar alternative in the end of its life. The least common multiple between alternatives must be found and then the analyses is repeated for the necessary number of periods. In such way is possible to compare alternatives with different life expectations on an uniform time basis (Cassimatis, 1988). The Equivalent Annual Annuities method implicitly considers the reinvestment, and therefore there is no need for the previous procedure (Paplona & Montevechi, 2006). Notice that this method does not cancel the difference in the lives of the two projects, but instead, it simply removes the difference from the analysis (Cassimatis, 1988).

3.2.4 Payback Period

The Payback Period method basically consist on the determination of the number of periods required to recover the initial outlay of an investment. It is obtained by calculating the number of periods it takes for the cumulative cash flows, discounted at the required rate of return, to equal the initial investment (Cassimatis, 1988).

3.2.5 Replacement Process Literature

The methods described above are used by different authors in different ways, according the specifications and objectives of the models they propose. Certain methods are more suited for some kinds of approaches at the same time that they are inadequate when some pre-considerations are taken. Using inappropriate investment evaluation techniques can lead to wrong decisions (Christer & Scarf, 1994). As so different business plans will be more suited for determined methods than others. It is therefore important to analyze the project specifications and details in order to select an adequate evaluation method. For example, when considering independent projects, both the IRR and the NPV methods give the same results. However, when considering mutually exclusive projects, which means, only one project can be selected, conflicting results may occur between the IRR and NPV (Lee & Petruzzi, 1984). Literature proposing methodologies for optimal replacement planning can be found since the 1940's (Katz, 1998). A review of some of the most important articles published in the field is next presented.

A survey conducted in the UK by Christer & Waller (1987), demonstrated the preferences that companies have when choosing some of the described methods to evaluate replacement decisions. This work, consisted of in-depth surveys of specific pieces of equipment within 19 organizations, with the objective of investigate the extent to which any modeling actually influenced replacement decision-making. The conclusion was that for major items of equipment, various forms of modeling were undertaken, often of a discounted cash flow type, but they had very little influence on the resulting decision, since such decisions were dominated by factors not included within the modeling. On the other hand, for minor items of equipment, modeling in some form did have a recognized influence upon the decision-making process, but it was considered in the main to be inadequate to its task (Christer & Scarf, 1994).

A much more positive picture, however, is portrayed by an on-distance questionnaire survey of 200 randomly selected Fortune 500 industrial firms, conducted by Hsu (1988) in the USA, which stated that 89% of the firms had definite policies for equipment replacement assisting the decision-making process. This survey had precisely the objective to investigate firms equipment replacement policy, especially, whether or not a firm had a definite policy for equipment replacement, and the methods adopted for measuring and determining equipment life (Hsu, 1988). Table 5. represents the different methods used to determine the replacement age. The various factors reportedly used in the replacement decision process are exhibited in Table 6.

Table 5. Company's service life calculation method (Hsu, 1988).

Method	% of firms
Discounted Rate of Return	83
Payback	63
Net Present Value	50
Maintenance Expense Limit	20
Company's own formulae	17

Table 6. Factors influencing life calculation (Hsu, 1988).

Factors	% of firms
Maintenance Expenditure	97
Downtime Cost	80
Depreciation	80
Taxes	73
Cost of parts inventory	64
Salvage Value	60
Market expansion and contraction	53
Inflation	30
Cost of deferring replacement	27
Cost of operator training	10

The apparently conflicting views of both surveys are probably related to the different research methodologies employed. For example, according to Hsu (1988), 30% of the firms reportedly take inflation into account in the replacement modeling. Similar statements have been found in Christer & Goodbody (1980) work, which started considering inflation rate as an issue in the formulation of replacement decision economic models. In this article the replacement process during a high inflation period is analyzed by introducing it in the calculation of the discount factor. However, further investigation indicated that inflation was not so much taken into account as worried about, being more often considered an external factor. Therefore inflation should be a factor in the decision process, but not in the decision model (Christer & Scarf, 1994).

Clapham (1957) proposes a way of calculating the average economic life, in which the calculated economic life would then be used as reference for evaluating if the equipment should be replaced or not. Clapham (1957) assumes that all the costs associated with a specific equipment result from the acquisition and maintenance costs for each period. The sum of all the equipment related costs, until a certain age, divided by that same age will give the average cost per period specific for that age. The age with the lower average cost per period will correspond to the equipment's economic life. The authors concluded that the average maintenance costs per period have a linear growth related with age, and that the economic life of the equipment will correspond to the number of years that minimizes the average cost per year.

Eilon & King (1966) question about the validity of some of the assumptions used in the economic life studies made at the time. Specifically, the authors wondered if it was correct to use a single average function to describe the maintenance costs, and if it was correct to consider in the same way costs occurring in distinct periods of time. In other words, a cost incurred in a more distant period of time shouldn't have the same weight in the decision process, as a cost incurred in a proximal future. The authors established an average annual cost function introducing a time variant salvage value for the equipment, which Clapham (1957) have neglected. They also introduced a discount factor, in order to consider a different weight for costs incurred in different periods of time. However when comparing the results obtained with and without this discount factor, the authors concluded that the differences between the two calculation methods were not very significant. The analyses indicated that the average maintenance cost per year would rise linearly with age and allowed to determine a 7 years average economic life for the items sample. The authors determined the equipments economic life using the individual maintenance costs of each item, in order to access the suitability of using average costs data. The results shown that the individual economic life of each item could range from 5 to 12 years. Comparing the cost results of using the 7 years average economic life with the cost results obtained using the individual economic life of each equipment, have shown that the difference between the two approaches wouldn't be relevant and using an average cost data would be a suitable measure to determine equipments economic life. Eilon & King (1966) also assumed that when an equipment is deactivated it has to be replaced by another, and so, an infinite chain of replacements must be considered. As so, they considered that to determine the economic life of a pool of equipments it is necessary to calculate the total costs present value for an hypothetical infinite replacement sequence where each item is to be replaced with the same period of time.

Both Clapham (1957) and Eilon & King (1966) consider the linear rise of the maintenance costs with age as a direct sign of deterioration and disregard any kind of technological evolution. This concept was later introduced in the decision analysis by Elton & Gruber (1976). They propose that technological innovation generates a constant extra value a over the economic profit generated by that type of equipment. Thus, the replacer of an N years old equipment would provide an extra profit of $N * a$ over the profit generated by the existing equipment. By predicting the evolution of profit in the future, it was concluded that it's possible to determine an unique economic life for several generations of equipments, independently of technological evolution. However, the authors modeled this process as regular and continuum, which according to Katz (1998) is an incorrect assumption.

Christer (1988) suggests that technological advances brought by a replacement equipment that cannot be converted in financial value, can be accounted as additional costs incurred by a late replacement. In this way it's possible to introduce quantitative evaluations that support the anticipation or delay of a replacement moment, previously scheduled by the methodology. This would facilitate the inclusion of technological evolution in the replacement decision, since it allows for an objective comparison between the costs of the existing equipment and its replacement Katz (1998). According to Christer (1988) this is a more reliable approach when compared with other approaches that attempt to estimate an index of technological evolution or consider an annual improvement in revenues.

Christer & Scarf (1994) announce a methodology specifically aimed for medical equipment replacement. This new work appears as an evolution of Christer's previous 1980 and 1988 papers, and tries to encompass as many factors as technological evolution, equipment deterioration and inflation. It also tries to include subjective aspects, particularly important when it comes to medical equipment, such as, patients well being and safety. These factors are included in a form of a penalty factor. The authors propose a limited horizon analyses until the moment where the replacer of the existing equipment is replaced, which is, one cycle. All operating, maintenance and replacement costs incurred within the established horizon were accounted as net present value considering the respective discount factor and according to the hypothetical replacement time for the existing item and its respective substitute. The total discounted costs will be the sum of the present value of all the costs within the horizon, allowing to determine the average annual cost, which will indicate the optimal replacement moment amongst the hypothetical timings considered.

Kierulff (2007) elaborated a work where he points out some limitations of the traditional economic methods applied in replacement decisions, and proposes some approaches to overcome these limitations. One of the limitations is pointed to the net present value decision model, one of the most widely used model by companies, in a way that it discounts only the differences between cash flows and salvage values of the replace and do-not-replace alternatives, assuming that the risk and inflation factors associated with these values are the same. According to the author, this can lead to wrong decisions. In an attempt to overcome this problem, it is proposed a model where each alternative cash flow and terminal value is assigned an appropriate risk and inflation discount factor.

Kierulff (2007) work is based on a review of 15 significant and highly-respected texts on basic finance for replacement decisions. Ten of those sources discuss replacement using a net incremental method and four others cover the subject under the heading of equivalent annual annuities (EAA). According to the author there are four distinct components in a capital budgeting exercise:

(1) An initial investment required (fixed assets and any upfront operating working capital);

(2) After-tax free cash flows over a discrete time period until a planning horizon is reached;

(3) A terminal value; and

(4) A discount factor that accounts for the required rate of return or cost of capital.

This last one is supposed to represent, in percentage form, an estimate of the risk, inflation, and liquidity preference inherent in forecasted free cash flows. Risk and inflation can be associated with any number of factors in a given investment's cash flow. The main purpose from the author is to point out that there is a different factor of risk and inflation associated to each periodic cash flow and to each terminal value. The incremental approach cannot incorporate these different rates (Kierulff,

2007) and the EAA is an infinite model which is helpful but not advised for one-time decisions (Emery & Finnerty, 2004).

Kierulff (2007) has shown trough a case example, that indeed the application of four different discount rates can lead to a different decision from the one obtained with the traditional methods mentioned. In this case example the two models produce the same decision of replacing the existing asset, for a constant discount rate. In fact they produce the same result whether the discount rate is 10% or 15%. However when different rates are used to measure the risk associated with each one of the defender cash flows, defender terminal value, challenger cash flows and challenger terminal value, the decision might be reversed. This is the case, even though the different discount rates for each alternative cash flows and terminal values are within the 10%-15% range.

3.3 Multi-Criteria Methods

In the early 90's a model to recommend and prioritize medical equipment replacement was introduced in the St. Luke's Medical Centre. The model, proposed by Larry Fennigkoh, contains a total of ten attributes addressing four primary replacement issues: *equipment service and support, equipment function, cost benefits and clinical efficacy (Fennigkoh, 1992)*. To minimize the model's sensitivity to the subjective information a simple scoring system of "yes-no" (0,1) was used for each attribute (Fennigkoh, 1992). According to the author this can be an advantage regarding to conventional deterministic methods, like net present value or internal rate of return, when only incomplete or subjective information is available.

Toporkov (2007) proposes the assessment of reliability, efficiency, and service life of sophisticated medical equipment in Russia Federation, as a response to the 80% of worn-out or obsolete equipment in use, at the time, in public health organizations (Toporkov, 2007). The author establishes the prognosis of the service life as an important parameter in the reliability and efficiency of technological equipment and proposes a method to make this prognosis. This method is based on mathematical principles such as stochastic principles resulting from equipment use or principles of risk conditions, related to the probability of failures and accidents. The method made possible the development of an automatic data system for medical equipment surveying, allowing monitorization of the current assets as well as possible upgrades. It also allows the evaluation of reliability and efficiency of a given equipment, establishing a set of parameters like time for next monitorization, number and time of repairs, safety and economical efficiency (Figueiredo, 2009).

Dondelinger (2004) took into consideration 3 primarily factors to assess the medical equipment replacement decision. The author considered the number of failures, since the item was put into service, the cumulative cost of repairs and the item's age as the 3 factors of extreme importance in the equipment evaluation. This information should be provided by a database with equipment's historical repair information, and therefore it's of vital importance that institutions keep these kind of databases (Dondelinger, 2004)

The author considers that the more often the equipment fails, the higher the likelihood that it should be replaced. These failures can be caused by age, poor design, user error, amongst other reasons. The objective of analyzing the cumulative costs of repairs is to detect and eliminate the 'dogs'. These are typically equipments that permanently consume the energy and resources of the company, by having intermittent problems of difficult troubleshooting or by spending more time in the repair shop that on the user's hands (Dondelinger, 2004).

A set of subjective factors that might be influential in the replacement decision, were also included in the analyses. Such factors are dependent on the interest of each organization, but the author suggested the advancement in technology, to quantify the technological improvement brought by the replacement. A second factor is suggested and refers to how well the replacement of a particular item fits into the organization five-year-plan (Dondelinger, 2004). Note that this model only evaluates the performance of the existing equipments and does not make a comparison with the estimated costs of a challenger alternative.

3.4 Real Options

A financial option is one type of derivative financial instrument that grants its owner rights over another financial asset, such as stocks or bonds (Baltazar, 2009). This asset is referred as the underlying asset and the value of the option depends on or is derived from it (Amram & Kulatilaka, 1998).

There are two kinds of options, *call* and *put* options. A *call* option gives its owner the right to buy an asset at a fixed price, during a predetermined period of time. In an opposite way a *put* option gives its owner the right to sell an asset at the exercise price. An option comes with a cost to the buyer, and grants him the right but not the obligation to exercise it. On the other hand, to the selling party, an option represents an obligation (Baltazar, 2009).

Options contracts can have several different features and are classified according to them. The most common contracts are the so called *European* and *American*. The only difference between them is that *European* options can only be exercised in the maturity date as while as *American* Options can be exercised at any given time until the maturity date is reached. This implies that the models used to evaluate options will have to take into consideration the type of option in analyses (Baltazar, 2009).

The Real Options approach is a line of thinking that tries to extend the option theory used in financial markets to the strategic management of real (nonfinancial) assets (Damodaran, 2010). An option is the right, not the obligation, to take an action in the future. In the financial market an option is the right to buy or sell a security at a given price. Analogously, companies that make an investment have the right, not the obligation to exploit these opportunities in the future (Amram & Kulatilaka, 1998). Real Options are capital budgeting decision contingent on the value assumed by some relevant and well specified state variables (Gamba, 2003). The value of an option, such as to expand, to extend or abandon a project, relies on the flexibility it provides to the company. Traditional valuation tools are centered in the cash flows If a typical discounted cash flows analysis results in a negative evaluation of a project, it will be discarded, not accounting for the growth opportunities that could arise from it in the future (Amram & Kulatilaka, 1998).

For instance, flexibility gives the company the opportunity to make the investment by stages, allowing for a partial commitment until more information is available and uncertainty is undone. If an initial investment goes well, then the manger can exercise the option to extend its commitment to the strategy. If the value of the project goes down, there is no commitment to further investment. This way options give the company the opportunity to better assess the value of a project while shielding them from big losses (Amram & Kulatilaka, 1998). Real options are a tool to measure the uncertainty and flexibility associated with the management of a non-financial asset. This method uses an analogy to financial option pricing theory and tools to evaluate real projects (Hull, 1999).

An example of this, is the investment on a production plant update that besides the increase in production can allow the company to expand to new business segments. Options are particularly valuable when the uncertainty is high. Contradicting the traditional manager's intuition, in the Real Options uncertainty is viewed as an opportunity and not as risk (Damodaran, 2010).

Another advantage of Real Options is that forecast of future cash flows is not necessary. In traditional tools usually only one single forecast is made, which tends to be overoptimistic and treated by managers as a reality, creating an illusion of certainty about the numbers. A Real Options analyses does not focus in one single projection of the project variables, but on a range of possible paths that this variable can follow, designated as cone of uncertainty. Its conception tries to overcome some of the limitations of the traditional tools for strategic investments evaluation (Amram & Kulatilaka, 1998).

3.4.1 The Option Valuation Model

The model to determine the value of an option was proposed in 1973 by Fisher Black and Myron Sholes, with the help of Robert Merton. At the time, it represented a huge breakthrough regarding the conventional discounted cash flows approaches in practice. For their work, Sholes and Merton were awarded the 1997 Nobel Prize in Economics, as Black had died prior to the award, in 1995 (Amram & Kulatilaka, 1998).

The authors established that the value of an option relies on its underlying asset. The underlying asset consists on a portfolio of assets that have the same payoff of the option, referred as tracking portfolio, which mimics the fluctuations in option value over time. When dealing with financial options the tracking portfolio consists on traded securities, as long as for real options it may or may not be constituted by financial assets.

The value of the option is combined with tracking portfolio in an offsetting manner, creating an hedged position. This way, a change in value of the underlying asset will be exactly offset by a change in value of the option. This process is known as dynamic tracking, and assures that the value of the option is dynamically up-dated to remain equal to the value of the tracking portfolio as the value of its constituting assets evolve (Amram & Kulatilaka, 1998). Consequently, and since they are in offsetting positions, the value of the hedged position is independent of fluctuations in the underlying asset and guarantees a constant risk-free return, as represented in Figure 1..This concept was the base for the risk-neutral approach to valuation, introduced by Cox, Ross and Rubenstein in 1976 (Amram & Kulatilaka, 1998). The authors concluded that, since fluctuations in the value of the underlying asset originate an update, by dynamic tracking, in the composition of the tracking portfolio to maintain a risk free hedge position, the option valuation can be done without risk preferences (Amram & Kulatilaka, 1998). Consequently, the value of the option and the tracking portfolio are independent of risk preferences, and so, there is no need to determine a risk-adjusted rate of return. A risk-free rate of return can be used in the valuation model, eliminating the need to estimate any sort of risk-premium, which substantially simplifies the calculations (Amram & Kulatilaka, 1998).

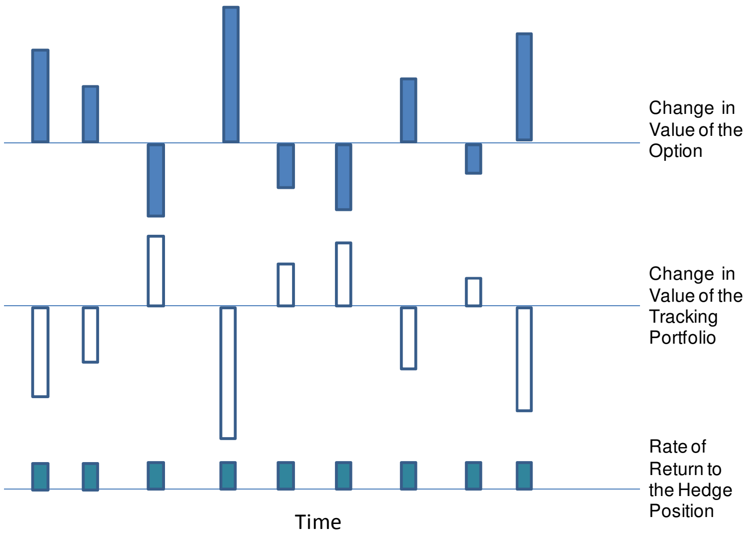

Figure 1. Dynamic Tracking *(Amram & Kulatilaka, 1998).*

The value of the option determined by dynamic tracking ensures that there is no arbitrage opportunity between the option and the tracking portfolio (Amram & Kulatilaka, 1998), which was in fact one the requirements, and one of the key features, of the Black-Merton-Scholes model. Arbitrage is the practice of buying an asset and simultaneously sell it, or an equivalent asset, for a higher price, guarantying a risk-free profit, resulting from the gap between prices (Amram & Kulatilaka, 1998).

It is not necessary to actually buy the assets constituting the tracking portfolio. The option valuation can be made by mere observation of the prices in the financial markets of the securities included in the tracking portfolio (Amram & Kulatilaka, 1998). The dynamic relationship between the composition of the hedged position and the risk-free rate of return, described above, is mathematically specified by the partial differential equation proposed by Black & Scholes (1973) which defines the value of the option in terms of the value of the underlying asset, its volatility, and the risk-free rate of return (Amram & Kulatilaka, 1998).

3.4.2 The Black-Scholes Equation

A partial differential equation (*PDE*) is a an equation that reflects the simultaneous rates of change of several variables. In option valuation, a PDE describes the conditions that the underlying asset value and the value of the option must satisfy over time with respect to each of the input variables (Amram & Kulatilaka, 1998). In addition to the PDE, a set of boundary conditions is required to determine the value of the option. Boundary conditions will be the equations that reflect the decision rule and determine the extreme values that the option value might assume. Since the PDE is specified to reflect the specific features of the option, different options have different partial differential equations, and not all partial differential equations have analytical solution. In an analytical solution, the option value can be expressed as a function of the inputs. This can usually be achieved for simple real options, with one single source of uncertainty and a single decision date. However, for more complex applications, analytical solutions cannot be found and the use of numerical methods is required (Amram & Kulatilaka, 1998).

The Black-Scholes equation is a solution to one particular partial differential equation. This PDE is the one formulated by Black & Scholes (1973) for an European call option in which for any underplaying asset A that follows a log-normal process, the value of the option V must satisfy

$$\frac{\partial V}{\partial t} + r\frac{\partial V}{\partial A}A + \frac{1}{2}\frac{\partial^2 V}{\partial A^2}\sigma^2 A^2 = rV \tag{6}$$

where t is time, r is the risk-free rate of return and σ is the volatility of the underlying asset. To obtain the current value of the option, the PDE must respect some boundary conditions. One of the boundary conditions for an European call option is that the value of the option on the final decision date, T, must be equal to $max[A_T - X, 0]$, where A_T is the value of the underlying asset on date T and X is the cost of investment (Amram & Kulatilaka, 1998).

The Black-Sholes equation is the analytical solution of the Black-Scholes PDE and above boundary condition, and can be expressed as follows:

$$V = N(d_1)A - N(d_2)Xe^{-rT} \tag{7}$$

V: Current value of call option;

A Current value of underlying asset;

X Cost of investment;

r Risk free rate of return;

T Time to expiration;

$N(d_1)\,, N(d_2)$ The value of the normal distribution at d_1 and d_2, respectively;

The parameters d_1 and d_2 necessary to determine the normal distribution $N(d_1)$ and $N(d_2)$ can be obtained with the following expressions:

$$d_1 = \frac{\ln(A/X) + (r + 0.5\sigma^2)T}{\sigma\sqrt{T}} \tag{8}$$

$$d_2 = d_1 - \sigma\sqrt{T} \tag{9}$$

where σ is the volatility of the underlying asset, which is estimated from its historical behavior (Amram & Kulatilaka, 1998).

3.4.3 The Binomial Option Valuation Model

The binomial option valuation model is appropriate to handle complex real options, with multiples sources of uncertainty, complex decision structures and complex relationships between the value of the option and the value of the underlying asset. The binomial model is a popular implementation of the dynamic programming techniques used for option valuation (Amram & Kulatilaka, 1998). Dynamic programming allows to determine the optimal decisions when the current decision influences future payoffs, in which the optimal strategy is determined according to the Bellman's Principle which states that *"an optimal policy has the property that whatever the initial state and decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision*." (Bellman, 2010) This way the optimal strategy is defined as the one that would be chosen if the entire analyses were to begin in the next period. The solution is obtained in a recursive way, folding back future values into the optimal initial decision (Damodaran, 2010).

The binomial option valuation model represents the evolution of the value of the underlying asset as a binomial tree. In each time period the underlying asset can make only up or down movement, laying out all the possible paths. In its most widely used version the uncertainty is expressed in a multiplicative binomial model, in which the value of the asset A, within a short time period, moves either up to Au or down to Ad, where u is a number higher than 1, reflecting a proportional increase in the asset value and $d = 1/u$ is a number smaller than 1 reflecting an equivalent decrease (Brandão, 2005). In the next period the asset value moves to Au^2 or Aud or Ad^2, and so on for the following periods. The resulting binomial tree and the corresponded distribution of outcomes in the final date is presented in Figure 2. where is possible to see that each possible final outcome as a specific probability of occur over all the possible paths in the binomial tree (Amram & Kulatilaka, 1998).

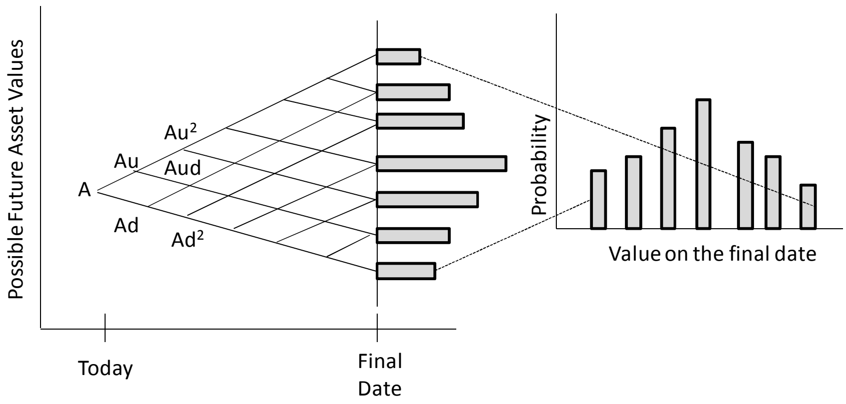

Figure 2. Binomial distribution of payoffs at maturity *(Amram & Kulatilaka, 1998).*

The specific parameter values are chosen so that the resulting final distribution corresponds to the empirical reality (Amram & Kulatilaka, 1998). When the risk-neutral approach is applied to the binomial model, the expected return to the underlying asset is the risk-free rate of interest r, but its volatility σ, will be the same as that observed in the real economy (Amram & Kulatilaka, 1998).With continuous compounding, the expected return during each period will be

$$\frac{pAu + (1-p)Ad}{A} = e^r \tag{10}$$

The probability p, weights the outcomes to obtain the risk-free rate of return and is called the risk-neutral probability (Amram & Kulatilaka, 1998). In a similar way, equating the variance of the return from the binomial model to that of the observed normal distribution gives:

$$pu^2 + (1-p)d^2 - [pu + (1-p)d]^2 = \sigma^2 \tag{11}$$

One solution to the above equations which assumes that the underlying asset has symmetric up and down movements, is given by

$$u = e^{\sigma}; d = e^{-\sigma} \tag{12}$$

$$p = \frac{(e^r - d)}{(u-d)} \tag{13}$$

The process through which the binomial tree of uncertainty is constructed is represented in Figure 3. For simplicity only 6 levels where represented. The number of levels in the tree represent the number of time periods in which the underlying asset A can change value, until the final date T is reached. As higher the number of time periods, the higher the accuracy of the valuation will be. However, this comes with the cost of a higher computational burden. To make it simpler to implement in a spreadsheet, upward movements in the tree are along the row, and downward movements are along the diagonal. The data inputs for the model, that must be known, are the final date at which the option can be exercised, T, the volatility σ calculated from the historical variation of the asset value, and the risk-free rate of return r. With these values it is possible to calculate the value of an upward movement $u = e^{\sigma}$ and a downward movement $d = 1/u$.

		Number of time periods until final date T					
		1	2	3	4	5	6
Asset Value	A	Au	Au^2	Au^3	Au^4	Au^5	Au^6
		Ad	Aud	Au^2d	Au^3d	Au^4d	Au^5d
			Ad^2	Aud^2	Au^2d^2	Au^3d^2	Au^4d^2
				Ad^3	Aud^3	Au^2d^3	Au^3d^3
					Ad^4	Aud^4	Au^2d^4
						Ad^5	Aud^5
							Ad^6

Figure 3. Rollout of the binomial tree for the value of the underlying asset.

The next step will be to establish the decision rule according the specific features of the option. This will provide the values of the option at the decision date. Considering values of the option S_{ij} in each node are represented in a matricial way, where i and j are the indexes of the superior matrix, as shown in Figure 4. Since the decision occurs only on the final moment T, the decision rule is imposed only on the final column of the binomial tree, which is, will allow to determine the values S_{06} till S_{66}.

		Number of time periods until final date T					
	Current day	1	2	3	4	5	6
Option Value	S_{00}	S_{01}	S_{02}	S_{03}	S_{04}	S_{05}	S_{06}
		S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
			S_{22}	S_{23}	S_{24}	S_{25}	S_{26}
				S_{33}	S_{34}	S_{35}	S_{36}
					S_{44}	S_{45}	S_{46}
						S_{55}	S_{56}
							S_{66}

Figure 4. Matricial representation of option values *S*.

The last step in the binomial option valuation is to bring back the future values to the present, trough a fold back process. It begins in the bottom right node, or position S_{66}. The value at each node of the optimal decisions at time T, will be given by the general expression:

$$S_{ij} = \left[S_{i,j+1}p + S_{i+1,j+1}(1-p)\right]e^{-r} \tag{14}$$

where p is the risk neutral probability and can be calculated with expression (13). Once the fold back process is completed, it is possible to determine the current value of the option S_{00}.

3.4.4 Replacement Process and Investment Literature

Application of Real Options can be found in a wide range of business types that can go from the development of new drug by a pharmaceutical company, the investment in a startup high-tech company or evaluating R&D projects. In fact, Real Options can be applied to any strategic project where uncertainty is a issue, including the equipment replacement problem, as presented in Lee & Petruzzi (1984). In this paper formulas developed for the valuation of securities options were used to evaluate the timing option and to derive decision rules for optimal investment timing, providing, amongst others, an application example for plant and equipment replacement (Lee & Petruzzi, 1984). The document considered the importance of timing for the decision maker's opportunity set. The authors establish a relation between the ability of the manager to choose when to undertake an investment and the ability of the holder of a securities option to choose when to exercise that option. The authors propose two stochastic models to evaluate the timing option and to determine the optimal timing, based on the different specifications of cash flows and risk associated with the particular investment project. The first model is based on Black & Scholes (1973), and formulates the opportunity of implementing an investment project within a certain time horizon as an American call option on a security which pays no dividends (Lee & Petruzzi, 1984). The second model is based on Roll (1977) and Whaley (1982) works, and considerers that if the project is implemented before time *t*, the project generates a known extra cash flow, at time *t*. On the other hand, if the project is implemented after time *t,* its cost will increase by the same amount at time *t*.

Kellogg & Charnes (2000) used a decision-tree and binomial-lattice methods to valuate a biotechnology company, as the sum of the of the values of its ongoing drug-development projects. They modulated each of these projects as a call option on the subsequent new drug. In their calculations the authors used two different discount rates for discounting future cash flows according to their nature, as suggested by Myers & Howe (1997). Real rates of 6% and 9% were used to respectively discount development cash flows and commercialization cash flows, at constant prices. The inflation was estimated from the *Gross Domestic Product* (*GDP*) deflator index in the U.S. over the five years prior to the analyses (Kellogg & Charnes, 2000).

The paper outlines the advantages of the decision-tree model as it is easy to construct and calculate, on the account of the limited (eleven) number of outcomes for the drug-development process, in addition to the good visual results produced which facilitates communication. It also includes a notion of abandonment a probabilistic ponderation of the future cash flows, that distinguish this method from the traditional NPV analyses. However this model is limited in the way that it ignores growth options brought to the company by a successful drug. To overcome this limitation the authors used the binomial-lattice method for valuation, with the addition of a growth option. The authors took into consideration the risk neutral valuation approach introduced by Cox, Ross and Rubenstein in 1979, which allow them to disregard a risk premium calculation for the discount rate, which was particularly appropriate for their work, in a way that the objective was to evaluate the market value (stock price) of the company, and not any kind of internal valuation. The risk-free rate of return used to determine the risk neutral probabilities of the binomial-lattice was the 10-year U.S. Treasure-Bill rate, which was of 7.09% in 1994 (Kellogg & Charnes, 2000).

The authors concluded that the decision-tree and binomial-lattice methods provided reasonable valuation results of the company for the early stages of the drug development process, and as the drug kept moving forward in the development stages the theoretical values obtained started to diverge from the actual stock prices observed in the market. This discrepancy was justified with the different pre-assumptions investors might had to the development process success. They also concluded that the growth option inserted in the binomial-lattice method had little influence on the value of the initial option, as the value of the growth option is low when compared to the initial investment required for developing a new drug (Kellogg & Charnes, 2000).

Copeland & Antikarov (2001) proposed an approach to value Real Options that may be applied to problems where the underlying asset has no correlation with any market-traded asset. For this, the authors use the so called *Marketed Asset Disclaimer (MAD)* assumption, which consists on the assumption that the present value of the project without options is the best unbiased estimator of the market value of the project. Under this assumption the value of the project without options can be used as the underlying asset in the tracking-portfolio. Considering this, if the changes in the value of the project without options are assumed to vary according to a *Geometric Brownian Motion (GBM)*, the options valuation can be done with traditional option pricing methods (Copeland & Antikarov, 2001).

Smith & Nau (1995) proposed a method that integrates option pricing theory and decision analyses, highlighting the distinction between market risks, that can be hedged by trading securities and valued using option pricing theory , and private uncertainties, which are project-specific risks and can be valued using decision analyses techniques. The authors had proven the adequacy of this distinction, however, Brandão (2005) reminds that the distinction between market and project-specific risks may not be obvious in all kinds of business fields

Considering the assumptions made by Copeland & Antikarov (2001) and Smith & Nau (1995), Brandão (2005) suggested an approach using decision tree analysis to solve Real Options valuation problems. The modulation of the problem was made with a binomial decision tree, rather than a binomial-lattice, in order to obtain a simpler, more appealing and intuitive solution, using common decision analyses software. The model begins by determining the current market value of the project without options, using a traditional NPV analyses of the expected cash flows of the project with a risk-adjusted discount rate. Then the market associated uncertainties are inserted into this deterministic model to perform a Monte Carlo simulation on the project cash flows. Two main sources of market uncertainty are considered as inputs for the simulation, selling prices and variable operating costs. These variables are assumed to follow a GBM stochastic diffusion process with a mean annual rate of increase of 2% and 3% and volatility of 10% and 15% for, respectively, the variable costs process and the price process (Brandão, 2005).

The Monte Carlo Simulation allowed to determine the standard deviation of the project returns which provided an estimate of the project volatility. It is also assumed that the project returns have a normal distribution, and so, the project values have a log-normal distribution and can be modeled as a *GBM* with a constant volatility. The binomial approximation to the GBM was then modeled using a commercial options software. The obtained binomial tree represents the underlying asset and could be used to evaluate Real Options by inserting the appropriate decision nodes in the tree. To address the problem of considering uncertainties that have no correlation with the market, the authors proposed the addition of chance nodes in the appropriate time periods of the tree, modulating their probability according to the additional information provided by project evolution (Brandão, 2005).

4 Methodology

Two models will be proposed in this work to evaluate replacement decision. These models are intended to become a valuable additional tool for the SIE practitioners, allowing them to better address the replacement problem in HSM. The first model will be based on the discounted cash flows model proposed by Christer & Scarf (1994). This model allows determining the replacement cycle that minimizes the costs associated with an equipment, assuming that the future costs will evolve in a determined way. This is a traditional deterministic model which estimates future costs based on the assumption that these will evolve according to their historical behavior. That means that costs will evolve in a similar pattern to the costs incurred in the past. The second model will be based on Real Options theory. In this model costs are assumed to evolve randomly, in an unpredictable way. Monte Carlo simulations will be used to determine the range of possible outcomes for cost evolution, and then Real Options valuation methods will be used to assess the replacement decision.

The models have the objective to aid replacement decision-making, by identifying a good replacement decision and the consequences of alternative ones. They highlight the economic performance, without neglecting the public service purpose of a health-care Institution. The models can not only contemplate the economic aspects, but also have to encompass a measure for subjective factors associated with the quality of medical service provided. Such subjective factors are not directly accountable but can, in fact, influence the costs in a considerable way (Christer & Scarf, 1994). Damage to the public image of the Institution caused by litigation processes or adverse media coverage. Patient suffering, inputted by a delayed treatment or by being treated with one type of machine rather than another. All these are examples of aspects that can fell into this category. Despite of being hard to quantify, such subjective factors should influence the decision making process.

To address this problem Christer & Scarf (1994) proposed the introduction of a penalty factor that would model a monetary value as a function of the number of failures of determined equipment. Equipment failures or unavailability due to malfunction can bring consequences to patient care, possibly requiring the use of different treatments that may be less effective, more expensive and require more medical resources. As so, patient care consequences have to be considered and the equipment failures associated with them should not be measured simply by their costs (Christer & Scarf, 1994). Penalty will then be the summation of all adverse effects to the patient and medical staff, as well its consequences to the institution, associated with medical equipment failure and its consequent unavailability. Of course, the modulation of penalty must be different for different types of equipments. A failure in a radiation therapy equipment such as the Linear Accelerator can have very serious consequences for either patients and technicians involved. On the other hand a failure in an ecograph is unlikely to cause a serious damage due to the non hazardous nature of ultrasounds. At most, a treatment delay will be in be in order, since, due to the large number of such equipments, there would be an alternative item available within the hospital facilities.

The existing equipment being considered for replacement is not new but had been in service for a number of years *N*. The decision will then be to replace it now, in one year,...., in *K* years, or only when forced be technical obsolescence (Katz, 1998). Equipment is unlikely to be replaced with like equipment. Medical equipment is in a fast-paced technological evolution and so, whether the replacement decision is being driven by technical obsolescence, or by changing medical requirements or by technological developments, the like-by-like replacement option does not exist (Christer & Scarf, 1994). However, estimating the future cost of a high-tech medical, over a long period of time, would be an extremely complex and unreliable procedure. For this reason it will be assumed that future replacements will be made with the most advanced equipment available today.

The equipment replacement age should be related to its usage and not necessarily to number of years in service. A higher maintenance cost does not necessarily mean that the equipment has a higher operating cost. In fact such equipment can have a lower cost per unit of usage. Usage can be defined as the measure of time that equipment is actually being used to serve patients (Katz, 1998). Usage units vary from one equipment to another. For example, for ecographs are the number of procedures performed, for dialysis machines are the number of hours connected to a patient and for equipments that serve by its presence, such as defibrillators or fire extinguishers, usage will be the actual number of hours the equipment is available in appropriate conditions to be used (Katz, 1998). It is therefore accepted that a usage measure will be more appropriate then a straight age-based replacement decision (Christer & Scarf, 1994). However, in this work, due to the lack of data available, it wasn't possible to establish an usage measure for the selected items for the study. Nevertheless, considering the small number of Linear Accelerators in service in HSM (during this study, the maximum number of Linear Accelerators operating simultaneously was 3) and the high demand for their services, it is acceptable to assume that each item will be constantly working, as long as it is available, without any kind of preference. Thus, for these kind of equipments, time can be taken as an appropriate measure.

On the other hand, for pooled equipment, or equipment with a variable demand over time (such as ecographs or ventilators), it would be useful to establish an adequate measure of usage, since, due to the high number of items available, some kind of priority system will be in place (Christer & Scarf, 1994).

Often equipments are not disposed after being replaced by newer models. Especially when considering pooled items, it is not unusual that replaced equipment is kept as a spare or even maintained in service, after going through a major overhaul. In this case, what is in fact being considered is a purchase decision. A purchase decision modeled as a replacement decision can prove to be very expensive (Christer & Scarf, 1994). A purchase decision can in fact be modeled as a replacement decision but in that case all cash flows for the older equipment must be zero (Guitman, 2003). The option to retain the old equipment is not useful for the problem in analyses, and so it won't be considered in this work. Consequently, the replacement problem will be modeled considering that the replaced equipment is always retired from service.

Equipment of one type or another will be required for the foreseeable future. This continual demand for equipment does not require to model the replacement process over an infinite horizon of time. It is recognized that the decision relates only to when the current equipment should be replaced, and this particular replacement decision does not realistically have operational consequences over all time (Christer & Scarf, 1994). Taking into consideration the fast evolution of medical equipment technology, the required future costs forecasts would became particularly speculative. Therefore, it is convenient for this work to confine the period over which the analyses will be made. Considering the assumptions above, it is now possible to construct the replacement models and describe the two different approaches used.

4.1 Deterministic Model

The deterministic model proposed consists on formulating the total expected cost of retaining the existing equipment for a further K years, replacing it with a new equipment, with a purchase cost Rn, retaining this for a period *L* and then replacing again with a new model, with an equivalent cost Rn. This process is represented in Figure 5.

The criteria function would then be the total expected discounted costs annualized over a series of *(K+L)* annuities, employing the Equivalent Annual Annuities method described in section 3.2.3. The objective is to minimize the annuity with respect to *K* and *L*. Christer & Scarf (1994) have used the Average Cost method to obtain their criterion function. However, since this method relies on the simple arithmetic division of the total discounted costs over the number of years in analyses, it would neglect the time value of money effect. The EAA method overcomes this limitation by making use of the *Capital Recovery Factor*, and therefore, was found to be more suitable for this work. Notice that *K* is the only actual decision parameter influencing action, being the *L* cycle, and the replacement in the end of it, introduced to influence optimal *K* by the ongoing need to retain operating equipment (Christer & Scarf, 1994).

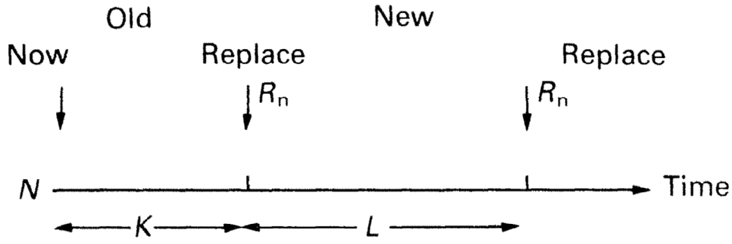

Figure 5. Replacement timeline(Christer & Scarf, 1994).

4.1.1 Mathematical Formulation

The total cost associated with an equipment during one year $C(i)$ is the result of its maintenance costs $m(i)$, and its operating costs $c(i)$, as expressed by

$$C(i) = m(i) + c(i) \tag{15}$$

where i is the year in which the costs are incurred. Thus, the total expected discounted cost of replacing a N years old existing equipment after K years, and again after further L years is denoted by $C(N;K,L)$ and is expressed by

$$\begin{aligned} C(N;K,L) = & \underbrace{\sum_{i=1}^{K}\left(C_0(N+i) + p_0(N+i)\right)r^i}_{term\ 1} \\ & + r^k \left\{ \underbrace{R_n - S_0(N+k)}_{term\ 2} + \underbrace{\sum_{i=1}^{L}(C_n(i) + p_n(i))r^i}_{term\ 3} + \underbrace{(R_n - S_n(L))r^L}_{term\ 4} \right\} \end{aligned} \tag{16}$$

where:

N	Age of existing equipment in years;
K	Remaining life of existing equipment, expressed in years;
L	Economic life of the new replacement equipment in years;
$'o'$, $'n'$	suffix $'o'$ denotes old equipment, suffix $'n'$ denotes new equipment;
$C(i)$	total expected maintenance and operating costs per year for equipment in its i^{th} year of operation;
$p(i)$	penalty measure for equipment in its i^{th} year;
$S(i)$	Residual value of equipment i years old;
R_n	Purchase cost of new equipment;
r	Discount factor;
$C(N;K,L)$	Total expected discounted cost incurred over a $K+L$ period of time for equipment currently N years old.

The *term 1* in equation (16) refers to the K cycle, with the sum of all costs and penalty values associated with the existing equipment for further K years. All these values are discounted, by an appropriate measure. The discount factor r, and the variables that affect it, will be outlined in Section 4.1.3. There is no possibility to determine the distribution of the costs along the year, and therefore all cost are assumed to be incurred in the end of the year. The remaining *terms (2,3,4)* are relative to the

K cycle. The *term 3* refers to the sum of all costs and penalty values associated with the new equipment, during its L years of service, discounted to the instant of time K.

The *term 2* and *term 4* represent the replacement costs of the old and the new equipment, respectively. The purchase cost of each equipment is subtracted to the resale value of the previous equipment. The first replacement already occurs in time instant K, and therefore it does not need to be discounted. However, since the second replacement occurs L years after the first replacement, it must be discounted to time instant K by L years, as represented in the *term 4*.

Notice that the purchase value for the second replacement and first replacement is the same and equal to R_n. Estimating the price of a new, technologically advanced medical device, over such a long period of time would be a highly speculative exercise. Therefore, this is not attempted, and it is assumed that the purchase cost R_n is the same for both replacements.

Equation (16) is no more than the Net Present Value (*NPV*) of all cash flows (accounting for a cost associated to penalty) incurred by the equipment during a $(K + L)$ period. The purpose is to minimize these costs relative to $(K + L)$. Obviously, larger periods of time will originate a higher total discounted cost. Consequently it is not valid to compare total discounted costs for different periods of time, and becomes necessary to establish an equivalent measure for these analyses. This can be accomplished by converting the *NPV* of each (K, L) pair combination into an annuity trough the Capital Recovery Factor described in expression (5). Since the analysis is based on the costs, the annuity will be designated as Equivalent Annual Cost and the criteria function becomes equal to:

$$EAC(N; K, L) = C(N; K, L) * (A/P\,, i, K + L) \tag{17}$$

The analyses will be made for all possible replacement periods, which is, for all possible combinations of (K, L) pairs. This will generate a multitude of time horizons $(K + L)$ for the analysis. Each time horizon can be generated by several combinations of (K, L) pairs, originating the columns in Figure 6. Each of these pairs will produce a different value of present cost $C(N; K, L)$, consequently a different equivalent annual cost $EAC(N; K, L)$ will be generated. The objective is to find the (K, L) pair that minimizes $EAC(N; K, L)$.

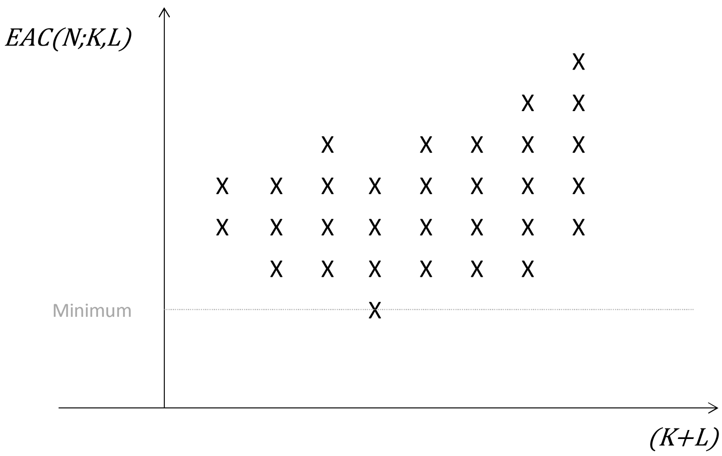

Figure 6. Graphical determination of the optimum (K,L) pair (Christer & Scarf, 1994).

4.1.2 Penalty Measure

The penalty cost associated with the equipment failure was modeled as a function of the item downtime. A collection of data was made, relative to the three Linear Accelerators in service in the Radiotherapy Department of HSM. Data regarding the number of procedures monthly performed by each device is available between June 2007 and July 2010. As Christer & Scarf (1994) described in their work, the probability of a severe failure becomes higher as the number of failures increases. As so, it is a requirement that the penalty measure increases as the equipment accumulates failures over time. It was decided that a function of downtime would the best way to describe this process. Therefore, a cumulative measure of downtime periods was established, in opposition of considering only the actual downtime incurred per month. In this way, the penalty will always grow as the total number of failures increase. The cumulative downtime up-to-date $D(i)$ was modeled as folows:

$$D(i) = D(i-1) + \frac{\sum_{j=1}^{i} T(j)}{i} \tag{18}$$

where $D(i-1)$ represents the average of cumulative downtime up to month $(i-1)$, $T(j)$ is effective downtime of the item in month j (in hours). The second term of the expression (18) represents the average downtime per month for i months of operation. The cumulative downtime $D(i)$ is obtained through an incremental process. The incremental value is not the actual downtime in the i^{th} month. Instead an average of the monthly downtime periods is employed as incremental value. This option was made in order to obtain a better data fitting, allowing for a linear fit. If the effective downtime increment was to be considered, a polynomial fit would be required. It would generate discrepant values, which wouldn't reflect the evolution of downtime in a realistic way.

In the context of the HSM Radiotherapy Department, every time an Linear Accelerator is unavailable, for whatever reason, there a is a necessity to outsource the scheduled treatments to a third party Medical Institution. This is done in order to assure, that the radiotherapy treatment is delivered, in a quality and timely fashion. Radiotherapy treatments are planed and scheduled according to the hospital delivery operational capacity. If, this plan cannot be executed, due to equipment unavailability, all the affected procedures will have to be outsourced.

The alternative would be to simply delay the treatment until equipment is operational again. In this case, all subsequent procedures would have to be postponed by the same amount of time. Consequently all the foreseeable planned procedures would be affected. Understandably, this would be an extremely hard task to put in practice, and it would ultimately result in an inefficient process. With the outsourcing solution, HSM manages to preserve the pre-planned schedule for procedures, maintaining the waiting list for the Radiotherapy department as much up-to-date as possible. Of course, this process has associated costs. Outsourcing treatments is more expensive than perform them in house. In this work, penalty cost will be associated with the extra cost incurred by outsourcing treatments due to equipment unavailability.

As said in Section 2.2, *CDTTs* represent an important source of revenues for the HSM. The hospital receives this fee as a compensation for the service provided to the patient, even when, for whatever reason, the Hospital does not have the capacity for delivering the service itself and has to outsource the procedure to a third party institution. This means that the Hospital revenues remain virtually the same. However, the outsourcing cost will be higher than the compensation value received by the hospital, which originates an economic loss, in opposition to the profit generating situation of performing the procedures in house. As so, the cost associated to one single procedure outsourced C_{out} will simply be the difference between the cost paid to a third party institution to perform it C_{ext} and the operating cost of performing that procedure in house C_{int}, as expressed by

$$C_{out} = C_{ext} - C_{int} \tag{19}$$

Where $\mathrm{C_{ext}}$ is the external cost paid by HSM to a third party institution to perform one procedure, $\mathrm{C_{int}}$ is the internal cost incurred by HSM to perform one procedure domestically. Since downtime is expressed in hours, it is convenient to express outsourcing costs on a hourly basis instead of considering unitary values. For these reason, all the costs represented in expression (19) shall be referred as costs per hour. Also, since the downtime measure is established in months, and the objective is to determine the penalty incurred per year, the measure shall be made from 12 to 12 months. The penalty process can now be modulated as the total cost associated with equipment downtime and it can be obtained by multiplying the total downtime up to date by the cost incurred by one hour of downtime, as expressed by

$$p_n(i) = D_n(12i) \cdot C_{out} \tag{20}$$

Where $p_n(i)$ is the n^{th} penalty cost profile incurred in year i and C_{out} is the outsourcing cost of a service during one hour of equipment unavailability.

4.1.3 Discount Factor

In order to consider for the time value of money principle, it is necessary to discount future cash flows to account for inflation and risk. Determine an appropriate interest rate to do so, is one of the key features of project evaluation. That rate is referred as the cost of capital, and the approach to determine it varies widely across different organizations and business fields. The cost of capital is composed by the costs of the various types of financing that a company or institution uses for its long-term capital investments (Cassimatis, 1988).

From an investor point of view, it is the minimum return rate required by the investor to finance a capital budgeting project, and reflects the investor's expectations about risk, future inflation and preference for liquidity. Preference for liquidity can be defined as the preference of the investor in maintaining the capital available in case a more attractive investment becomes available (Kierulff, 2007). As so, a capital budgeting project comes with an opportunity cost. The opportunity to invest in an alternative project, which is lost. The option to replace an equipment this year comes with an opportunity cost of maintaining the existing equipment for an additional year plus the loss of return that would be obtained if the required initial investment was applied in a secure financial application, such as treasury bonds. Despite of being an important consideration in the decision-making process, the opportunity cost is not treated as an actual cost in the financial analyses (Horngren & Foster, 1999).

There are several ways of financing available for an institution, being the most common equity and debt. The cost of capital will be the weighted average cost of each one of these sources of financing, and is designated as *Weighted Average Cost of Capital (WACC)* (Padrão, 2007).

Weighted Average Cost of Capital (WACC)

WACC is defined as the calculation of an organization's cost of capital in which each category of capital is proportionately weighted (Brealey & Myers, 1984). As so the weights to be used in this calculation should reflect realistically the proportions of the sources of funds the organization intends to use (Cassimatis, 1988). The *WACC* can be calculated using the following expression:

$$WACC = \frac{E}{A} \cdot i_e + \frac{D}{A} \cdot i_d(1 - T) \tag{21}$$

Where:

i_e	Cost of equity;
i_d	Cost of debt;
E	Market value of the institution's equity;
D	Market value of the institution's debt;
$A = E + D$	Total liabilities and equity of the institution. Equivalent to the institution's total Assets;

E/A	Percentage of financing that is equity;
D/A	Percentage of financing that is debt;
T	Tax rate applied to the institution.

Since HSM is not a publicly traded company there is no market information about the hospital's sources of capital. As so, the best estimates available for these values were considered to be the ones in the HSM balance sheet. The values of debt and equity and its correspondent proportions in the HSM's capital structure can be found in the condensed version balance sheet represented in Attachment 3. The cost of debt i_d is the effective rate of interest the HSM has to pay on new debt issues (Cassimatis, 1988). Since interest expense is tax-deductible, the second term in the WACC expression is corrected by $(1-T)$, and so i_d represents the before-tax cost of debt and $i_d(1-T)$ refers to the after-tax cost of debt.

Calculating the cost of equity is a considerably more complex task, and several approaches are used by companies to determine it. The most widely used method in business firms is the *Capital Asset Pricing Model (CAPM)(Padrão, 2007)*. This model specifies the relationship between the expected rate of return and the market risk of the firm's stock (Brealey & Myers, 1984), and is expressed as

$$i_e = i_f + \beta(R_m - i_f) \qquad (22)$$

where i_f is the risk-free rate of return available to investors, R_m is the average return of stocks in the market, represented by a stock index, and β is the stock's measure of market risk, working as an historical measure of stock volatility when compared to the evolution of the market index. Expression (22) translates the investor's return expectation for holding an asset equivalent to a riskless asset plus a premium for risk. The premium reflects the amount of compensation the investor wants for assuming additional risk on the asset ownership (Brealey & Myers, 1984).

The *CAPM* is an useful tool for business firm's to determine their cost of equity, but it is mainly based on the behavior of traded securities in the stock market. Even for companies not publicly traded the *CAPM* can be used considering β values of traded companies in the same business segment, such as competitors, clients or even suppliers (Padrão, 2007). However, the HSM is not a publicly traded company and is entirely financed by public funds, as so, financial information about a suitable private health institution will be used.

4.1.4 Real Values vs. Nominal Values

On cash flows forecasting, it is important to define whether nominal or real terms are being considered. The difference between this two concepts is concerned with the way inflation is considered on the estimation of future cash flows. It is recognized that prices will rise over time due to inflation. It is therefore important to take the evolution of future inflation into account when estimating the future cash flows of a project. Cash flows expressed in nominal terms account for the effect of inflation, reflecting the rising trend in prices and costs on the forecasted cash flows, which are expressed at current prices (Cassimatis, 1988). On the other hand, real values discount the nominal values to remove the effect of inflation on price changes over time. Real cash flows are expressed at constant prices, and are obtained by deflating nominal cash flows by an appropriate deflator(Cassimatis, 1988). This relation can be mathematically expressed by

$$CF_R(i) = \frac{CF_N(i)}{(1+p)^i} \tag{23}$$

where $CF_R(i)$ is the cash flow incurred in year i in constant princes (or real terms), $CF_N(i)$ is the cash flow incurred in year i in current prices (or nominal terms) and p is the average annual rate of inflation. To maintain coherency, if the cash flows are expressed in constant prices the interest rate used to discount them as to expressed in real terms. Nominal interest rates can be converted into real terms as follows:

$$i_R = \frac{1+i_N}{1+p} - 1 \tag{24}$$

where i_R is the interest rate in real terms and i_N is the interest rate in nominal terms. The current or constant price consideration determines a different estimative of future cash flows but, since the correspondent discount rate is adjusted in the same proportion the result of the discounting process will be the same. However there is an exception to this rule. Depreciation does not increase with inflation, as it is based on the initial investment cost, according to the tax laws in practice at the moment (Mills, 1996). When taxes are being considered in the analysis, depreciation will induce a positive tax effect over cash flows forecasts, by reducing taxes over earnings. Therefore, under taxes considerations, current prices and constant prices analysis will generate different results. On the other hand, if tax effects can be neglected, the option between these two considerations becomes irrelevant when calculating the total expected discounted cost $C(N;K,L)$ expressed in equation (16). In practice, however, it is neither convenient nor advantageous to use constant prices in cash flow analyses (Cassimatis, 1988). Hence, all the cash flows presented in this work will be expressed in nominal terms, which is, considering current prices. Consequently the interest rate obtained with the WACC calculation for HSM will also be in nominal terms. This means that the determined interest rate will have component for inflation embedded in it. The inflation rate to be used, was settled in 3.2%, accordingly with the *Harmonized Index of Consumer Prices,* determined by Banco de Portugal for the spring 2012.

4.1.5 Residual Value

Since no data was available regarding the residual value S mentioned in expression (16), an appropriate measure had to be established to determine this parameter. The residual value S is directly correlated with the commercial market value MV of the equipment. In fact, residual value and market value are the same if taxes can be neglected. However, if taxes are to be considered in the analyses this is no longer true, and calculations have to be made in order to determine the resale value S as a function of the market value MV. The purpose is therefore to model the market value parameter MV. A measure was created assuming that the commercial market value of a medical equipment in service will decrease exponentially over time, until it reaches a minimum value after which remains unchanged. It was assumed that the initial value was the items purchase cost, in time instant zero, and the minimum value reached after 10 years of service.

The 2010 deal for the replacement of two Linear Accelerators in HSM provided valuable information for the calculation of the residual value. The provider of the new items was Philips, which paid to the Hospital 280,000€ to remove two of the exiting equipments, specifically, Mevatron and Varian. For this reason, it is reasonable to assume that the minimum value for large medical devices such as the Linear Accelerator, will be no less than 140,000€ per item. Taking into consideration the acquisition cost of two new Linear Accelerator, budgeted in 3,312,636.60€ per item, and assuming an exponential depreciation, it is possible to determine a function, connecting the two values, that describes the evolution of the market value MV over time, as presented next

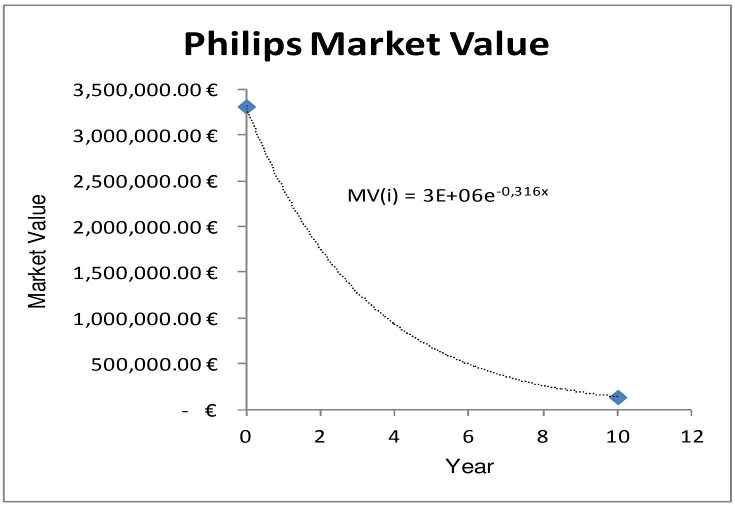

Figure 7. Graphical estimation of the evolution of market value *MV.*

The exponential equation to model the market value MV can be expressed by

$$MV(i) = R_n e^{-0.316i} \tag{25}$$

where $MV(i)$ is the market value of an equipment i years old and R_n is the equipment purchase price.

However, modeling the residual value as the market value can prove to be a limited approach to the problem. Taxes can in fact influence the replacement decision, and therefore neglecting them is removing accuracy form the analyses. In Section 5.1.4., an analyses will be made to what extent taxes can determine a different decision for replacement.

Taxes will incur over earnings, that occur when an asset is sold by a higher price than its book value. This means that when the replacement is being considered, if the current market value is superior to the book value, the replacement operation will generate an earning over which taxes will be in order. The cost associated with taxes will reduce the positive impact of selling the existing equipment, over cash flows The influence of taxes in the residual value S can be mathematically described by the following expression

$$S(i) = MV(i) - [MV(i) - BV(i)]t \tag{26}$$

where $S(i)$ will be actual value received by the Hospital after taxes, considering that the sell is made in year i, $MV(i)$ is commercial market value at which the equipment is sold, $BV(i)$ is the equipment book value, and t is the tax rate incurred over profits at which the HSM is subjected. The tax rate t is determined in the *IRC* (Imposto sobre Pessoas Colectivas) code for the year 2011, settled in 25%. The depreciation rate used to amortize the book value of an hospital asset, is also determined in the IRC table, and is established in 33.33%. This means that by the end of the third year in service, the book value of a medical equipment in HSM is zero.

4.2 Real Options Model

Switching options provide the opportunity to switch between two alternatives by paying a predetermined price for the switch. The Real Options model proposed in this section will be based on the method outlined by Copeland & Antikarov (2001) to evaluate switching options. As described by the authors, switching options are intended to evaluate projects where there is the possibility of choosing between two concurrent alternatives (for example, choosing between two modes of operation in a factory or choosing between exit and reenter a market or choosing between two different technologies). The choice between alternatives can be motivated by the price of a determined resource or the evolution of the market conditions.

The purpose is to apply switching options concepts to the medical equipment replacement problem. To convert a switching option in a replacement option, some changes has to be introduced in the model proposed by Copeland & Antikarov (2001). The replacement option can be modeled as an one time switching option. In this way, the option to switch can only be exercised once, with no turning back, even if the economic conjecture changes. The option to switch is dynamic and allows to jump back and forward between alternatives. A replacement decision has an irreversible nature. After replaced the equipment is scraped, no longer is available to come back to service.

In a deterministic world, where all future cash flows are known and switching costs are zero, the optimum policy will be to switch between alternatives in accordance with profits. The choice will fall over the alternative with the highest revenue margin. With uncertainty and switching costs this might not be true. The asset switch should only the take place when the value of expected costs is superior to the costs of the alternative in addition to the switching cost. This means that the optimum policy can be to stay in the current situation, assuming losses, as long as that losses don't motivate the investment required to switch (Copeland & Antikarov, 2001). Thus, the objective is to find the first switching point on the binomial tree. This point will provide the first time the replacement becomes advisable and will constitute a local optimum replacement point.

The document assumed that total costs associated with the medical equipment will follow a *Geometric Brownian Motion* (as described in section 3.4.3.). At each stage the cash flows can move up by u or down by d, according with the following expressions: $u = e^{\sigma}$ and $d = 1/u$ where σ represents the volatility of a specific type of costs. The different nature of costs associated with medical devices cause discrepancies of volatility between them. As so, the operating and maintenance costs were modulated separately from the penalty cost. Therefore, two binomial trees will be constructed to each equipment, two for the equipment in activity (defender) and two for the replacing equipment (challenger). The objective is obtaining a more precise representation of the two different costs. For each equipment, node to node, the values of these two trees are summed into a total cost tree. The resulting total costs trees represent all the equipment's possible future cash flows within a predefined time horizon. The Binomial Model requires an appropriate horizon of time that represents the maturity of the option. To determine such time horizon, first, the model stipulates the economic life of the new equipment as if it was introduced today. Second, compares the performance of the defender against the challenger during that period.

The Economic Life, as defined in section 3.1, can be determined by calculating the minimum Equivalent Uniform Annual Cost ($EUAC$) for the equipment's life cycle. This process consists on calculating the EAC for all the possible service time horizons the equipment may have. As described in section 3.2.3., the capital recovery cost becomes smaller as the perspective period of time in service becomes wider. In opposition, due to the inflation, overall operation and maintenance costs will rise over time. As so, the $EUAC$ curve, that results from the combination of these two factors, will eventually meet an inflexion point that will correspond the equipment's Economic Life. In other words this will be the optimum retirement time. Notice that optimal retirement time is not necessarily the optimum replacement time. A replacement procedure has to take into consideration other factors such as the acquisition costs of the new item and the corresponding maintenance and operation costs during its expected service life.

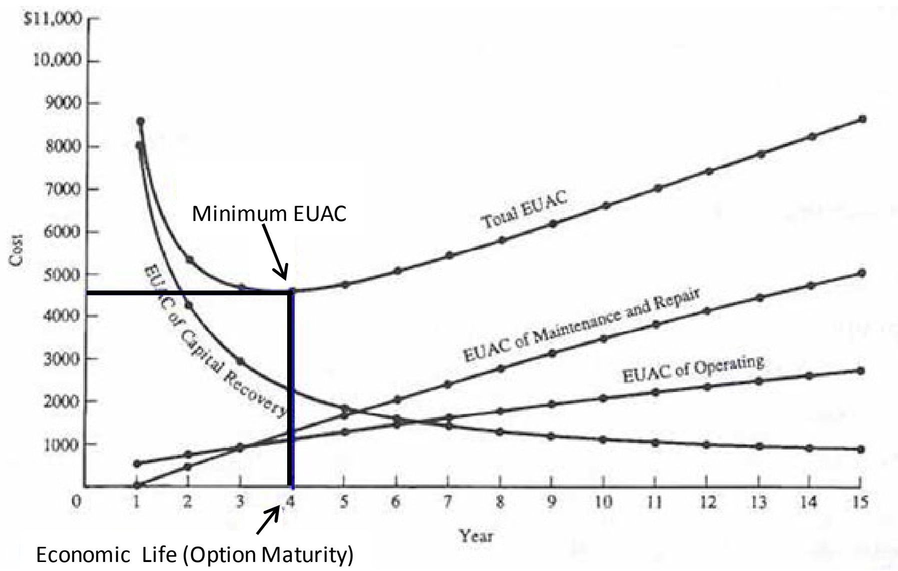

Figure 8. Graphical determination of the Economic Life (Option Maturity) (Oliveira, 2011).

4.2.1 Binomial Model

Once determined the challenger's economic life, the time horizon can be settled for the Real Options analysis. The analysis with switching option consists on elaborating two binary trees to calculate the present cost value of each alternative. This process follows the principles outlined in section 3.4.3 with some changes as departing from an initial Cash Flows tree. Considering an initial cash flow CF, Figure 9. describes the range of possible future cost flows , according with the different types of costs volatilities. At each step, the cash flows can go up (u) or down (d), as described by

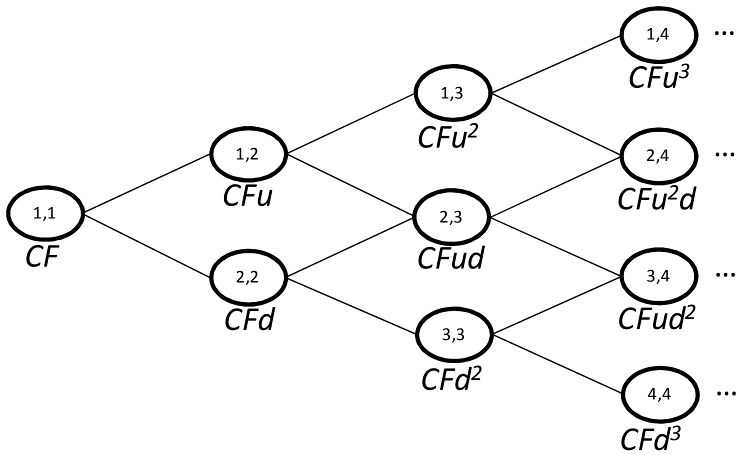

Figure 9. Binomial Cash Flow's tree.

It is now possible to discount the expected cash flows along the event tree of each type of cost to determine the corresponding present value of costs for the defender:

$$PVd_{i,j} = \frac{\left[PVd_{i,j+1}p + PVd_{i+1,j+1}(1-p)\right]}{(1+WACC)} + FCF_{i,j} \quad (26)$$

Where $PVd_{i,j}$ represents the present value of costs associated with the defender equipment at specific stage i,j and $FCF_{i,j}$ corresponds to free cash flow from operations at each stage of the fold back process. This free cash flow is composed by operation and maintenance costs plus the penalty costs incurred in stage i,j. This process is represented in Figure 10.

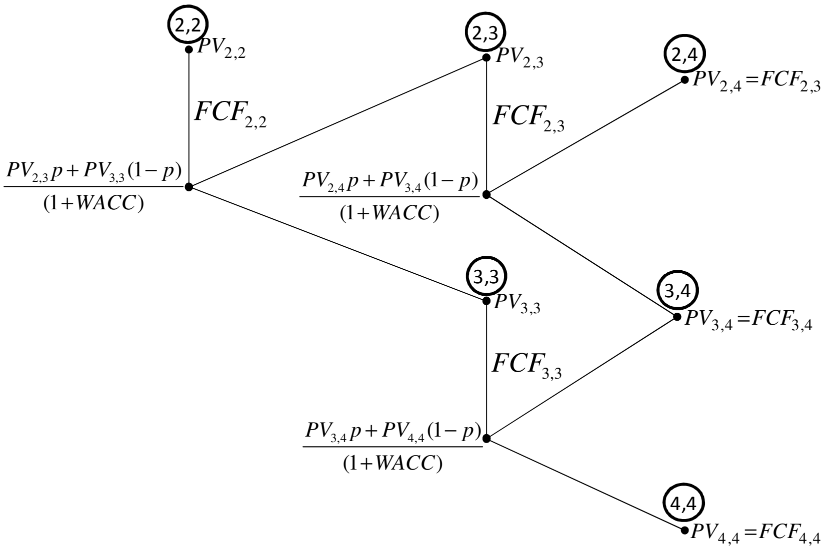

Figure 10. Fold back process to calculate the defender's PV tree.

Two distinct methods will be used to compute the present value of the equipment costs. The defender's present cost will be calculated using the risk neutral approach, as described in Figure 10., while the challenger's present cost will be constructed from a replicating portfolio. It will be constituted of m units of the underlying asset, constituted by the defender's cost flows, and B units of the risk-free bonds, which represent an adjustment measure to discount the defender's cash flows:

$$m = \frac{PVc_{i,j+1} - PVc_{i+1,j+1}}{PVd_{i,j+1} - PVd_{i+1,j+1}} \tag{27}$$

$$B_{i,j} = \frac{PVc_{i,j+1} - mPVd_{i+1,j+1}}{1 + r_f} \tag{28}$$

At each stage, the present value of costs for the challenger equipment will be given by

$$PVc_{i,j} = mPVd_{i+1,j+1} + B + FCFc_{i,j} \tag{29}$$

This information already allow for an informed decision based on an Net Present Value analyses. According with expression $PVd_{1,1} > PVc_{1,1} + Rn$, if the defender PV of costs is higher that PV of costs for the challenger plus the cost of switching between alternatives, the replacement shall be made immediately.

Departing from the PV trees it is also possible to perform an analysis that accounts with the flexibility of switching the equipment at any time. Since it is known that in the initial state the defender equipment in service, it is only needed to construct a flexible tree for the defender. A flexible tree for the challenger would represent the switch back from the new to the old equipment, which in this particular case does not make sense (in a traditional switching option analysis there would be the possibility of switch back and forward several times between alternatives).

The fold back process, based on the methodology described in section 3.4.3, starts at the end nodes of the decision tree, where the following condition applies:

$$if\ PVd > PVc + Rn \Rightarrow Switch\ to\ New\ Equipment \tag{30}$$

And so, the end-of-period states of the tree are represented by $S = MIN(PVd, PVc + Rn)$. After identified the optimal values for the end nodes, we successively move backwards until the root of the tree is reached. The present value of cost with flexibility is calculated at each node to determine whether is preferable to remain in the present state or to switch to the challenger alternative. At each node the decision will be given by the following expression:

$$PV^f d_{i,j} = \frac{PV^f d_{i,j+1} p + PV^f d_{i+1,j+1}(1-p)}{(1+WACC)} + FCFd_{i,j} \tag{31}$$

Expression (31) allows to determine the PV tree with the flexibility to switch in the end-of-period, or the so called maturity of the option. This represents an European Option. To consider the flexibility to switch at any given time during the analyses it is necessary to test the switching condition in all the nodes. This modeling is analogous to an American Option and can be obtained by $S_{i,j} = MIN(PV^f d_{i,j}, PVc_{i,j} + Rn)$. This way it is possible to obtain a real options valuation of the replacement problem, that provides not only a correct valuation of the project with flexibility, but also an optimal contingent plan for executing the option. An example of such plan is represented in Figure 11.

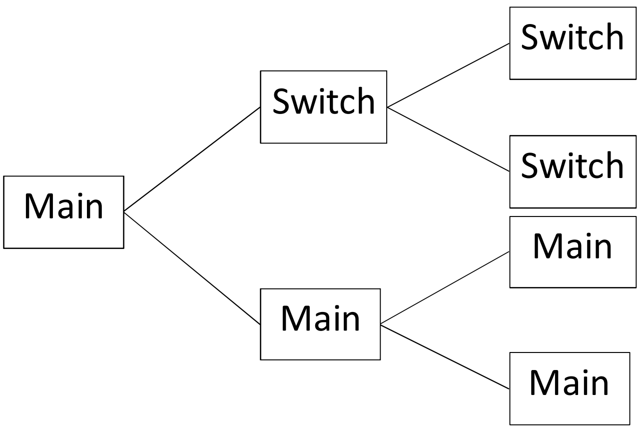

Figure 11. Optimal execution plan of a replacement option.

5 Application and Results of the Models

In this section an application of the models described in the previous section will be made. In the first part, the chapter will determine the optimum replacement cycle for the existing equipment and its successor using the deterministic model. In the second part, a Real Options application will be made. It will be highlighted the building procedures for the cash flows tree and the fold back procedure to get the Present Value with flexibility.

The two models proposed were applied in the Hospital de Santa Maria equipment replacement context. The equipments selected for the study are the three Linear Accelerators currently in operation at the Department of Radiotherapy. It's constituted by one Siemens Oncor and two Philips Elekta Synergy models. The first equipment is in operation for five years. The Philips models have begun their activity in 2011. So, they are one year old.

The procedures will be put into practice to determine the optimum replacement time for each of the two different Linear Accelerators models currently in service in HSM. Siemens Oncor and Philips Elekta will be the defender alternatives in this study. Since the Philips Elekta is a recent model, it can be considered the more technologically advanced option available in the market at the moment. So, it will act also as a challenger for the two defender alternatives. Therefore, in the case of the Philips equipment replacement, a like-by-like procedure will be done.

5.1 Deterministic Model

The Deterministic Model will be implemented according with the methodology outlined in section 4.1., beginning with the definition of the models input parameters. The first input to be determined is the penalty cost, according to section 4.1.2. Then, the determination of an appropriate WACC value to describe the HSM cost of capital will be attempted. This will allow to determine the model discount factor r according to section 4.1.3. The last input consists on the description of the Residual Value over the years, as established in section 4.1.5. Finally, an analysis of the obtained results is presented.

5.1.1 Penalty Cost Estimation

The first step for the penalty cost estimation is to determine a function that describes the equipment downtime evolution over time. Data regarding the downtime periods for each item is available in Attachment 4. A collection of monthly downtime periods for the three Linear Accelerators is presented in the following table:

Table 7. Effective monthly downtime periods during the year of 2009 (hours).

Equipment	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09	TOTAL
AL1 - CLINAC (VARIAN)	12.5	0.5	40.5	28.0	19.0	35.1	12.2	9.7	18.0	49.0	0.0	0.0	224.5
AL2 -Mevatron (Siemens)	16.1	3.9	55.4	42.8	14.6	40.4	33.6	11.0	16.3	3.0	0.0	0.0	237.1
AL3 - ONCOR (SIEMENS)	69.0	25.0	5.2	29.7	28.7	16.2	15.2	2.5	21.4	38.9	77.2	24.8	353.8

Making use of expression (18) it is possible to calculate cumulative downtime (in hours) over the year 2009, as represented in Table 8.

Table 8. Monthly cumulative downtime during the year 2009 (hours)

Equipment	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09
AL1 - CLINAC (VARIAN)	12.5	13	53.5	81.5	100.5	135.6	147.8	157.5	175.5	224.5	224.5	224.5
AL2 -Mevatron (Siemens)	16.1	20	75.4	118.2	132.8	173.2	206.8	217.8	234.1	237.1	237.1	237.1
AL3 - ONCOR (SIEMENS)	69	94	99.2	128.9	157.6	173.8	189	191.5	212.9	251.8	329	353.8

Representing graphically the data above, it is possible to define three distinct downtime profiles functions. They are used to extrapolate the evolution of downtime over the complete equipment economic life. These three profiles and respective linear regressions are represented in Figure 12.

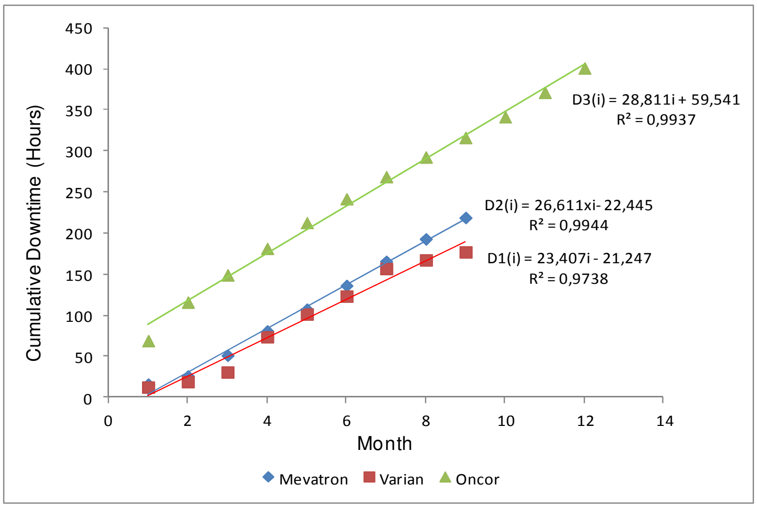

Figure 12. Downtime profiles for the three Linear Accelerators (2009).

The three functions representative of the three downtime profiles can be expressed as:

$$Profile\ 1: \qquad D_1(i) = 23.407i - 21.247 \qquad (32)$$

$$Profile\ 2: \qquad D_2(i) = 26.611i - 22.445 \qquad (33)$$

$$Profile\ 3: \qquad D_3(i) = 28.811i - 59.541 \qquad (34)$$

Being $D_1(i)$, $D_2(i)$, and $D_3(i)$ the downtime profiles up to month i of operation relatives to *Mevatron*, *Varian* and *Oncor* Linear Accelerators respectively. Since *Mevatron* and *Varian* were withdrawn in October 2009, there are only 9 data points available to perform the regression of their downtime profile.

The three profiles will be used to model the penalty process for the different equipments. A sensitivity analyses will be made to determine which one of them is more suited for the equipment analysis conducted in this work. After established a measure for the downtime it is necessary to determine the cost associated with that measure. Considering the operating costs of the Radiotherapy Department discriminated in Attachment 5. it is possible to determine a global operating cost of 1,599,207.00€, mainly attributable to the activity of the three Linear Accelerators in this service. Assuming a similar usage between these equipments, an average operating cost of 533,069.00€ can be attributed to each one of them. According to Attachment 6., a total of 34,641 treatments have been performed in the HSM Radiotherapy Department during the year of 2009. This represents a unitary cost per treatment of 46.17€. According with the data obtained from the HSM accounting department, the external cost C_{ext} is 102.00€. Applying expression (19) it is possible to establish the effective outsourcing cost C_{out} for the HSM in 55.83€ per procedure. It is now necessary to determine the number of procedures that are actually lost during an hour of equipment downtime. From the data available in Attachment 4. it is possible to estimate an average number of 3.59 procedures per hour of effective labor. This represents a cost of 200.56€ per hour of equipment unavailability. From this value it is possible to describe the Penalty Cost for the three Downtime Profiles established above. These values are represented in Table 9. for a ten year window.

Table 9. Penalty Cost profiles for a 10 year period (euros).

Penalty Cost	1	2	3	4	5	6	7	8	9	10
Profile 1 - Varian	53,740	115,458	181,071	250,765	324,734	403,181	486,315	574,357	667,536	766,090
Profile 2 -Mevatron	61,450	131,628	206,234	285,480	369,586	458,783	553,310	653,418	759,365	871,424
Profile 3 - Oncor	84,058	160,778	242,321	328,919	420,811	518,247	621,488	730,806	846,484	968,817

5.1.2 WACC Calculation

Considering the theoretical assumptions in section 4.1.3 and the data obtained from the financial report, presented in Attachment 3., it is possible to determine the $WACC$ for HSM. The capital structure gives an equity percentage E/A equal to 48% and a debt percentage D/A equal to 52%. The cost of debt should be estimated from the average interest rate paid by the Hospital on its current banking loans, according with the data from the financial report exhibited in Attachment 7. However the values in this statement are relative to a loan obtained through the FASP (Fundo de Apoio ao Sistema de Pagamentos do Serviço Nacional de Saúde), a fund created by the Portuguese Government to help Health Institutions financing with lower interest rates, by subscribing a participation in the fund. This was a punctual operation resulting from a special law background. Therefore, this kind of finance shall not be seen as an effective financing solution for HSM and so these values cannot be used to calculate the HSM cost of debt. In the absence of market relative information in the HSM financial report, it was decided to use to the best available approximation. Hence, it was decided to use the financial data from José de Mello Saúde, presented in Table 10. José de Mello Saúde is a private company specialized in hospital administration, that is responsible for the management of several Health Institutions within Portugal and Spain. It is one of the branches of a larger investment group, Grupo José de Mello, which is a publicly traded company and has investments in several business areas. In this way it was possible to use actual market data to calculate the WACC parameters, which was found to be a more adequate solution.

Table 10. Relevant financial from José de Mello Saúde balance Sheet. Calculation of the cost of debt and cost of equity (Values in euros).

Assets	2010	2009
Equity Capital (E)	38,404,962	32,155,884
Net Income	4,156,725	2,156,140
Return on Equity	10.82%	6.71%
Dividends (D)	2,568,912	2,887,292
Cost of Equity (i_e): (D)/(E)	6.69%	8.98%
Noncurrent Liabilities	2010	2009
Loans	98,120,213	87,775,012
Leases	16,972,285	14,525,631
Current Liabilities		
Loans	57,139,104	66,054,150
Leases	6,631,881	5,790,658
Total (L)	178,863,483	174,145,451
Interest Expenses (I)	8,796,698	9,090,724
Cost of Debt (i_d): (I)/(L)	4.92%	5.22%

The current economic conjecture is being dominated by high uncertainty about the future and an increase in the interest rates demanded to public institutions. As a result, the 2009 values are more appropriate to describe such economic environment and therefore they were selected for the WACC calculation. This way the cost of debt can be settled in $i_d = 5.22\%$ and the cost of equity can be settled in $i_e = 8.98\%$. Computing the values one obtain

$$WACC = 0.48 \cdot 0.0898 + 0.52 \cdot 0.0522(1 - 0.25) = 0.0635$$

This value can now be used to obtain the discount factor r expressed in equation (16) Consequently the discount factor used in this work to discount future cash flows will be of 0.94.

5.1.3 Residual Value

Considering the process specified in section 4.1.5., it is possible to determine the equations to estimate the market value of the equipments being considered for replacement:

Table 11. Acquisition cost and Market Value MV estimate functions (i in years).

Manufacturer/Model	Acquisition Cost	Market Value Function (Euros)
Philips Elekta Synergy	3,312,636€	$\mathrm{MV(i)} = 3{,}312{,}636\mathrm{e}^{-0.316\mathrm{i}}$
Siemens Oncor	2,000,000€	$\mathrm{MV(i)} = 2{,}000{,}000\mathrm{e}^{-0.362\mathrm{i}}$

Making use of the expressions contained in the third column of the above table, it is possible to describe the market value over the variable period of the item life cycle. The evolution of the Market Value and the calculations of the Residual Values for each equipment, are presented in Table 12. and Table 13. When the replacement occurs in year i, the Residual Value $S(i)$ is obtained after considering the tax effect over the Market Value $MV(i)$, obtained by the Hospital as a revenue.

Table 12. Residual Value for Oncor Linear Accelerator during 10 years (euros).

Year (i)	0	1	2	3	4	5	6	7	8	9	10
Aquisition Cost	2,000,000	0	0	0	0	0	0	0	0	0	0
MV(i)	0	1,581,930	1,251,252	989,697	782,816	619,180	489,750	387,375	306,400	242,352	191,692
Depreciation (33%)	0	666,667	666,667	666,667	0	0	0	0	0	0	0
Book Value	2,000,000	1,333,333	666,667	0	0	0	0	0	0	0	0
Tax (25%)	0	62,149	146,146	247,424	195,704	154,795	122,437	96,844	76,600	60,588	47,923
S(i)	0	1,519,781	1,105,106	742,272	587,112	464,385	367,312	290,531	229,800	181,764	143,769

Table 13. Residual Value for Philips Linear Accelerator during 10 years (euros).

Year (i)	0	1	2	3	4	5	6	7	8	9	10
Acquisition Cost	3,312,637	0	0	0	0	0	0	0	0	0	0
MV(i)	0	2,492,393	1,875,250	1,410,918	1,061,560	798,706	600,938	452,139	340,185	255,951	192,575
Depreciation (33%)	0	1,104,212	1,104,212	1,104,212	0	0	0	0	0	0	0
Book Value	3,312,637	2,208,424	1,104,212	0	0	0	0	0	0	0	0
Tax (25%)	0	70,992	192,759	352,729	265,390	199,677	150,234	113,035	85,046	63,988	48,144
S(i)	0	2,421,400	1,682,490	1,058,188	796,170	599,030	450,703	339,104	255,139	191,964	144,431

5.1.4 Analysis of Results

Once determined the parameters, it is now possible to apply the deterministic model to establish an optimum replacement plan for the two Linear Accelerators models currently in activity in HSM. Calculations were made considering different combinations of penalty profiles for both defender and challenger alternatives. The purpose was to assume a wide range of possible scenarios, in which the alternatives can follow any of the three *Penalty Profiles* created in Section 5.1.1.

Despite *Penalty Profile 3* was built based on the failure pattern of Siemens Oncor, it was assumed that this equipment can follow a different pattern in the future. Also, a study was made on the impact of taxes over each of the replacement analysis, totalizing a number of 18 combinations for each equipment. The results consist on the optimum replacement time (K, L), as well as the corresponding equivalent annual cost $EAC(K, L)$ values. The results of the analysis without taxes are presented in Table 14. Since the challenger is always the same (Philips Elekta), the replacement studies for both equipments can be grouped in the same table. On the left, there are the results for Siemens Oncor, and on the right, the results for the replacement study of Philips Elekta are shown.

Table 14. Minimum Equivalent Annual Cost, retain of the Defender (K) and replacement of Challenger (L), in years.

		Defender Penalty Profile					
EAC(K,L)		Oncor			Philips		
(K,L)		1	2	3	1	2	3
Challenger Penalty Profile Philips	1	1,707,445 € (3 , 9)	1,669,106 € (1 , 10)	1,676,321 € (1 , 10)	1,467,361 € (6 , 5)	1,492,056 € (4 , 7)	1,509,539 € (4 , 7)
	2	1,689,851 € (3 , 9)	1,705,864 € (2 , 9)	1,717,896 € (1 , 10)	1,484,002 € (6 , 5)	1,506,873 € (5 , 6)	1,528,162 € (4 , 7)
	3	1,720,821 € (5 , 8)	1,743,686 € (2 , 9)	1,822,171 € (3 , 8)	1,497,264 € (6 , 5)	1,521,599 € (6 , 5)	1,547,733 € (5 , 5)

K - Number of remaining years in operation (Defender)

L - Recommended age for replacement of the Challenger

The results in Table 14. for the Oncor as a Defender exhibit values of EAC between [1,676,321€; 1,822,171€], with an weighted average value of 1,717,018€. The results for Philips exhibit EAC values between [1,467,361€; 1,577,733€], with an weighted average of 1,506,065€. Therefore, the average EAC of the Philips, as a Defender, is 12.29% lower than the average EAC obtained for the equipment Oncor. The reason for a lower average EAC value for the Philips equipment is that the Oncor has been in operation for 5 years. Consequently, it will present a higher Penalty Cost, that will determine a higher EAC.

Regarding the replacement periods results, the Oncor exhibits retaining periods for the Defender (K) between [1;5] years, with an average value of 2.33 years. The replacement periods for the Challenger (L) are between [8;10] years, with an average value of 9.11 years. The Philips replacement study results exhibit K values between [4;6] years, with an average value of 5.11, and L values ranging from [5;7] years, being the average value 5.78 years. The Oncor results present an average replacement time 54.35% lower for the Defender and 57.69% higher for the Challenger, than the Philips results. The lower average replacement value for the Oncor (as a Defender) is explained by the fact that it is in operation for 5 years when compared with the 1 year operation for the Philips. Therefore the Oncor is expected to have an earlier replacement recommendation.

Since it is an isolated case, the 5 years replacement value for the Defender in Penalty Profile combination (1,3) for the Oncor, has a small influence over the final average result of 2.33 years. This indicates that the combination of a low penalty costs for the Defender and high penalty costs for the Challenger, result in a retaining of the low cost equipment for a longer period. The 57.69% difference between the replacement timing of the Philips as a Challenger, in both studies, can demonstrate that the economic life of an equipment it is not independent on the predecessor equipment. Considering now the tax effect in the analysis, the following results are obtained:

Table 15. Replacement analysis considering taxes.

		Defender Penalty Profile					
EAC(K,L)		Oncor			Philips		
(K,L)		1	2	3	1	2	3
Challenger Penalty Profile Philips	1	1,718,894 € (3 , 9)	1,684,203 € (1 , 10)	1,694,336 € (1 , 10)	1,491,868 € (6 , 7)	1,513,296 € (5 , 7)	1,534,760 € (4 , 8)
	2	1,701,309 € (3 , 9)	1,775,690 € (3 , 9)	1,735,151 € (2 , 10)	1,503,550 € (7 , 6)	1,527,486 € (6 , 6)	1,551,572 € (5 , 7)
	3	1,729,287 € (5 , 8)	1,756,354 € (3 , 9)	1,835,967 € (3 , 8)	1,515,764 € (7 , 5)	1,543,432 € (6 , 6)	1,570,943 € (6 , 6)

K - Number of remaining years in operation (Defender)

L - Recommended age for replacement of the Challenger

Analyzing the results Table 15. it is possible to observe that the Oncor exhibit values of EAC between [1,694,336€; 1,1835,967€] with an weighted average value of 1,736,799€. The Philips results exhibit EAC values between [1,491,868€; 1,570,943€] with a weighted average of 1,528,074€, therefore 12.02% lower than the average value obtained for the Oncor replacement study. The effect of taxes over the replacement periods results originates, for the Oncor study, values for the Defender

(K) between [1;5] years, with an average value of 2.67 years, and replacement periods for the Challenger (L) between [8; 10] years, with an average value of 9.11 years. The Philips replacement study results exhibit K values between [4;7] years, with an average value of 5.78 years, and L values ranging from [5;8] years, being the average value 6.44 years. The Oncor results present an average replacement time 53.85% lower for the Defender and 41.38% higher for the Challenger, than the Philips results. To analyze the differences induced by considering taxes in the analysis, Table 16. was constructed. It highlights the percentage variation in the EAC values, and the absolute variation in the replacement periods K and L.

Table 16. Difference between results with taxes and without taxes.

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	Oncor 2	Oncor 3	Philips 1	Philips 2	Philips 3
Challenger Penalty Profile Philips	1	0.67% (0 , 0)	0.90% (0 , 0)	1.07% (0 , 0)	1.67% (0 , 2)	1.42% (1 , 0)	1.67% (0 , 1)
	2	0.68% (0 , 0)	4.09% (1 , 0)	1.00% (1 , 0)	1.32% (1 , 1)	1.37% (1 , 0)	1.53% (1 , 0)
	3	0.49% (0 , 0)	0.73% (1 , 0)	0.76% (0 , 0)	1.24% (1 , 0)	1.43% (0 , 1)	1.50% (1 , 1)

It is possible to observe a variation in the EAC values for the Oncor between [0.49%, 4.09%] with an average increase of 1.16%. The Philips results exhibit a variation between [1.24%, 1.67%] with an average increase of 1.46%. The Philips results present a 26.44% higher variation in the EAC when taxes are taken into consideration, in comparison with the variation obtained for Oncor. This means that the tax effect is more relevant on the Philips replacement study than on the Oncor one. This result is according with expectations, since the Philips, as a Defender, is still on its depreciation period. The tax effect is only felt during this period and therefore it will become more relevant for the Philips replacement. Notice that both replacement studies experience the influence of taxes in the replacement of the Challenger.

Analyzing the tax effect over the replacement periods, the Oncor exhibits a variation in the K values between [0;1] years with an average increase of 0.33 years, and a null variation in the L values. As for the Philips replacement study, a variation between [0;1] years is observed for the K values, with an average increase of 0.67 years, and variation in the L values of [0;2] years, with an average increase of 0.67 years. The Philips results present a variation in the Defender replacement time 100% higher than the results obtained for Oncor. As for the Challenger replacement time, the Philips exhibits a 0.67 years increase and the Oncor presents a null variation.

The results obtained for the variation in the replacement periods corroborates the conclusions extracted from the analysis of the variation in EAC when considering taxes. These results indicate that the tax effect is more relevant in the Philips replacement study, generating changes in the replacement periods of all the Penalty Profile combinations considered in the analysis. Again these results are explained by the fact the tax effect is felt in the Defender and Challenger replacements for the Philips replacement study, as long as it is only felt in the Challenger replacement in the Oncor replacement study.

The results highlight the sensitivity of the model as even for small changes in the EAC values produce significant changes in the replacement periods. This signifies that small changes in acquisition or maintenance contracts can become very relevant for the recommended service life of the equipment.

As a conclusion, the deterministic model proposed managed to accurately identify an optimum replacement recommendation for the two linear accelerator models in service in the Radiotherapy Department. It is reasonable to say that this model could be applied to all kinds of high budget medical devices. Since in HSM taxes are a reality, the most accurate values shall be the ones for the analysis with taxes. The model provided an average replacement horizon for the Siemens Oncor of 2.67 years and a 9.11 years replacement horizon for its substitute. The Philips Elekta recommended service life could be established in 5.44 years for the defender and in 6.44 for the Challenger.

5.2 Real Options Model

To implement the Real Options Model, according with the methodology described in section 4.2, it is necessary to the determine an appropriate time horizon for the option maturity and determine the volatilities associated with the different costs typologies. Once determined these parameters, the binomial model is constructed, following the steps outlined in section 4.2.1, and the corresponding results are analyzed.

5.2.1 Option Maturity

The first step for the Real Options analysis is to establish an appropriate maturity for the option exercise. This is accomplished by calculating the challenger's Economic Life, as presented in Attachment 8., with the corresponding graphical representation in Figure 13.

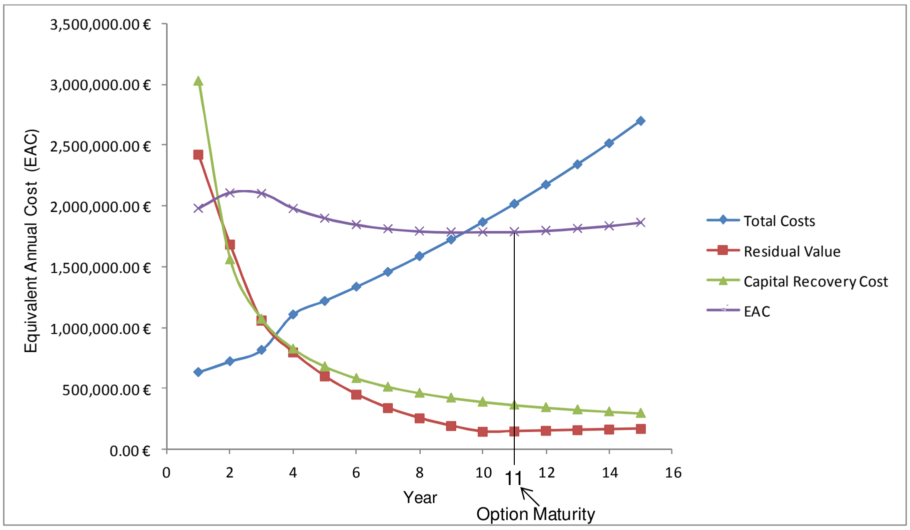

Figure 13. Graphical determination of the option maturity.

According to Figure 13. the Economic Life for Philips Elekta can be settled at 11 years. This result is slightly different from the results obtained in the deterministic model for the Philips Elekta life time, which exhibited an average replacement age of 9.11 years for Oncor replacement analysis and 6.44 years for the Philips one. This emphasizes the importance of the current equipment costs over the optimal replacement time of its successor.

5.2.2 Costs Volatility Estimation

Once determined the time horizon (maturity) for the analysis, a Monte Carlo simulation is performed to evaluate a stochastic evolution of future costs. The Monte Carlo simulation parameters are determined according with the historical data available from the HSM Radiotherapy Department. The uncertainty lies over three types of costs: Maintenance, Operating and Penalty Costs. The remaining cost sources have a pre-established or an estimated nature. So, it was considered that there was no uncertainty about their future evolution.

Costs volatility can be obtained by measuring the standard deviation of the costs growth rate over time. Considering the monthly Operating Costs data available for the year 2009 (Table 17) it is possible to determine the average growth rate. It constitutes the first input parameter of the Monte-Carlo simulation. The second input is the standard deviation and can be determined through a data fit. The data fit allowed to determine a standard deviation of 7.65% for the operating costs growth rate.

Table 17. Monthly Operating Costs (euros) and corresponding growth rates for the Radiotherapy Department.

Month	Jan-09	Fev-09	Mar-09	Abr-09	Mai-09	Jun-09	Jul-09	Ago-09	Set-09	Out-09	Nov-09	Dez-09	Total
Monthly Costs	130,030	145,815	161,796	127,951	124,133	136,062	149,902	122,646	134,589	124,791	122,999	118,492	1,599,207
% Growth Rate		12.14%	10.96%	-20.92%	-2.98%	9.61%	10.17%	-18.18%	9.74%	-7.28%	-1.44%	-3.66%	
Average Growth Rate	-0.17%												
Standard Deviation	7.65%												

Using the inputs from Table 17., the Monte Carlo simulation was employed to determine the standard deviation that will characterize the stochastic growth rate for the Operating Costs. The simulation is conducted for 10,000 iterations. Each iteration generates, according to an adequate distribution, a random growth rate value. The binomial model can assume a Normal or a log-normal distribution for the data. Since the operating costs can exhibit positive and negative variations every month, negative growth rates can be obtained. Therefore, the Normal distribution was used to run the simulation. From the simulation output presented in Figure 14., it is possible to establish a growth rate standard deviation of 7.52% per month, for the Operating Costs. The extracted standard deviation will allow to determine the up and down movements, described in expression (12) and used in the binomial tree construction.

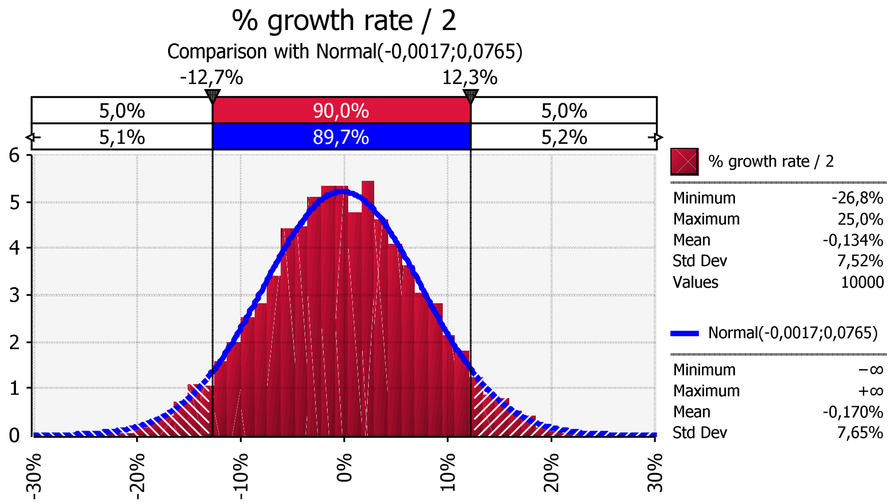

Figure 14. Simulation results for the Monthly Operating Costs. Standard Deviation = 7.52%.

Considering the available data regarding the maintenance contracts over the equipment service life, it was possible to determine the standard deviation for this cost typology. The information available refers to the maintenance contracts of the year 2009. It belongs to the three Linear Accelerators in service at time and corresponds to the adjustment incurred to the previous year contract. The contract of Mevatron raised by 2.3%, the contract of Varian raised 0.8% and the contract of Siemens Oncor remained unchanged. It was considered that a satisfactory approach to describe maintenance costs volatility would be to calculate the standard deviation of this very small sample. Therefore the maintenance costs standard deviation value used in the Cash Flows Tree construction was 0.95%.

Once determined the implicit volatilities for both maintenance and operating costs it was necessary to combine these volatilities to build a single Cash Flows Tree.[1] In order to determine the

[1] This can be accomplished by calculating the variance associated with each variable, according to the following expression:

$$var(m+c) = var(m) + var(c) + 2cov(m,c)$$

being m and c variables representing the maintenance and operating costs respectively. Since there is no correlation between these two types of costs the covariance between variables will be zero. Therefore, considering the relation between variance and standard deviation, the combined standard deviation for maintenance and operating costs can determined by

$$\sigma_{m+c}{}^2 = \sigma_m{}^2 + (\sigma_c \cdot \sqrt{12})^2$$

Since σ_c is a monthly value it must be converted to an annual value. Performing the calculations it is possible to determine that $\sigma_{m+c} = 26.07\%$.

volatility associated with the Penalty Cost, a measure of the cumulative downtime growth rates is made. The Penalty Cost arises from the damages associated with a determined downtime period. Since the objective is to determine a growth rate, it becomes indifferent to perform the analysis over the downtime periods historical data or over the penalty cost calculated from it. Table 18. exhibits the effective cumulative downtime periods for each equipment, the resulting growth rates and the corresponding averages, as well as the standard deviation of each data set. Notice that the effective cumulative downtime is employed, in opposition to the averaged cumulative downtime used to determine the Penalty Cost. The averaged measure would reduce the measured volatility, mitigating its impact in the Cash Flows Tree construction.

Table 18. Historical effective cumulative downtime (hours), corresponding growth rates and standard deviations.

Equipment	Jan-09	Fev-09	Mar-09	Abr-09	Mai-09	Jun-09	Jul-09	Ago-09	Set-09	Out-09	Nov-09	Dez-09	Total (Hours) Average Growth	Standad Deviation
Profile 1 - Varian	12.5	13	53.5	81.5	100.5	135.6	147.8	157.5	175.5				877.4	
% Growth Rate		4.00%	311.54%	52.34%	23.31%	34.93%	9.00%	6.56%	11.43%				56.64%	17.80%
Profile 2 - Mevatron	16.1	20	75.4	118.2	132.8	173.2	206.8	217.8	234.1				1194.4	
% Growth Rate		24.22%	277.00%	56.76%	12.35%	30.42%	19.40%	5.32%	7.48%				54.12%	17.70%
Profile 3 - Oncor	69	94	99.2	128.9	157.6	173.8	189	191.5	212.9	251.8	329	353.8	2250.5	
% Growth Rate		36.23%	5.53%	29.94%	22.27%	10.28%	8.75%	1.32%	11.17%	18.27%	30.66%	7.54%	16.54%	6.06%

Since there are three data sets (one per equipment), the Real Options analysis was made considering each one of this profiles for the Penalty Cost Tree construction. Since a cumulative measure of downtime is being considered, there are no negative variations of monthly downtime values. Therefore, negative growth rates cannot be obtained. A log-Normal distribution represents a better fit for the Penalty Cost data. For this reason, a log-normal distribution was used to run the simulations. Considering the parameters obtained from the Penalty Costs historical data, it was possible to run the Monte Carlo simulations and determine the stochastic volatilities. The simulation results are shown in Attachment 9, Attachment 10 and Attachment 11 respectively for Varian, Mevatron and Oncor. The standard deviation values obtained for the penalty costs are monthly values. Once again it is necessary to convert these values to annual values. This conversion is presented in the following table:

Table 19. Conversion of simulated monthly standard deviations into annual values.

Standard deviation (σ)	$\sigma_{monthly}$	$\sigma_{monthly}\sqrt{T}$	σ_{annual}
Profile 1 - Varian	18.2%	$18.2\sqrt{12}$	63.05%
Profile 2 - Mevatron	17.5%	$17.5\sqrt{12}$	60.62%
Profile 3 - Oncor	6.18%	$6.18\sqrt{12}$	21.41%

5.2.3 Analysis of Results

Once obtained the standard deviation for all types of costs, it was possible to apply the Real Options model developed in this document. Analogously to the deterministic model, the Real Options analysis will be made considering the combination of all the penalty profiles for Defender and Challenger. This means that each alternative can assume any of the Penalty Cost volatilities established in Table 19. In a stochastic model, it is only necessary to determine the first value (root) of the binomial tree. The future values are randomly estimated. As so, the root values in the Penalty Cost Tree were attributed the first year cost of the corresponding Penalty Cost Profile in the deterministic model. Two separate replacement studies were performed, one for the Siemens Oncor and another for the Philips Elekta. The objective was to determine the year where the first switch occurs. As so, Oncor and Philips acted alternatively as defenders and Philips acted as the challenger in both studies.

In the following paragraphs, an example of the methodology application will be given considering the Penalty Profile combination (1,1), for the Oncor Replacement study. This description will give the steps and values used, until the final PV^f Tree is obtained. Additionally, it will be given the corresponding replacement recommendation. The results of the model for the remaining Penalty Profile combinations will be given in the form of a summary table.

The application of the Real Options model began with the construction of the Binomial Trees for each type of cost. The root of the Operating and Maintenance Costs Tree was filled with first year cash flow value recovered from the deterministic model. The starting value for the Defender corresponds to its sixth year of operation, 719,064€ (Figure 15). In the same way the starting value for the Challenger's Operating and Maintenance Costs Tree is the first year operating cost for a Linear Accelerator, which is 574,181€ (Figure 16). During the first three year of service the Philips Elekta maintenance contract cost was supported by the supplier and so, only operating costs are incurred. As the Operating and Maintenance costs volatilities remain unchanged, the corresponding Trees will be equal for all the different Penalty Profile combinations under analysis.

Year 0	1	2	3	4	5	6	7	8	9	10	11
719,064	933,228	1,211,179	1,571,915	2,040,091	2,647,708	3,436,297	4,459,758	5,788,044	7,511,945	9,749,290	12,653,001
	554,047	719,064	933,228	1,211,179	1,571,915	2,040,091	2,647,708	3,436,297	4,459,758	5,788,044	7,511,945
		426,900	554,047	719,064	933,228	1,211,179	1,571,915	2,040,091	2,647,708	3,436,297	4,459,758
			328,932	426,900	554,047	719,064	933,228	1,211,179	1,571,915	2,040,091	2,647,708
				253,446	328,932	426,900	554,047	719,064	933,228	1,211,179	1,571,915
					195,283	253,446	328,932	426,900	554,047	719,064	933,228
						150,468	195,283	253,446	328,932	426,900	554,047
							115,937	150,468	195,283	253,446	328,932
Defender Maint. And Operating Costs								89,331	115,937	150,468	195,283
u =		1.2978							68,831	89,331	115,937
d =		0.7705								53,035	68,831
Standard Deviation =		26.07%									40,864

Figure 15. Operating and Maintenance Costs Tree for the Defender (Values in euros).

Year 0	1	2	3	4	5	6	7	8	9	10	11
574,181	745,194	967,141	1,255,192	1,629,037	2,114,226	2,743,924	3,561,169	4,621,821	5,998,377	7,784,923	10,103,571
	442,413	574,181	745,194	967,141	1,255,192	1,629,037	2,114,226	2,743,924	3,561,169	4,621,821	5,998,377
		340,885	442,413	574,181	745,194	967,141	1,255,192	1,629,037	2,114,226	2,743,924	3,561,169
			262,656	340,885	442,413	574,181	745,194	967,141	1,255,192	1,629,037	2,114,226
				202,379	262,656	340,885	442,413	574,181	745,194	967,141	1,255,192
					155,936	202,379	262,656	340,885	442,413	574,181	745,194
						120,150	155,936	202,379	262,656	340,885	442,413
							92,577	120,150	155,936	202,379	262,656
Chalenger Maint. And Operating Costs								71,332	92,577	120,150	155,936
u =		1.2978							54,962	71,332	92,577
d =		0.7705								42,349	54,962
Standard Deviation =		26.07%									32,630

Figure 16. Operating and Maintenance Costs Tree for the Challenger (Values in euros).

The starting values for the Penalty Cost Trees are the values of the correspondent Penalty Profile. Thus, under the current example, the starting cash flow for the Defender Penalty Cost Tree is the sixth value of Penalty Profile 1, determined in Table 9, 403,181€ (Figure 17). Accordingly, the starting value for the Challenger Penalty Cost Tree will be the first cash flow in Penalty Profile 1, 53,740€ (Figure 18). The volatility value to be used in Defender Penalty Cost Tree , will be the one obtained from Table 19. for Penalty Profile 1 (Varian). Since the Penalty Profile combination (1,1) is being considered, the volatility used to the Challenger Penalty Cost Tree construction will be the same.

Year	0	1	2	3	4	5	6	7	8	9	10	11
	403,181	757,370	1,422,709	2,672,539	5,020,329	9,430,622	17,715,297	33,277,950	62,512,186	117,428,308	220,587,512	414,370,702
		214,631	403,181	757,370	1,422,709	2,672,539	5,020,329	9,430,622	17,715,297	33,277,950	62,512,186	117,428,308
			114,257	214,631	403,181	757,370	1,422,709	2,672,539	5,020,329	9,430,622	17,715,297	33,277,950
				60,824	114,257	214,631	403,181	757,370	1,422,709	2,672,539	5,020,329	9,430,622
					32,379	60,824	114,257	214,631	403,181	757,370	1,422,709	2,672,539
						17,237	32,379	60,824	114,257	214,631	403,181	757,370
							9,176	17,237	32,379	60,824	114,257	214,631
								4,885	9,176	17,237	32,379	60,824
Defender Penalty Cost									2,600	4,885	9,176	17,237
u =			1.8785							1,384	2,600	4,885
d =			0.5323								737	1,384
Standard Deviation =			63.05%									392

Figure 17. Defender Penalty Cost Tree considering Penalty Profile 1 (Values in euros).

Year	0	1	2	3	4	5	6	7	8	9	10	11
	53,740	100,950	189,634	356,225	669,163	1,257,014	2,361,285	4,435,642	8,332,294	15,652,103	29,402,267	55,231,767
		28,608	53,740	100,950	189,634	356,225	669,163	1,257,014	2,361,285	4,435,642	8,332,294	15,652,103
			15,229	28,608	53,740	100,950	189,634	356,225	669,163	1,257,014	2,361,285	4,435,642
				8,107	15,229	28,608	53,740	100,950	189,634	356,225	669,163	1,257,014
					4,316	8,107	15,229	28,608	53,740	100,950	189,634	356,225
						2,298	4,316	8,107	15,229	28,608	53,740	100,950
							1,223	2,298	4,316	8,107	15,229	28,608
								651	1,223	2,298	4,316	8,107
Chalenger Penalty Cost									347	651	1,223	2,298
u =			1.8785							185	347	651
d =			0.5323								98	185
Standard Deviation =			63.05%									52

Figure 18. Challenger Penalty Cost Tree considering Penalty Profile 1 (Values in euros).

Applying the steps described in Section 4.2.1.,it is possible to construct the Present Value Tree without flexibility. Figure 19. is for the Defender and Figure 20. for the Challenger. The Risk-Neutral rate of return used to construct the replicating portfolio and to calculate the Risk-Neutral probability, has to be similar to the return rate of a traded financial product considered to be a safe investment, hence without risk. Considering these requirements it was decided to take as a reference the Treasury Obligations issued by the Portuguese Government with a coupon rate of 4.95% with a maturity of 11 years, in October 2023. The fold back process for the Defender PV Tree requires a risk-neutral probability, calculated according to expression (13). For that reason it is necessary to combine the volatilities used in the Binomial Tree (footnote 1), in order to obtain a new set of u and d values according to the expression (12). Under these considerations, the analysis obtained a new value of volatility σ. This value was obtained from the combination of the volatility, 26.07%, (Figure 15) for the

Operating and Maintenance Costs and the volatility, 63.05%, for the Penalty Cost (Figure 17). The new volatility used in the fold back process of the Defender's PV Tree, was settled in 68.22%, originating a risk-neutral probability of 37.02% (Figure 19).

Year	0	1	2	3	4	5	6	7	8	9	10	11
	9,461,387	13,798,318	20,562,796	31,215,460	48,024,133	74,358,758	114,860,687	175,013,571	258,886,441	362,076,835	452,985,196	427,023,703
		5,970,204	8,357,358	11,924,900	17,312,490	25,459,891	37,646,434	55,356,293	79,618,879	108,978,757	134,143,669	124,940,253
			3,870,466	5,207,220	7,104,580	9,819,815	13,694,114	19,106,615	26,275,597	34,665,223	41,441,929	37,737,708
				2,560,833	3,318,531	4,329,243	5,676,980	7,444,568	9,650,264	12,068,965	13,778,791	12,078,330
					1,715,300	2,144,949	2,675,187	3,314,874	4,043,295	4,753,171	5,112,674	4,244,454
						1,152,914	1,391,224	1,654,891	1,922,676	2,138,358	2,166,001	1,690,598
							770,125	893,758	1,006,072	1,075,809	1,039,569	768,678
								505,468	558,923	583,801	547,365	389,756
Defender Present Value Tree									320,953	331,039	305,179	212,520
Risk-Neutral Probability=			37.02%							192,126	175,575	120,822
Risk-Free Rate Of Return=			4.95%								102,648	70,215
WACC			6.35%									41,256

Figure 19. PV Tree for the Defender considering Penalty Profile 1 (Values in euros).

Year	0	1	2	3	4	5	6	7	8	9	10	11
	10,883,288	13,752,568	17,665,383	23,070,690	30,568,786	40,882,893	54,691,528	72,131,303	91,615,637	107,450,853	106,107,892	65,335,338
		7,703,178	9,396,398	11,568,386	14,376,887	17,996,517	22,558,986	27,995,268	33,679,430	37,730,363	35,947,129	21,650,480
			5,521,692	6,529,103	7,729,737	9,153,622	10,802,737	12,596,315	14,256,671	15,096,892	13,713,462	7,996,811
				3,968,998	4,562,124	5,203,886	5,871,524	6,505,291	6,968,747	6,979,955	6,020,405	3,371,241
					2,832,121	3,166,081	3,476,361	3,721,389	3,826,873	3,662,089	3,012,343	1,611,417
						1,984,252	2,151,034	2,259,633	2,265,114	2,098,595	1,660,039	846,144
							1,346,984	1,403,759	1,388,318	1,260,094	967,245	471,021
								870,302	855,351	766,977	576,428	270,763
									522,163	465,047	344,936	158,233
										279,787	205,999	93,228
Chalenger Present Value Tree											122,721	55,147
Risk-Free Rate Of Return=			4.95%									32,683

Figure 20. PV Tree for the Challenger considering Penalty Profile 1 (Values in euros).

Figure 21. shows the Binomial Tree with flexibility, highlighting the nodes where the replacement is advisable. These occur when the Present Value of the expected future cost of Defender is higher than the equivalent Present Value of Challenger. The last one includes the cost of acquiring the Challenger equipment in that same year minus the Residual Value obtained from the sale of the Defender. Notice that the inflation effect makes the Challenger's acquisition more expensive over the years, and taxes are incurred over the Residual Value. Figure 21. permits to observe that the first replacement will occur in year 4. That means that after the fourth year a replacement shall be considered.

Year	0	1	2	3	4	5	6	7	8	9	10	11
	9,031,361	12,756,786	18,065,104	25,291,409	34,144,466	44,616,806	58,544,818	76,107,898	95,719,484	111,686,025	110,478,590	69,845,899
		5,856,321	8,066,883	11,189,722	15,468,235	20,880,669	26,412,275	31,971,863	37,783,277	41,965,535	40,317,827	26,161,041
			3,848,918	5,148,895	6,947,297	9,397,480	12,565,589	16,108,035	18,360,518	19,332,063	18,084,160	12,507,372
				2,558,734	3,312,501	4,311,922	5,627,223	7,301,642	9,239,704	10,889,623	10,391,103	7,881,802
					1,715,300	2,144,949	2,675,187	3,314,874	4,043,295	4,753,171	5,112,674	4,244,454
						1,152,914	1,391,224	1,654,891	1,922,676	2,138,358	2,166,001	1,690,598
							770,125	893,758	1,006,072	1,075,809	1,039,569	768,678
								505,468	558,923	583,801	547,365	389,756
									320,953	331,039	305,179	212,520
										192,126	175,575	120,822
Defender Present Value Tree											102,648	70,215
First Switch			Year 4									41,256

Figure 21. PV tree with flexibility, highlighting the nodes where a switch occur (Values in euros).

The same process was repeated for the remaining eight Penalty Profile combinations (Oncor) and for all Penalty Profile combinations (Philips). The results of the Real Options analysis are presented in Table 20. They show the year where the first replacement is incurred and the obtained EAC. Notice that in this analysis only the Defender's replacement occurs, and so, only one replacement value is exhibited for each combination. Penalty profile combinations (3,1) and (3,2), for the Oncor as a defender, and combinations (3,1), (3,2) and (3,3), for Philips as a defender, originated never replacement decisions. In this case, the option to switch is never exercised during the option maturity, and so, it is considered that the replacement is made for obsolescence reasons.

Table 20. EAC of the first replacement and year of first replacement.

		Defender Penalty Profile					
EAC		Oncor			Philips		
1st Switch		1	2	3	1	2	3
Challenger Penalty Profile Philips	1	9,302,044 €	11,135,000 €	2,337,448 €	9,015,740 €	10,038,283 €	1,564,124 €
		4	4	11	11	11	11
	2	5,170,518 €	10,190,001 €	2,337,448 €	14,004,214 €	8,130,217 €	1,564,124 €
		4	4	11	10	11	11
	3	6,679,318 €	6,820,918 €	2,000,139 €	5,357,573 €	8,512,226 €	1,564,124 €
		3	3	11	6	6	11

Table 20. exhibits, for Oncor (Defender), EAC values ranging between [2,000,139€; 9,302,044€] with an average value of 6,219,204€. The Philips (Defender) has EAC values between [1,564,124€;14,004,214€] with an average value of 6,638,959€, which corresponds to a value 6.75% higher than the value obtained for the Oncor replacement study.

For the year of the first replacement, the Oncor shows results between [3;11] years, being the average value 6.11 years. The Philips results exhibit replacement values between [6;11] years, with an average value of 9.78 years. The results for Oncor exhibit a first replacement average value 37.5% lower than the average value obtained for the Philips.

The Real Options Model results highlights that, as expected, low uncertainty, characterized by low volatility values, conduce to later replacements. In fact, low volatility scenarios can actually conduce to never-replace decisions. It is also possible to realize that volatility is the more relevant parameter in the analyses outcomes, as similar volatilities produce similar results even if the starting cash flows are different.

5.3 Results Comparison and Sensitivity Analysis

In this section, a comparison will be made between the results obtained for the Real Options and Deterministic models. Also, a sensitivity analyses will be made to determine the models robustness. In the deterministic model the influence of the WACC and penalty cost will be investigated. In the Real Options model the effect of the cash flows volatility over the replacement results will be verified. A 30% variation will be applied to each of these parameters and consequent changes in results will be analyzed.

5.3.1 Deterministic and Real Options Comparison

Comparing the results obtained for the for the two models in analysis, the considerable higher EAC values obtained for the Real Options Model are explained by the shorter time horizon of the analysis. The Deterministic Model exhibits an overall time horizon K+L of 2.67+9.11 = 11.78 years for the Oncor Replacement study and 5.78+6.44 = 12.22 years for the Philips one. This represents a 92.79% higher time horizon for the Deterministic Oncor Replacement study, and a 24.95% higher time horizon for the Deterministic Philips Replacement study, when compared with the time horizon values obtained for the Real Options Model. Since the number of annuities to distribute the costs is smaller for the Real Options Model it will originate higher equivalent annuities.

Regarding the replacement time results it is possible to observe a 56.30% lower value for the Defender replacement time in the Deterministic Oncor Replacement study and a 40.89% lower value for the Defender replacement time for the Deterministic Philips replacement study. The higher replacement periods exhibited by the Real Options model are explained by the fact that some Penalty Profile combinations originate late (11 years) or never replace recommendations, elevating the average replacement recommendation. Namely, Penalty Profile combination (3,3) in the Oncor replacement study and Penalty profiles combinations (1,1), (1,2), (2,1) and (2,2) in the Philips replacement study exhibit 11 years recommendations. Penalty Profile combinations (3,1), (3,2) for the Oncor and combinations with Penalty Profile 3 for the Defender in the Philips Replacement study, exhibit never replace recommendations. These values are the ones that most contribute for the increase in the average replacement time for the Real Options Model. These elevated values are explained by the fact that low volatility values for the Defender and high volatility values for the Challenger tend to delay the replacement, as the uncertainty about the Challenger future costs increases. This way it is preferable to maintain the low uncertainty equipment for longer. This is the reason why never replace recommendations only occur in the combinations with Penalty Profile 3 for the Defender, in both for Oncor and Philips.

5.3.2 Deterministic Model

Considering a 30% increase in the WACC, to 8.25%, the results change according to Table 21. when neglecting the tax effect, and according to Table 22. for the analysis with taxes. In these tables it is possible to observe the variation (%) in the EAC value and the corresponding decrease/increase in the K,L values.

Table 21. Variation in results without taxes for a 30% increase in *WACC* (8.25%).

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	2	3	Philips 1	2	3
Challenger Penalty Profile Philips	1	-0.89% (2 , 0)	-0.50% (1 , 0)	-0.42% (0 , 0)	-1.93% (1 , 0)	-1.62% (1 , 0)	-1.46% (0 , 1)
	2	-0.81% (0 , 0)	-0.60% (0 , 1)	-0.51% (0 , 0)	-1.95% (1 , 0)	-1.70% (1 , 0)	-1.48% (0 , 0)
	3	-1.15% (0 , 0)	-0.73% (1 , 0)	-0.70% (0 , 1)	-2.10% (1 , 0)	-1.82% (0 , 0)	-1.60% (0 , 1)

Analyzing the results in Table 21. it is possible to observe a variation in the EAC values for the Oncor replacement study between [-1.15%;-0.42%] with an average variation of -0.70%. The Philips results exhibit a variation between [-2.10%;-1.46%] with an average variation of -1.74%. The Oncor results present a 59.76% lower variation in the EAC when compared with the variation obtained for Philips. This results indicate that an increase in the WACC produce a reduction in the EAC values, being the reduction more relevant in the Philips Replacement study. The decrease in the EAC values in expected and is justified by the EAC calculation formula. Since the discount rate is higher, the discounted cash flows will be lower, and so the corresponding EAC value.

Considering now the effect of a 30% increase in *WACC* over the replacement periods, the Oncor exhibits a variation in the K values between [0;2] years with an average increase of 0.44 years, and a variation in the L values between [0;1] years, with an average increase of 0.22. As for the Philips replacement study, a variation between [0;1] years is observed for the K values, with an average increase of 0.56 years, and variation in the L values of [0;1] years, with an average increase of 0.22 years. The Philips results present a variation in the Defender replacement time 25% higher than the results obtained for Oncor. Both studies exhibit the same variation in the L values (+0.22 years) and therefore there is no difference in their variation. The results obtained for the variation in the replacement periods indicate that even small variations in the EAC values will generate changes in the replacement periods. It is also possible to observe that an increase in WACC produces similar changes in both replacement studies. The variation in results induced by the same increase in *WACC*, for the analysis with taxes is presented in the following table.

Table 22. Variation in results with taxes for a 30% increase in *WACC* (8.25%).

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	2	3	Philips 1	2	3
Challenger Penalty Profile Philips	1	-1.16% (2 , 0)	-0.59% (1 , 0)	-0.36% (0 , 0)	-2.08% (1 , 0)	-1.90% (1 , 0)	-1.72% (1 , 0)
	2	-0.93% (2 , 0)	-0.83% (0 , 0)	-0.62% (0 , 0)	-2.19% (0 , 0)	-1.93% (0 , 1)	-1.70% (1 , 0)
	3	-1.22% (1 , 0)	-0.79% (0 , 0)	-0.83% (0 , 1)	-2.22% (1 , 0)	-2.03% (1 , 0)	-1.86% (0 , 0)

When taxes are taken into consideration, a 30% increase in the WACC originates a variation in the EAC values for the Oncor replacement study between [-1.22%;-0.36%] with an average variation of -0.81%. The Philips results exhibit a variation between [-2.22%;-1.72%] with an average variation of -1.96%. The Oncor results present a 58.43% lower variation in the EAC when compared with the variation obtained for Philips. The variations in the results for the analysis with taxes produced by a 30% increase in the WACC, are similar to the ones obtained for the results without taxes.

The results in Table 22 regarding the variation in the replacement periods, the Oncor exhibits a variation in the K values between [0;2] years with an average increase of 0.67 years, and a variation in the L values between [0;1] years, with an average increase of 0.11 years. As for the Philips replacement study, a variation between [0;1] years is observed for the K values, with an average increase of 0.67 years, and variation in the L values of [0;1] years, with an average increase of 0.11 years. Both studies present the same variation in the K and L values, and therefore an increase in the WACC produce the same variation in results, both for Oncor and Philips replacement studies with taxes. It is so reasonable to say that if an increase in the *WACC* is observed, an increase in the optimal replacement periods is expected, with higher prevalence in the defender replacement time (K).

Considering now an opposite economical evolution, with a reduction in WACC to 4.44% the results are exhibited in table Table 23. and Table 24., without taxes and with taxes, respectively.

Table 23. Variation in results without taxes for a 30% decrease in WACC (4.44%).

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	2	3	Philips 1	2	3
Challenger Penalty Profile Philips	1	0.95% (0 , 0)	0.64% (0 , 0)	0.61% (0 , 0)	1.80% (-1 , 1)	1.58% (0 , 0)	1.51% (0 , 0)
	2	0.86% (-1 , 0)	0.70% (0 , 0)	0.53% (0 , -1)	1.90% (0 , 0)	1.68% (0 , -1)	1.44% (0 , -1)
	3	0.93% (-2 , 0)	0.73% (0 , -1)	0.69% (-1 , 0)	1.95% (0 , 0)	1.74% (-1 , 0)	1.55% (-1 , 1)

The results in Table 23. exhibit a variation in the EAC values for the Oncor replacement study between [0.53%, 0.95%] being the variation of 0.74%. The Philips results exhibit a variation between [1.44%, 1.95%] with an average variation of 1.68%. The Oncor results exhibit a 56.18% lower variation in the EAC when compared with the variation obtained for Philips. As expected, a 30% decrease in WACC produces an opposite effect to the one observed in the increase of the *WACC*.

For a 30% decrease in WACC, the replacement periods exhibit a variation in the K values, for the Oncor, between [-2;0] years with an average decrease of -0.44 years, and a variation in the L values between [-1;0] years, with an average varaition of -0.22 years. As for the Philips replacement study, a variation between [-1;0] years is observed for the K values, with an average decrease of 0.33 years, and variation in the L values of [-1;1] years, with a null average variation. The Philips results present a variation in the Defender replacement time 25% lower than the results obtained for Oncor. The Oncor presents a -0.22 years variation in the Challenger replacement time and Philips has no variation in the Challenger replacement time. The reduction the in the WACC originates a reduction in the replacement periods. However this reduction is not very significant. To analyze the effect of a decrease in WACC over the results with taxes, Table 24. is constructed.

Table 24. Variation in results with taxes for a 30% decrease in WACC (4.44%).

ΔEAC (ΔK,ΔL)		Defender Penalty Profile: Oncor 1	Oncor 2	Oncor 3	Philips 1	Philips 2	Philips 3
Challenger Penalty Profile Philips	1	0.95% (0 , 0)	0.75% (1 , 0)	0.55% (0 , 0)	2.05% (0 , -1)	1.79% (0 , 0)	1.62% (0 , 0)
	2	0.93% (0 , 0)	0.93% (0 , -1)	0.67% (0 , -1)	2.12% (-1 , 0)	1.97% (0 , 0)	1.77% (0 , 0)
	3	1.20% (0 , 0)	0.90% (-1 , 0)	0.80% (0 , 0)	2.24% (0 , 0)	2.03% (0 , 0)	1.79% (-1 , 0)

Analyzing the variation in results with taxes (Table 24.) it is possible to observe a variation in the EAC values for the Oncor replacement study between [0.55%, 1.20%] with an average variation of 0.85%. As for Philips, the results exhibit a variation between [1.62%, 2.24%] with an average variation of 1.93%. The Oncor results present a 55.82% lower variation in the EAC when compared with the variation obtained for Philips.

When taxes are being considered, the effect of a 30% decrease in WACC over the replacement periods originate a variation in the Oncor defender retaining periods between [-1;1] years with null average variation, and a variation in the L values between [-1;0] years, with an average decrease of 0.22 years. As for the Philips replacement study it is possible to observe a variation between [-1;0] years is for the K values, with an average decrease of 0.22 years, and variation in the L values of [-1;0] years, with an average decrease of 0.11 years. The Philips results present a variation of -0.22 years in the Defender replacement time as the Oncor exhibits a null variation. The Oncor presents a 100% higher variation for the Challenger replacement time when compared to the Philips replacement study.

As expected a 30% decrease in the *WACC* induces an opposite effect over the analysis results when compared to the one created by a 30% increase in *WACC*. When the *WACC* decreases the replacement periods K and L tend to decrease. These results indicate that an economic scenarios characterized by low interest rates and low risk, accelerates the replacement. However this effect is not very significant, indicating that the WACC parameter has a little influence in the model. Analyzing the results of the WACC variation it is also possible to observe that positive variations in the WACC have higher impact, over the Model results, than negative ones.

A study will now be conducted on the effect of the Penalty Factor over the replacement results. The Penalty Cost, for the three profiles determined in Table 9. with a 30% increase would become:

Table 25. Penalty Cost profiles with a 30% increase, for a 10 year period.

Penalty Cost	1	2	3	4	5	6	7	8	9	10
Profile 1	69,862	150,096	235,393	325,995	422,155	524,135	632,209	746,664	867,796	995,917
Profile 2	79,885	171,116	268,104	371,124	480,462	596,418	719,304	849,443	987,174	1,132,851
Profile 3	109,276	209,011	315,018	427,595	547,054	673,721	807,935	950,048	1,100,429	1,259,462

Considering the values of Table 25, the results representing the variation in the EAC and replacement values K,L, for the analysis without taxes is presented in Table 26.

Table 26. Variation in results without taxes for a 30% increase in Penalty Cost.

		Defender Penalty Profile					
ΔEAC		Oncor			Philips		
(ΔK,ΔL)		1	2	3	1	2	3
Challenger Penalty Profile Philips	1	7.01% (-1 , -1)	6.17% (1 , -1)	6.32% (0 , -1)	4.44% (-1 , 0)	4.68% (0 , -1)	5.08% (0 , -1)
	2	6.52% (-1 , -1)	6.69% (0 , 0)	6.55% (0 , -1)	4.88% (-1 , 0)	4.87% (-1 , -1)	5.09% (0 , -1)
	3	7.07% (-2 , 0)	6.94% (0 , -1)	7.83% (-1 , -1)	5.26% (-1 , 0)	5.26% (-1 , 0)	5.25% (-1 , 0)

Considering these results it is possible to observe a variation in the EAC values for the Oncor (as the Defender) between [6.17%;7.83%] with an average variation of 6.79%. The Philips results (as the Defender) exhibit a variation between [4.44%;5.26%] with an average variation of 4.98%. The Oncor results present a 36.38% higher variation in the EAC when compared with the variation obtained for Philips.

Considering the variation in the replacement periods provoked by a 30% increase in Penalty Cost it is possible to observe, for the Oncor, a variation in the K values between [-2,1] years with an average decrease of 0.44 years, and a variation in the L values between [-1,0] years, with an average decrease of 0.78. For Philips as defender, a variation between [-1;0] years is observed for the K values, with an average decrease of 0.67 years, and a variation in the L values of [-1;0] years, with an average decrease of 0.44 years. The Philips results present a variation in the Defender replacement time 50% higher and a variation in the Challenger replacement time 42.86% lower than the results obtained for Oncor.

Considering the same variation in the Penalty Value over the analysis with taxes, the following results would be obtained:

Table 27. Variation in results with taxes for a 30% increase in Penalty Cost.

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	2	3	Philips 1	2	3
Challenger Penalty Profile Philips	1	7.11% (0 , -1)	6.45% (0 , -1)	6.41% (0 , -1)	5.10% (-1 , -1)	5.18% (0 , 0)	5.22% (0 , -1)
	2	6.82% (0 , -1)	7.62% (-1 , -1)	6.68% (-1 , -1)	5.25% (-1 , -1)	5.35% (-1 , 0)	5.62% (-1 , -1)
	3	7.36% (-2 , 0)	7.21% (-1 , -1)	8.02% (-1 , 0)	5.54% (-1 , 0)	5.70% (0 , -1)	5.84% (-1 , 0)

Table 27. exhibits a variation in the EAC values for the Oncor replacement study between [6.41%;8.02%] with an average variation of 7.08%. The Philips results exhibit a variation between [5.10%;5.70%] with an average variation of 5.42%. The Oncor results present a 30.52% higher variation in the EAC when compared with the variation obtained for Philips.

Considering now the effect of a 30% increase in Penalty Cost over the replacement periods for the analysis with taxes, the Oncor exhibits a variation in the K values between [-2,0] years with an average decrease of 0.67 years, and a variation in the L values between [-1,0] years, with an average decrease of 0.78. The Philips replacement study exhibits a variation between [-1;0] years is observed for the K values, with an average decrease of 0.67 years, and a variation in the L values of [-1;0] years, with an average decrease of 0.56 years. Philips results present the same variation than the Oncor in the Defender replacement time, therefore, with a null variation between these values. The variation in the Challenger replacement time is 28.57% lower for the Philips Replacement study when compared with Oncor one. For a 30% decrease in the Penalty Factor, the following values would be obtained:

Table 28. Penalty Cost profiles with a 30% decrease, for a 10 year period.

Penalty Cost	1	2	3	4	5	6	7	8	9	10
Profile 1	37,618	80,821	126,750	175,536	227,314	282,226	340,420	402,050	467,275	536,263
Profile 2	43,015	92,140	144,364	199,836	258,710	321,148	387,317	457,392	531,555	609,997
Profile 3	58,841	112,544	169,625	230,243	294,568	362,773	435,042	511,564	592,539	678,172

The corresponding variation in results is exhibited in Table 29. for the analysis without taxes.

Table 29. Variation in results without taxes for a 30% decrease in Penalty Cost.

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	2	3	Philips 1	2	3
Challenger Penalty Profile Philips	1	-8.23% (3 , 0)	-6.69% (1 , 0)	-6.51% (0 , 0)	-5.19% (1 , 1)	-5.28% (2 , 0)	-5.45% (0 , 2)
	2	-7.80% (3 , 0)	-7.22% (1 , 1)	-7.27% (1 , 0)	-5.59% (2 , 0)	-5.59% (2 , 0)	-5.66% (1 , 0)
	3	-8.53% (2 , 0)	-7.94% (4 , 0)	-8.73% (3 , 0)	-5.94% (2 , 0)	-5.95% (1 , 0)	-6.06% (1 , 1)

The results in Table 29. highlight a variation in the EAC values for the Oncor (as a Defender) between [-8.73%;-6.51%] with an average variation of -7.66%. The Philips results exhibit a variation between [-6.06%;-5.19%] with an average variation of -5.63%. The Oncor results present a 35.93% higher variation in the EAC when compared with the variation obtained for Philips.

For a 30% decrease in Penalty Cost the replacement periods for the Oncor exhibits a variation in the K values between [0,4] years with an average increase of 2.0 years, and a variation in the L values between [0,1] years, with an average increase of 0.11. As for the Philips replacement study, a variation between [0;2] years is observed for the K values, with an average increase of 1.33 years, and a variation in the L values of [0;2] years, with an average increase of 0.44 years. The Philips results present a variation in the Defender replacement time 33.33% lower and a variation in the Challenger replacement time 300.00% higher than the results obtained for Oncor.

Table 30. Variation in results with taxes for a 30% decrease in Penalty Cost.

ΔEAC (ΔK,ΔL)		Defender Penalty Profile Oncor 1	Oncor 2	Oncor 3	Philips 1	Philips 2	Philips 3
Challenger Penalty Profile Philips	1	-8.47% (3 , 0)	-6.81% (2 , 0)	-6.72% (1 , 0)	-5.64% (2 , 0)	-5.74% (1 , 1)	-5.93% (2 , 0)
	2	-8.05% (3 , 0)	-8.70% (3 , 0)	-7.43% (0 , 0)	-5.91% (1 , 0)	-6.01% (1 , 1)	-6.15% (1 , 1)
	3	-8.57% (2 , 0)	-8.25% (3 , 0)	-9.06% (3 , 1)	-6.11% (2 , 0)	-6.28% (2 , 0)	-6.51% (1 , 1)

When considering taxes (Table 30.) it is possible to observe a variation in the EAC values for the Oncor replacement study between [-9.06%;-6.72%] with an average variation of -8.01%. The Philips results exhibit a variation between [-6.51%;-5.64%] with an average variation of -6.03%. The Oncor results present a 32.72% higher variation in the EAC when compared with the variation obtained for Philips.

Considering now the effect of a 30% decrease in Penalty Cost over the replacement periods for the analysis with taxes, the Oncor exhibits a variation in the K values between [0,3] years with an average increase of 2.22 years, and a variation in the L values between [0,1] years, with an average increase of 0.11. As for the Philips replacement study, a variation between [0;2] years is observed for the K values, with an average increase of 1.44 years, and a variation in the L values of [0;1] years, with an average increase of 0.44 years. The Philips results present a variation in the Defender replacement time 35.00% lower and a variation in the Challenger replacement time 300.00% higher than the results obtained for Oncor.

Analyzing the results obtained for the sensitivity analysis over the Penalty Cost variation it is possible to conclude that, as expected, a variation in penalty originates a considerable change in results, both for the EAC values and for the replacement periods K, L. These results demonstrate the high importance of this parameter in the Deterministic Model.

It is also possible to observe that, contrary to the *WACC* variation, negative Penalty Cost variations produces a higher impact in the results. A decrease in the Penalty Cost profile will originate a higher variation both in the EAC values and replacement periods. This reduction in particularly relevant for the retaining periods for the Defender. Consequently, in the replacement decision context low penalty profiles equipments shall have higher retaining periods.

The model is considerable more sensitive to Penalty Costs variations, rather than changes in the WACC. As so, for the replacement process in HSM the analysis of the equipment failures profile shall be more relevant than the analysis of the Operating and Maintenance Costs. As the penalty costs arise from the downtime periods, it becomes of extreme importance for HSM to minimize such periods.

As a conclusion, the sensitivity analysis for the deterministic model highlighted that an increase in the interest rates and financing costs, would produce an increase in the replacement periods. With an opposite evolution a decrease in these values can be expected. Analogously, equipments with an elevated record of failures will exhibit shorter replacement periods. On the other hand, equipment revealing a good reliability, with a small record of downtime periods, should be kept for longer.

5.3.3 Real Options Model

The sensitivity analyses for the Real Options model, that will investigate the influence of volatility over the model outputs, will be performed considering the set of volatilities values presented in Table 31.

Table 31. Volatilities variation (+/-30%) for sensitivity analysis.

Cost Typology	Standard	+30%	-30%
Penalty Profile 1 (Varian)	63.05%	81.96%	44.13%
Penalty Profile 2 (Mevatron)	60.62%	78.81%	42.44%
Penalty Profile 3 (Oncor)	21.41%	27.83%	14.99%
Main. And Operating Costs	26.07%	33.89%	18.25%

The results obtained for a 30% increase, exhibited in Table 32., highlight the variation in the year of first replacement, and the corresponding variation in the EAC of the first replacement.

Table 32. Variation in Real Options analysis results considering volatilities 30% higher.

ΔEAC / Δ1st Switch		Defender Penalty Profile: Oncor 1	Oncor 2	Oncor 3	Philips 1	Philips 2	Philips 3
Challenger Penalty Profile Philips	1	6.16%	59.80%	126.23%	-62.46%	-78.54%	-56.71%
		0	0	0	-1	0	0
	2	138.73%	51.41%	126.23%	-75.98%	-59.30%	-56.71%
		-1	0	0	0	-1	0
	3	26.76%	27.22%	94.77%	-33.50%	-55.82%	-56.71%
		-1	-1	0	-1	-1	0

Analyzing the results in Table 32. it is possible to observe a variation in the EAC values, for the Oncor as the Defender, between [6.16%;138.73%] with an average variation of 73.04%. The Philips results exhibit a variation between [-75.98%;-33.50%] with an average variation of -59.53%. The Oncor results present an absolute variation 22.69% higher variation in the EAC when compared with the variation obtained for Philips. The variation in EAC values for the two replacement studies follows opposite directions, increasing in the Oncor case and decreasing in the Philips case.

The 30% increase in Volatilities, originates a variation the Oncor first replacement year values between [-1;0] years with an average decrease of 0.33 years. For the Philips replacement study, a variation between [-1;0] years is observed for the first replacement year, with an average decrease of 0.44 years. The Philips results present a variation in the first replacement year 33.33% higher than the results obtained for Oncor.

Considering now a volatility reduction of 30%, the following results would be obtained.

Table 33. Variation in Real Options analysis results considering volatilities 30% lower.

ΔEAC / Δ1st Switch		Defender Penalty Profile: Oncor 1	Oncor 2	Oncor 3	Philips 1	Philips 2	Philips 3
Challenger Penalty Profile Philips	1	-66.63%	-37.52%	-55.58%	-77.53%	-78.54%	-56.71%
		1	1	0	0	0	0
	2	23.04%	-35.69%	-55.58%	-85.86%	-75.64%	-56.71%
		1	1	0	1	0	0
	3	-7.86%	-8.36%	-48.08%	-42.96%	-53.19%	-56.71%
		0	0	0	2	2	0

Table 33. highlights a variation in the EAC values for the Oncor replacement study between [-66.63%;23.04%] with an average variation of -32.47%. The Philips results exhibit a variation between [-85.86%;-42.96%] with an average variation of -64.87%. The Oncor results present a variation 49.94% lower variation in the EAC when compared with the variation obtained for Philips.

Considering the effect of a 30% decrease in Volatilities over the first replacement year, the Oncor exhibits a variation in replacement time values between [0;1] years with an average increase of

0.44 years. As for the Philips replacement study, a variation between [0;2] years is observed for the first replacement year, with an average increase of 0.56 years. The Philips results present a variation in the first replacement year 25.00% higher than the results obtained for Oncor.

The results of the sensitivity analyses of the variation in volatility over the Real Options model highlighted that the model is more sensitive to negatives variations in this parameter. A decrease in volatility produce a slightly bigger impact in the timing of first replacement. An increase in volatilities results on a decrease of the time until the first replacement and a decrease of volatilities extends the retaining period of the equipment.

The EAC results obtained indicate that higher volatilities generate higher values to the project options. This can be explained by the fact that higher volatilities generates higher possible final payoffs, elevating the reduction of costs obtained if the option to replace is exercised. Having an option to replace allows to avoid the high value possible paths, if the evolution of economic events point in that direction, generating value to its owner. High volatilities are a result of economic uncertainty, and therefore, the reduction in replacement periods is expected, as the option owners will try to dispose of the risky asset sooner, in order to avoid costly future outcomes.

As a conclusion the sensitivity analyses performed for the Real Options model indicates that highly uncertainty periods will tend to precipitate the replacement. In an opposite way the equipment should be retained for longer for predictable future evolutions of economic conditions.

6 Conclusions

The objective of developing a methodology to address the medical equipment replacement process at HSM has been accomplished. A deterministic and a stochastic model were constructed, with the purpose to identify the optimum replacement timing for selected medical devices, in a cost-effective way, potentiating a reduction of costs in HSM. The models proposed managed to accurately identify optimum replacement timings for the two linear accelerator models in service in the Radiotherapy Department. Another goal of the dissertation was to create a measure to value the subjective aspects regarding medical activity, such as patient safety or quality of medical service provided. This goal was accomplished by creating a penalty measure as a function of the costs incurred with equipment downtime due to malfunction.

It is reasonable to say that the models proposed could be applied to all kinds of high budget medical devices. Since the penalty cost parameter plays a significant role in the proposed analysis, it is not expectable that the models produce accurate valuations of low budget equipment replacements, where the penalty costs are potentially lower. However, a further study would be necessary to determine the applicability of the models in this range of medical devices.

The deterministic model proposed managed to accurately identify an optimum replacement plan for the equipments selected for the study. From the several analysis performed, considering different combinations of Penalty Profiles, it was possible to establish an average replacement horizon for the Siemens Oncor (defender) of 2.33 years. Assuming that it will replaced by a Philips Elekta like equipment, it was possible to determine an average replacement time for this substitute (Challenger), within the next 9.11 years. The effect of taxes over the analysis was investigated, determining a change in results to 2.67 and to 9.11 years, respectively. This allow to conclude that taxes have little influence over the results, especially when the depreciation period of the existing equipment already expired. The replacement analysis for the Philips Elekta (Defender) allowed to obtain an average replacement value of 5.11 years. Assuming a like-by-like replacement for this equipment, a 5.78 years average value was obtained for the replacement of this new item (Challenger). The tax effect induces a change in values to 5.78 years and 6.44 years, respectively.

The exact time for these replacements shall be influenced by two factors. The first one is the evolution of equipment failures record. A high record of failures shall precipitate the replacement in both alternatives. The second factor regards the evolution of the economic conjecture. The current economic conjecture has been evolving to an increase of uncertainty, with a consequent increase in institutions financing costs. As a result, it is expected that HSM's WACC keeps increasing, which also shorten replacement horizons.

It has been demonstrated that the Penalty Cost parameter is more relevant for the deterministic analysis than the Operating and Maintenance costs evolution. This indicates that under the HSM replacement context, a privileged importance should be given to the analysis of the equipment's failure profile when compared with the analysis of the associated Operating and Maintenance costs. The different results obtained to the deterministic model and the simple evaluation of Economic Life, have demonstrated the limitations of evaluating equipment replacement without consider its previous and future replacement conditions.

In the Real Options model, a more complete range historical data would increase the accuracy of the model results. Even though, it was possible to obtain reliable values for potential costs of equipment replacement, highlighting the relevance of studying the volatility as a tool for the Real Options analysis. The model determined an average replacement timing for the Siemens Oncor of 6.11 years and 9.78 years for the Philips Elekta. It is so possible to conclude that the Real Options model exhibits longer replacement periods than the Deterministic model, highlighting the influence of volatility over the results. High volatility values for the defender and low volatilities for the challenger equipment originate faster replacements. In opposition when the defender exhibits low volatility values and the challenger exhibits high volatilities, the replacement periods tend to increase. The Real Options results also revealed a higher influence of Penalty Costs volatility over the final outcomes when compared with the volatility of Operating and Maintenance costs. This indicates that uncertainty about equipment failures and consequent downtime, shall be more relevant in the replacement process in HSM, than the uncertainty about the evolution of operating costs or the value of future maintenance contracts.

The robustness of the models was confirmed by using a wide range of values for the Penalty Cost parameter as well as trough a sensitivity analysis. The sensitivity analysis performed indicates that the Deterministic model is more sensitive to positive variations in the WACC and negative variations for the Penalty Costs. The Real Options model revealed to be more sensitive to negative variations in the volatility parameter.

It would be advisable to implement, in the HSM, a database to keep an accurate historic record of equipment failures and related costs. The existence of extensive data would allow for a higher number of analysis, with more parameters, in a more accurate and reliable fashion. This decision would constitute a contribution to promote future works of this nature at HSM. In conclusion, despite of the data limitations, this work made an useful contribution for the creation of a cost-effective and methodological strategy for the management of medical equipment in HSM.

7 Bibliography

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8 Attachments

8.1 Attachment 1

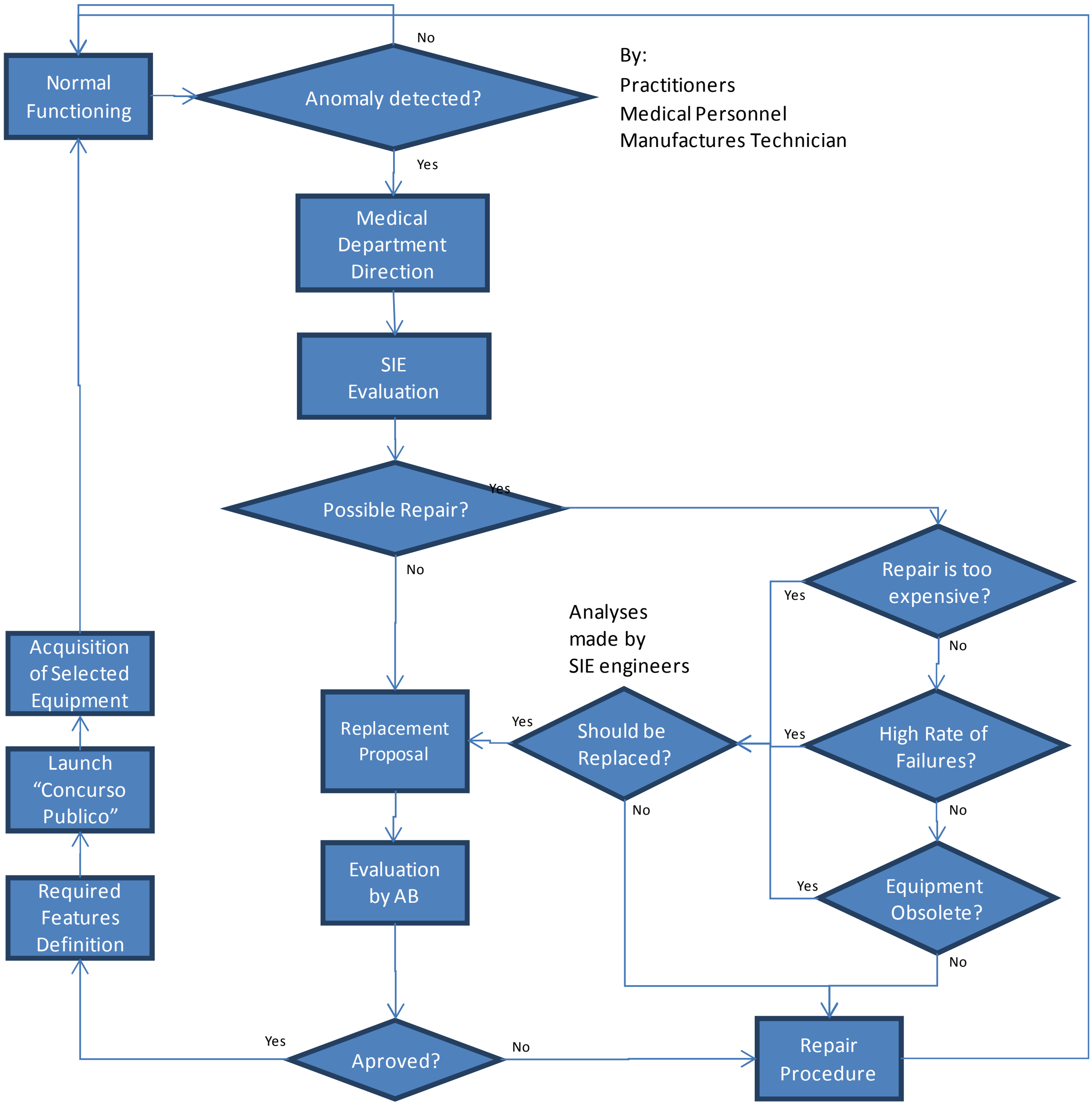
Table 34. Weight factor table for some clinical procedures performed in Portugal.

Code	Designation	Price (€)	Weight
	ECOTOMOGRAPHY (Ecography)		
	Head and neck		
17005	Encephalic ecography	28,00	4,8
17060	Neck ecography (including thyroid gland)	28,80	4,9
	Thorax		
17120	Thoracic ecography	28,80	4,9
	COMPUTARIZED TOMOGRAPHY (CT)		
	Head and neck		
16010	Cranium CT	74,30	12,7
	Vertebral column		
16040	Spine CT - cervical, dorsal, lumbar	77,80	13,3
	EXTERNAL RADIOTHERAPY		
	PLANNING		
45010	Simple planning - includes one single irradiation field or opposite fields for treatment of a single area with or without protection blocks		18,9
	CLINICAL TREATMENT (Radiotherapy)		
45160	Simple treatment - one single treatment area with single field or parallel opposite fields in linear accelerator		14,1
45170	Intermediate treatment - two areas to treat or three or more fields to treat one single area or tangential fields or usage of protection blocks, in linear accelerator		16,4
45181	Complex treatment - three or more areas to treat with complex protections, tangential fields, rotational technique, usage of wedged filters and compensators, in linear accelerator		19,2
45190	Radiosurgery - planning, dosimetry and stereotactic treatment in single dose in linear accelerator (radiosurgery)		1498,7
45193	Fractioned stereotactic radiotherapy, each fraction		63,1

(From: Diário da República, 1.ª série -N.º21-30 de Janeiro de 2009)

8.2 Attachment 2

Figure 22. Flowchart representing the replacement process in HSM.



8.3 Attachment 3

Table 35. Balance sheet for HSM in 2007 (HSM, 2008).

BALANCE 2007

ASSETS		EQUITY	
Fixed Assets	127,846,552.15	Equity Capital	169,900,273.80
Intangible Fixed Assets	202,650.68	Reserves	14,851,563.58
Tangible Fixed Assets	127,643,901.47	Result from previous years	938,308.45
Investments	0.00	Net Income	6,000,030.23
Inventory	19,719,154.35		
Receivables – medium and long-term	0.00	Total Equity	191,690,176.06
Receivables – short-term	110,644,041.64	LIABILITIES	
Stocks	0.00	Provisions	63,378,491.73
Cash and bank balances	108,702,541.09	Medium and long-term Liabilities	0.00
Accrued Income and Deferrals	32,506,380.62	Short-term Liabilities	106,097,266.05
		Accruals and Deferrals	38,252,736.01
		Total Liabilities	207,728,493.79
Total Assets	399,418,669.85	Total Equity and Liabilities	399,418,669.85

8.4 Attachment 4

Table 36. Downtime periods for the three Linear Accelerators, in year 2009 (Hours).

	DESCRIÇÃO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTAL DECIMAL	TOTAL EM TEMPO
Jan-09	Total tempos de paragem		0,8			0,8	3,6	12	0,4	0			2,5	7,3	0	2	0,9			0,5	2,3	1,5	17,2	0,4			20,9	13	11	0,5	0		97,600000	97 H 36 ' 00 ''
	AL1 -Mevatron (Siemens)						3,3			0					0	2					2,3	1,5					7				0		16,100000	16 H 6 ' 00 ''
	AL2 - CLINAC (VARIAN)					0,4				0					0		0,3						4,2	0,4			7,2				0		12,500000	12 H 30 ' 00 ''
	AL3 - ONCOR (SIEMENS)		0,8			0,4	0,3	12	0,4	0			2,5	7,3	0		0,6			0,5			13				6,7	13	11	0,5	0		69,000000	69 H 0 ' 00 ''
Fev-09	Total tempos de paragem		3	2,3	0	2,1	4,2			0,4	0,8	4	0	6,9			0,8	0,8	0	0	0,3			1,1		2,2	0	0,5					29,400000	29 H 24 ' 00 ''
	AL1 -Mevatron (Siemens)				0	0,8							0					0,5	0	0	0,3					1,8	0	0,5					3,900000	3 H 54 ' 00 ''
	AL2 - CLINAC (VARIAN)			0,3	0		0,2						0						0	0							0						0,500000	0 H 30 ' 00 ''
	AL3 - ONCOR (SIEMENS)		3	2	0	1,3	4			0,4	0,8	4	0	6,9			0,8	0,3	0	0				1,1		0,4	0						25,000000	25 H 0 ' 00 ''
Mar-09	Total tempos de paragem		1,5	0	13	5,8	0			0,8	3,6	10	0,2	0,6			0,4	0,3	11,2	11	1,8			12,4	0	0	0	5,4			10,1	13	101,100000	## H 6 ' 00 ''
	AL1 -Mevatron (Siemens)			0	0,4		0				3,6	10	0,2						0,2	0	1,8			12,4	0	0	0	5,4			8,4	13	55,400000	55 H 24 ' 00 ''
	AL2 - CLINAC (VARIAN)			0	11,8	5,8	0							0,3					11	11	0			0	0	0	0	0			0,6	0	40,500000	40 H 30 ' 00 ''
	AL3 - ONCOR (SIEMENS)		1,5	0	0,8		0			0,8				0,3			0,4	0,3	0	0	0			0	0	0	0	0			1,1	0	5,200000	5 H 12 ' 00 ''
Abr-09	Total tempos de paragem	14,1	4,4	3,8			1,2	0	4,8	0,4				7,3	19,3	6,6	0,8	0			0	0,5	14,8	5,7	0			10,9	2,3	0,5	3,1		100,500000	## H 30 ' 00 ''
	AL1 -Mevatron (Siemens)	13	4,4	3,8			0	0	0	0,4				0,5	0,5	0,5	0	0			0	0	11	1,7	0			1,9	1,8	0,5	2,8		42,800000	42 H 48 ' 00 ''
	AL2 - CLINAC (VARIAN)	0,3	0	0			0,5	0	4,8	0				6	8,8	2,5	0,8	0			0	0	0	4	0			0	0	0	0,3		28,000000	28 H 0 ' 00 ''
	AL3 - ONCOR (SIEMENS)	0,8	0	0			0,7	0	0	0				0,8	10	3,6	0	0			0	0,5	3,8	0	0			9	0,5	0	0		29,700000	29 H 42 ' 00 ''
Mai-09	Total tempos de paragem				3,4	0	11,5	0	1,8			0,8	1,6	18	0	0,4	0		0,8	0,2	7,7	2,8	0,3			0,7	2,2	10,1	0	0			62,300000	62 H 18 ' 00 ''
	AL1 -Mevatron (Siemens)				0	0	0,2	0	0,8			0	0	10	0	0	0		0	0,2	1,6	1,8	0			0	0	0	0	0			14,600000	14 H 36 ' 00 ''
	AL2 - CLINAC (VARIAN)				1	0	0,3	0	0,5			0	1,6	0	0	0,4	0		0	0	1,8	1	0,3			0,1	2,2	9,8	0	0			19,000000	19 H 0 ' 00 ''
	AL3 - ONCOR (SIEMENS)				2,4	0	11	0	0,5			0,8	0	8	0	0	0		0,8	0	4,3	0	0			0,6	0	0,3	0	0			28,700000	28 H 42 ' 00 ''
Jun-09	Total tempos de paragem	1	0,6	0	3,6	0			2,8	0	0	0	0,3			8,9	0,3	14,7	13	0			2	7,8	0,2	0,2	13			13,3	10		91,700000	91 H 42 ' 00 ''
	AL1 -Mevatron (Siemens)	0	0,6	0	0	0			2	0		0	0,3			0,8	0	0	0	0			0,3	0,2	0	0,2	13			13	10		40,400000	40 H 24 ' 00 ''
	AL2 - CLINAC (VARIAN)	0	0	0	0,2	0			0	0		0	0			7,5	0,3	12	13	0			0,8	1,1	0,2	0	0			0	0		35,100000	35 H 6 ' 00 ''
	AL3 - ONCOR (SIEMENS)	1	0	0	3,4	0			0,8	0		0	0			0,6	0	2,7	0	0			0,9	6,5	0	0	0			0,3	0		16,200000	16 H 12 ' 00 ''
Jul-09	Total tempos de paragem	1,9	1,3	1,8			5,9	13	0	2,2	0,8			0	2,3	0	0,2	0			0,4	0,6	0	1	1,2			3,6	12	1,6	11,2	0	61,000000	61 H 0 ' 00 ''
	AL1 -Mevatron (Siemens)	0	1	0			3,4	13	0	2	0			0	0,8	0	0	0			0	0	0	0,3	0			1,3	0	0,8	11	0	33,600000	33 H 36 ' 00 ''
	AL2 - CLINAC (VARIAN)	1,9	0,3	0			2,2	0	0	0,2	0,8			0	1,5	0	0,2	0			0,4	0,6	0	0,7	0,7			1,7	0	0,8	0,2	0	12,200000	12 H 12 ' 00 ''
	AL3 - ONCOR (SIEMENS)	0	0	1,8			0,3	0	0	0	0			0	0	0	0	0			0	0	0	0	0,5			0,6	12	0	0	0	15,200000	15 H 12 ' 00 ''
Ago-09	Total tempos de paragem			0,5	0	0	0	0			1,1	0,2	0	0,4	0,6			0,2	0,3	0	0,6	2,3			1,4	13,7	0	1,5	0			0,4	22,800000	22 H 48 ' 00 ''
	AL1 -Mevatron (Siemens)			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	11	0	0	0			0	11,000000	11 H 0 ' 00 ''
	AL2 - CLINAC (VARIAN)			0,1	0	0	0	0			0,9	0,2	0	0	0,6			0	0,3	0	0	2,3			1,1	2,7	0	1,5	0			0	9,700000	9 H 42 ' 00 ''
	AL3 - ONCOR (SIEMENS)			0,4	0	0	0	0			0,2	0	0	0,4	0			0,2	0	0	0,6	0			0,3	0	0	0	0			0,4	2,100000	2 H 6 ' 00 ''
Set-09	Total tempos de paragem	0,8	7,4	0,9	0,3			1,5	4,5	1,4	1,7	4,9			0	0,5	5,7	0,3	0			1,1	4	11,1	1,7	1,1			0,3	0	6,5		55,700000	55 H 42 ' 00 ''
	AL1 -Mevatron (Siemens)	0,7	0	0	0			0	0	0,2	0	0			0	0,5	3,9	0	0			0	0	11	0	0			0	0	0		16,300000	16 H 18 ' 00 ''
	AL2 - CLINAC (VARIAN)	0,1	0,4	0,4	0,3			1	4,5	0,4	1,7	0			0	0	1,8	0,3	0			0,2	4	0,1	1,7	1,1			0	0	0		18,000000	18 H 0 ' 00 ''
	AL3 - ONCOR (SIEMENS)	0	7	0,5	0			0,5	0	0,8	0	4,9			0	0	0	0	0			0,9	0	0	0	0			0,3	0	6,5		21,400000	21 H 24 ' 00 ''
Out-09	Total tempos de paragem	0	0,6				4,6	5,4	0,2	0			0,5	2,8	0,8	0	0,3			14	11	6,5	0	14,5			3,7	11,8	8,2	6	0		90,900000	90 H 54 ' 00 ''
	AL1 -Mevatron (Siemens)	0	0				2,6	0,4	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0		3,000000	3 H 0 ' 00 ''
	AL2 - CLINAC (VARIAN)	0	0				0	0	0,2	0			0	0	0,5	0	0			14	11	6,5	0	7,3			3,2	0,8	2,2	3,3	0		49,000000	49 H 0 ' 00 ''
	AL3 - ONCOR (SIEMENS)	0	0,6				2	5	0	0			0,5	2,8	0,3	0	0,3			0	0	0	0	7,2			0,5	11	6	2,7	0		38,900000	38 H 54 ' 00 ''
Nov-09	Total tempos de paragem		0	0	0	3,3	6,2			13	5,5	0	0	0			1,7	2	0	0	0			5	13	13	12	0			2,5		77,200000	77 H 12 ' 00 ''
	AL1 -Mevatron (Siemens)																																0,000000	0 H 0 ' 00 ''
	AL2 - CLINAC (VARIAN)																																0,000000	0 H 0 ' 00 ''
	AL3 - ONCOR (SIEMENS)		0	0	0	3,3	6,2			13	5,5	0	0	0			1,7	2	0	0	0			5	13	13	12	0			2,5		77,200000	77 H 12 ' 00 ''
Dez-09	Total tempos de paragem		0	0	0			0	0	0	0	1,5			2	10	0	0,2	0	0	0	2,3	0	0	0	0	0	0	6,5	0	0	2,3	24,800000	24 H 48 ' 00 ''
	AL1 -Mevatron (Siemens)																																0,000000	0 H 0 ' 00 ''
	AL2 - CLINAC (VARIAN)																																0,000000	0 H 0 ' 00 ''
	AL3 - ONCOR (SIEMENS)		0	0	0			0	0	0	0	1,5			2	10	0	0,2	0			2,3	0	0	0	0			6,5	0	0	2,3	24,800000	24 H 48 ' 00 ''

8.5 Attachment 5

Table 37. Accounting report on the Radiotherapy Department expenditures, for the year 2009.

DADOS ESTATISTICOS

MINISTÉRIO DA SAÚDE
CENTRO HOSPITALAR LISBOA NORTE, E.P.E.

SECÇÃO HOMOGÉNEA
30153005 - Serviço Radioterapia - MCDT'S

UNIDADE DE OBRA	N.	C. MÉDIO UNITÁRIO
Exame Ponderado	34,650	113.52

Código	RUBRICAS	CUSTO TOTAL (Euros)	C. MÉDIO UNITÁRIO (Euros)	%
	ELEMENTOS DIRECTOS			
612	Mercadorias	0.00	0.00	0.00
6161	Produtos Farmaceuticos	12,455.16	0.36	0.32
6162	Material de consumo clinico	48,060.96	1.39	1.22
6163	Produtos alimentares	0.00	0.00	0.00
6164	Material de consumo hoteleiro	1,463.36	0.04	0.04
6165	Material de consumo administrativo	615.61	0.02	0.02
6166	Material de manut. e conservacao	592.38	0.02	0.02
6169	Outro material de consumo	0.00	0.00	0.00
621	Subcontratos	825,755.00	23.83	20.99
622	Fornecimentos e servicos	876,128.00	25.29	22.27
63	Transferências correntes concedidas	0.00	0.00	0.00
64	Custos com o pessoal	0.00	0.00	0.00
641	Remuneracoes de Orgãos de Directivos	0.00	0.00	0.00
64211	Pessoal Dirigente	0.00	0.00	0.00
642121	Pessoal Médico	201,279.33	5.81	5.12
642122	Pessoal Técnico Superior Saúde	0.00	0.00	0.00
642123	Pessoal Técnico Superior Segurança Social	0.00	0.00	0.00
642129	Outro Pessoal Técnico Superior	0.00	0.00	0.00
64213	Pessoal de Enfermagem	67,280.39	1.94	1.71
642141	Pessoal Tecn. Diagnóstico e Terapêutica	280,353.70	8.09	7.13
642149	Outro Pessoal Técnico	0.00	0.00	0.00
64215	Pessoal Técnico Superior	65,736.98	1.90	1.67
64216	Pessoal de Assistente Técnico	8,268.38	0.24	0.21
64217	Pessoal Asssitente Operário	33,558.93	0.97	0.85
64218	Pessoal Informático	0.00	0.00	0.00
64219	Outro Pessoal	96,980.05	2.80	2.47
64221	Horas Extraordinárias	62,134.39	1.79	1.58
642212	Prevenções	0.00	0.00	0.00
64222	Noites e suplementos	7,305.21	0.21	0.19
642222	Subsídio de Turno	0.00	0.00	0.00
64223	Abono para Falhas	0.00	0.00	0.00
64224	Subsídio de Refeição	38,323.40	1.11	0.97
64225	Ajudas de Custo	223.73	0.01	0.01
64226	Vestuário e Artigos Pessoais	0.00	0.00	0.00
64227	Alimentação e Alojamento	0.00	0.00	0.00
64228	Outros Suplementos	276,428.00	7.98	7.03
6423	Prestações Sociais Directas	23,987.00	0.69	0.61
6424	Subsídio Férias e Natal	114,107.63	3.29	2.90
6425	Prémios de Desempenho	3,500.00	0.10	0.09
643	Pensões	0.00	0.00	0.00
645	Encargos Sobre Remunerações	164,875.41	4.76	4.19
646	Seguros Acidentes Trab. E Doença Prof.	66.68	0.00	0.00
647	Encargos Sociais Voluntários	0.00	0.00	0.00
648	Outros Custos com Pessoal	39,901.95	1.15	1.01
65	Outros Custos e Perdas Operacionais	0.00	0.00	0.00
66	Amortizações do Exercício	278,562.61	8.04	7.08
67	Provisões do Exercício	0.00	0.00	0.00
68	Custos e Perdas Financeiras	0.00	0.00	0.00
69	Custos e perdas extraordinárias	51,708.37	1.49	1.31
	TOTAL (1)	3,579,652.61	103.31	91.00

8.6 Attachment 6

Table 38. Number of Radiotherapy treatments delivered in year 2009, by equipment (up) and by treatment typology (down).

FONTE DE INFORMAÇÃO 1: LANTIS

	7																12
	MÉDIA 07	TOTAL 08	MÉDIA 08	Jan-09	Fev-09	Mar-09	Abr-09	Mai-09	Jun-09	Jul-09	Ago-09	Set-09	Out-09	Nov-09	40148	TOTAL 09	MÉDIA 09
	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis	Lantis
MEVATRON	640	10.163	847	904	868	981	926	1.029	1.072	913	435	463	269	0	0	7.860	786
CLINAC	1.018	11.305	942	1.144	1.070	1.189	1.207	1.206	1.373	1.484	1.371	1.433	748	0	0	12.225	1222,5
SUB-TOTAL	**1.658**	**21.468**	**1.789**	**2.048**	**1.938**	**2.170**	**2.133**	**2.235**	**2.445**	**2.397**	**1.806**	**1.896**	**1.017**	**0**	**0**	**20.085**	2008,5
ONCOR	705	11.182	932	1.064	979	1.341	1.268	1.261	1.031	1.079	1.575	1.486	1.490	1.194	1.154	14.922	1243,5
TOTAL	**2.363**	**32.650**	**2.721**	**3.112**	**2.917**	**3.511**	**3.401**	**3.496**	**3.476**	**3.476**	**3.381**	**3.382**	**2.507**	**1.194**	**1.154**	**35.007**	**3252**
Nº AL em pleno funcionamento	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	3
Produção média mensal por AL	**1.182**	**10.883**	**907**	**1.037**	**972**	**1.170**	**1.134**	**1.165**	**1.159**	**1.159**	**1.127**	**1.127**	**836**	**398**	**385**	**11.669**	1084
3				1.037	972	1.170	1.134	1.165	1.159	1.159	1.127	1.127	836	398	385		
932				11%	4%	26%	22%	25%	24%	24%	21%	21%	-10%	-57%	-59%		

FONTE DE INFORMAÇÃO 2: SISTEMA DE GESTÃO HOSPITALAR

	12		12												12		
Códigos:	MÉDIA 07	TOTAL 08	MÉDIA 08	Jan-09	Fev-09	Mar-09	Abr-09	Mai-09	Jun-09	Jul-09	Ago-09	Set-09	Out-09	Nov-09	Dez-09	TOTAL 09	MÉDIA 09
	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº	Nº
45160	14	106	9	0	0	0	9	0	15	13	3	0	0	0	0	40	3
45170	1.288	14.007	1.167	1.349	1.256	1.423	1.419	1.349	1.127	1.132	1.310	1.226	867	395	504	13.357	1.113
45180	953	17.676	1.473	1.708	0	0	0	0	0	1	0	0	0	0	0	1.709	142
45181	-	-	-	0	1.604	1.961	1.881	2.066	2.266	2.242	1.983	2.076	1.632	794	650	19.155	1.596
45185	-	-	-	0	0	0	1	2	0	0	0	0	0	0	0	3	0
45190	2	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45193	17	416	35	20	38	65	43	42	31	39	36	62	1	0	0	377	31
TOTAL	**2.274**	**32.218**	**2.685**	**3.077**	**2.898**	**3.449**	**3.353**	**3.459**	**3.439**	**3.427**	**3.332**	**3.364**	**2.500**	**1.189**	**1.154**	**34.641**	**2.887**
Nº AL em pleno funcionamento	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Produção média mensal por AL	**1.137**	**10.739**	**895**	**1.026**	**966**	**1.150**	**1.118**	**1.153**	**1.146**	**1.142**	**1.111**	**1.121**	**833**	**396**	**385**	**11.547**	**962**

8.7 Attachment 7

Table 39. Relevant financial data on HSM debt status (HSM, 2008).

EQUITY AND LIABILITIES			
Equity		2007	2006
51	Equity Capital	169.900.273,80	169.900.273,80
	Reserves		
571	Legal Reserves	959.455,00	
574	Free Reserves	3.837.817,69	
575	Subsidies received	7.288.282,25	7.288.282,25
576	Donations	2.766.008,64	2.667.936,56
577	Revaluation Reserves		
59	Result from previous years	938.308,45	154.809,20
88	Net Income	6.000.030,23	4.797.272,69
	Total Equity (E)	191.692.183,06	184.810.580,50
	Cost of Equity (ie): 88/(E)	3,13%	2,60%
Liabilities			
221	Suppliers	56.487.536,73	81.637.852,74
228	Accounts Payable	4.988.869,85	5.755.725,65
2611	Suppliers of fixed assets	5.660.268,65	3.947.752,94
267/8	Others	32.578.321,79	32.205.329,74
	Total (B)	99.714.997,02	123.546.661,07
68	Interest Expenses	33.336,24	39.250,26
	Cost Of Debt (id): (68)/(B)	0,03%	0,03%

8.8 Attachment 8

Table 40. Option maturity calculation for the challenger equipment, Philips Elekta (Values in euros).

Year		0	1	2	3	4	5	6
Total maint. And operting costs	(1)		574,181	592,554	611,516	823,939	850,305	877,515
Penalty Measure New Item (Pn)	(2)		53,740	115,458	181,071	250,765	324,734	403,181
Total Costs	(3)=(1)+(2)		627,921	708,013	792,588	1,074,705	1,175,040	1,280,696
Residual Value Old Item (So)	4	464,385	0	0	0	0	0	0
Acquisition Cost Rn	5	3,312,637	0	0	0	0	0	0
Residual Value New Item (Sn)	6		2,421,400	1,682,490	1,058,188	796,170	599,030	450,703
Discounted Cash Flow	(7)=(3)+(5)-(4)	2,848,252	601,771	650,271	697,633	906,558	949,917	992,214
Capital Recovery Cost			2,972,020	1,517,610	1,033,099	791,063	646,016	549,463
PV of Costs until year i			1,028,623	2,417,804	3,739,739	4,908,315	6,055,372	7,195,912
PV of Final Replacement			854,121	1,497,200	1,984,358	2,122,744	2,193,713	2,217,272
EAC maintaining i years			1,964,557	2,085,999	2,076,207	1,952,780	1,870,986	1,815,921

(continuation)		7	8	9	10	11	12	13
Total maint. And operting costs	(1)	905,596	934,575	964,481	995,344	1,027,196	1,060,066	1,093,988
Penalty Measure New Item (Pn)	(2)	486,315	574,357	667,536	766,090	870,268	980,329	1,096,542
Total Costs	(3)=(1)+(2)	1,391,911	1,508,932	1,632,017	1,761,434	1,897,463	2,040,394	2,190,530
Residual Value Old Item (So)	4	0	0	0	0	0	0	0
Acquisition Cost Rn	5	0	0	0	0	0	0	0
Residual Value New Item (Sn)	6	339,104	255,139	191,964	144,431	148,479	153,230	158,133
Discounted Cash Flow	(7)=(3)+(5)-(4)	1,033,469	1,073,698	1,112,920	1,151,151	1,188,409	1,224,710	1,260,070
Capital Recovery Cost		480,622	429,100	389,123	357,228	331,211	309,601	291,382
PV of Costs until year i		8,340,980	9,498,644	10,674,739	11,873,422	13,057,783	14,277,742	15,532,909
PV of Final Replacement		2,207,795	2,175,599	2,128,078	2,070,519	1,981,757	1,896,376	1,814,582
EAC maintaining i years		1,780,030	1,758,768	1,749,098	1,748,851	1,748,882	1,758,105	1,774,683

8.9 Attachment 9

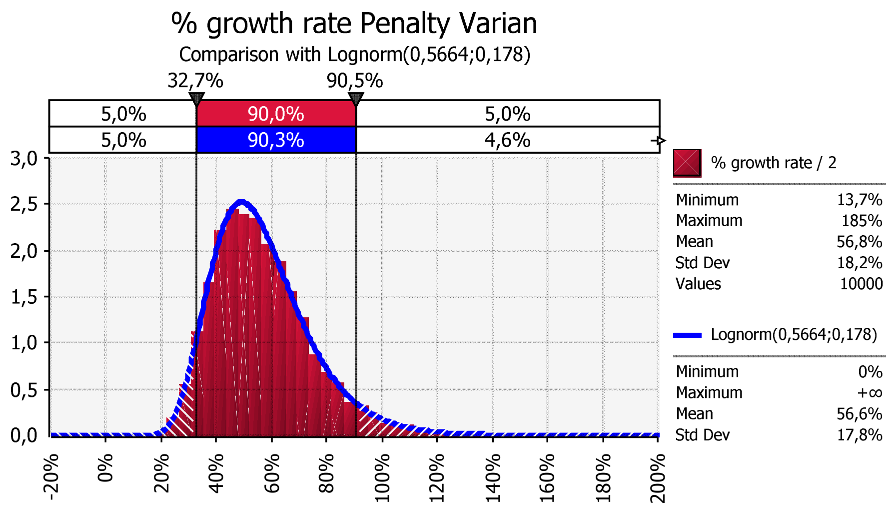


Figure 23. Simulation for Varian penalty profile, using a Normal distribution. Standard Deviation = 18.2%.

8.10 Attachment 10

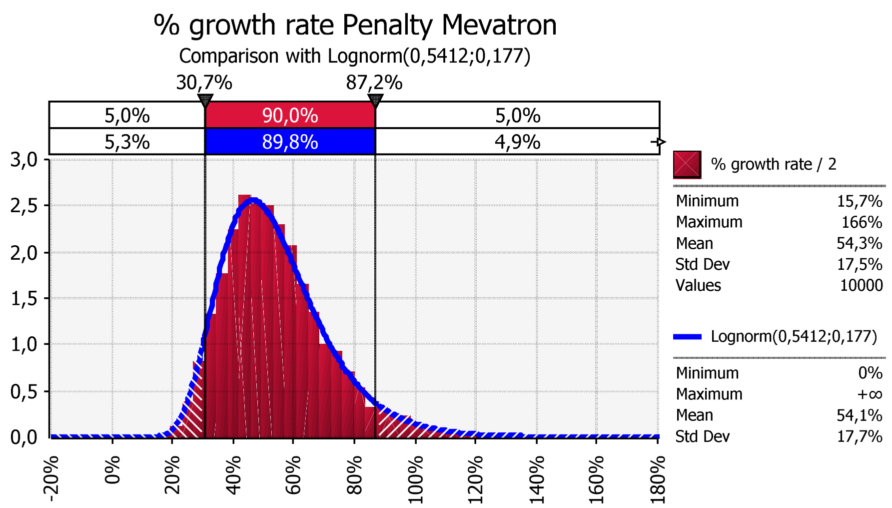


Figure 24. Simulation for Mevatron penalty profile, using a Normal distribution. Standard Deviation = 17.5%.

8.11 Attachment 11

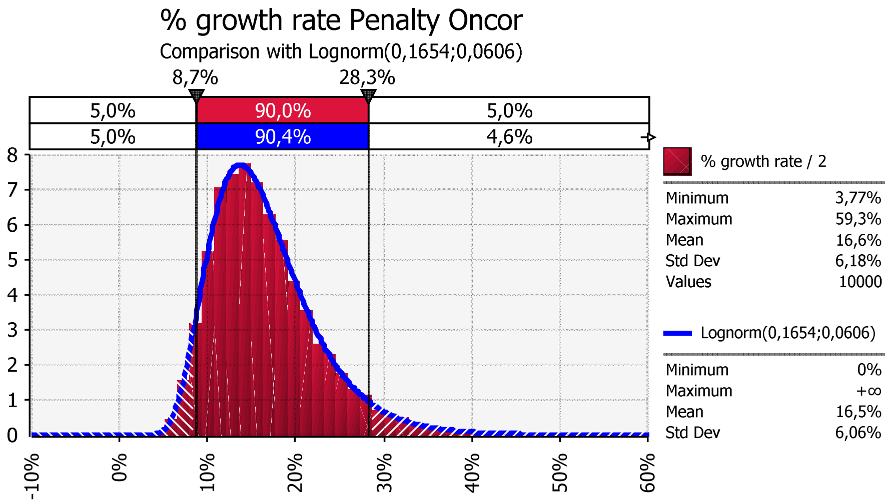


Figure 25. Simulation for Oncor penalty profile, using a log-normal distribution. Standard Deviation = 6.18%.