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Licenciatura em Ciências de Engenharia Biomédica

Scenario Planning and Multicriteria Analysis in the acquisition of a sophisticated medical equipment: The Case of Instituto Português de Oncologia

Dissertação para obtenção do Grau de Mestre em Engenharia Biomédica

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UNIVERSIDADE NOVA DE LISBOA

Março 2016

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"Start by doing what's necessary; then do what's possible; and suddenly you are doing the impossible"

Francis of Assisi

Acknowledgements

This work represents the end of a very important and defining part of my life. I would like to first thank my advisor, Professor Luís Lapão, for giving me the opportunity to work on this project, and for all his support and guidance.

I would also like to thank Dr. Miguel Lemos, from Instituto Português de Oncologia, for allowing me to partake in this project, for his support, and for his availability and patience, which without would have made my work very difficult, if not impossible.

A special thanks to my family who always tried to support me, and encouraged me to follow my dreams. Thank you for believing in me when I did not, and for listening even when you didn't understand what I was talking about.

To Cláudia & Carolina, the best friends a girl can have. We have been together for half our lives, and I cannot wait to see what the future holds for us. I know that wherever we are in the world, we will always be friends, and that no one will make me laugh as hard as you. Thank you for always listening to me, even when I complain non-stop. I promise I'll return the favour when it's your turn!

I also want to say thank you to *Família Fertagus e Companhia*. Thank you for always being there for me, in the good and in the bad moments. I can say for sure, that I would not have been able to go through this five and half years without you. Thank you for giving a new meaning to friendship, and for becoming a second family. University was just the beginning; now let’s enjoy the rest of our lives!

To my new friends in my new Master, thank you for always encouraging me and making me laugh.

Last, but not least, I would also like to thank Professor Carmo Lança, Professor Jorge Silva and Professor João Borges. Unfortunately, it was a project that did not work, but that I hold dear, and hope to see it accomplished in the near future.

To all the others that I did not mention here, but were part of this journey, thank you.

Abstract

Healthcare management is a process that is becoming more and more challenging. Due to constant changes, either economic, political, social or others, the healthcare industry suffers certain uncertainties in their services. One of the challenges is the increase in costs of medical equipment, which is also associated with a fast evolution of technology and lack of good practices of procurement. Being one of the most valuable sources for any company, technology is especially important in healthcare, since it helps to improve the diagnostic and quality of the service provided. But, with the current economic crisis, hospitals are suffering budget cuts, affecting the options available in terms of technology. Hence, the job of healthcare managers is becoming more difficult, but also increasing in importance, since a good decision in necessary to please both customer, and employer. In this work, the case of Instituto Português de Oncologia de Lisboa will be analysed, where the decision to either acquire, or not, a new computerized axial tomography is being considered. Scenario Planning and the Multicriteria Decision Analysis were the methodology implemented. It was concluded that the best option for IPO is to replace their old computerized axial tomography by a new one, with a leasing contract, instead of direct acquisition.

Keywords: Scenario Planning, Multicriteria Decision Analysis, Computerized Axial Tomography, Healthcare Equipment Management, Healthcare

Resumo

A gestão hospitalar é um processo que se está a tornar cada vez mais desafiante. Devido a mudanças constantes, quer de carácter económico, político, social, ou outro, o sector da saúde sofre várias incertezas nos seus serviços. Um dos desafios deve-se ao constante aumento dos custos relacionados com equipamento médico, que estão também associados a uma rápida evolução em termos de tecnologia. Sendo um dos mais importantes recursos de uma empresa, a tecnologia é especialmente importante quando se fala do sector da saúde, já que ajuda a melhorar o diagnóstico e a qualidade do serviço proporcionado. No entanto, com a atual crise económica, os centros hospitalares estão a sofrer cortes nos seus orçamentos, afectando assim as opções disponíveis em termos de tecnologia. Pode-se dizer assim que o trabalho do gestor de saúde torna-se cada vez mais difícil, mas também cada vez mais importante, já que é crucial tomar uma boa decisão, tanto para agradar o cliente ou paciente, e a própria gestão do hospital. Nesta dissertação, o caso de estudo do Instituto Português de Oncologia vai ser analizado, para se tomar a decisão de adquirir, ou não, um novo equipamentos de tomografia axial computorizada. A análise de cenários e a análise multicritério foram as metodologias escolhidas para aplicar a este caso. Concluiu-se que o IPO deve substituir a sua TAC antiga, por uma nova em contrato de leasing, em vez de aquisição directa.

Palavras-chave: Análise de Cenários, Análise Multicritério, Tomografia Axial Computorizada, Gestão Hospitalar, Sáude

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Acronyms and Abbreviations

IPO-L	Instituto Português de Oncologia de Lisboa Francisco Gentil E.P.E.
CAT Scan	Computerized Axial Tomography Scan
SP	Scenario Planning
MCDA	Multicriteria Decision Analysis
CT	Computed Tomography
DMs	Decision Makers
MODM	Multiple Objective Decision Making
MADM	Multi-Attribute Decision Making
ELECTRE	Elimination and Choice Translating Reality
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
AHP	Analytical Hierarchy Process
PC	Pairwise Comparison
TOPSIS	Technique for order preference by similarity to ideal solutions
PV	Present Value
CI	Consistency Index
CR	Consistency Ratio
RI	Random Index

1. Introduction

Healthcare management is an area that is becoming more and more challenging. Due to constant changes in its processes, either economic, political, social, or others, the healthcare industry suffers certain uncertainties in their services.

Also, managers of healthcare institutions, like hospitals, have the difficult task of having to implement a long-term strategy, but having to focus on their short-term performance. This means that managers should have the ability to answer to opportunities of change that arise from day to day, in order to align their services with the changing environment [1].

Another challenge is that healthcare costs keep increasing due to the cost rise of medical equipment and complexity of care. This also includes their maintenance and accountability within the healthcare organization [2]. It is very difficult to keep track of all medical equipment, but it is also very important, since it is necessary for inventory and in order to maintain it and make sure it doesn’t need repair or substitution. Since most equipment is now mobile, and doesn’t necessarily belong to one department, it becomes increasingly difficult to keep track of each equipment, and to understand either it is needed an upgrade or in higher number [2].

Furthermore, it is known that technology is a valuable resource for all organizations. While companies need access to leading technologies in order to remain competitive, healthcare organizations, like hospitals, need them in order to improve their performance and quality of service provided.

Thus, besides the basic healthcare management, managers also need to take into account technology management, since it will have a large impact in their overall management.

Besides these facts, organizations need to be able to forecast new and emerging technologies. The problem is that the development of new technologies comes with an increase in cost, and with the recent economic crisis and budget cuts, healthcare organizations need more affordable options. By forecasting technology's acquisitions according to their needs, healthcare organizations can help to reduce their long-term costs, while at the same time increasing the quality of the services they provide.

Overall, in order to work efficiently, healthcare institutions need to have the ability to analyse how the services they provide are aligned with their demand, and measure their effectiveness and results, while making an efficient use of all their resources[3].

1.1 Objectives

This work is part of a pre-analysis project research in order to decide the optimal choice in the acquisition of medical technology for Instituto Português de Oncologia de Lisboa Francisco Gentil E.P.E. (IPO-L).

The case will be conducted on the possible acquisition of a Computerized Axial Tomography Scan (CAT Scan). The main objectives of this project are:

- ✓ Decide if IPO-L should retain the old CAT Scan, or acquire a new one;
- ✓ In case of a new acquisition, decide to:
    - Either do a direct acquisition or to sign a leasing contract

This dissertation, which was conducted with the purpose of helping Instituto Português de Oncologia de Lisboa, proposes a multi-layered research, which includes the combining of Scenario Planning (SP) and Multicriteria Decision Analysis (MCDA), in order to find the best option for the healthcare institution in question.

1.2 Dissertation Overview

This dissertation is organized in six main chapters, with the first one being this introduction. The remainder of this dissertation is organised as follows:

Chapter 2: Background
Chapter 3: Methods
Chapter 4: Development of the Methodology
Chapter 5: Results/Discussion
Chapter 6: Conclusion

2. Background

In this chapter the background information necessary to understand this work is addressed. In section 2.1, the context and background of IPO-L is discussed, followed by a small explanation of the TAC Scan in section 2.2. Sections 2.3 and 2.4 introduce the methods that will be used in this to develop this thesis.

2.1 Portugal and IPO-L

Instituto Português de Oncologia de Lisboa Francisco Gentil E.P.E. is an oncologic centre located in Lisbon that was founded in 1923 by Professor Francisco Gentil. It has as a main goal to fight against cancer and oncologic diseases, by practising medicine through 3 main pillars – care, teach, and research – in order to help the oncologic patient [4].

IPO-L attends to the following regions: Lisboa e Vale do Tejo, Alentejo, Algarve, and the islands of Açores and Madeira (Figure 2.1). Overall, IPO-L serves a population of about 4 million habitants. Although the majority of the patients come from those regions, it does not mean that IPO-L won't treat patients from other areas [4].

Also, IPO-L is the only healthcare institution from its coverage area that has a service dedicated to paediatric oncologic patients. The institution has a capacity of around 287 beds for patients' admission, plus a nursing home with 178 beds for ambulatory patients and their caregivers [4].

Figure 2.1: Population areas covered by IPO-L [4]

2.2 X-Ray computed tomography

CT scan, X-Ray Computed Tomography or Computerized Axial Tomography Scan (CAT scan) (Figure 2.2) is a diagnostic technique that uses x-rays in a non-invasive way. The CAT scan provides doctors with information about the structure and anatomy of the patient, by reconstructing sections of the human's body. The computed tomography (CT) was invented in the 70's by Nobel laureates Sir Godfrey N. Hounsfield and Allan M. Cormack [5], more than 70 years after Wilhelm Conrad Röntgen first discovered the use of x-rays.

Figure 2.2: CAT Scan [6]

The CT uses X-ray to obtain data from several segments of the body, which are afterwards treated in a computer and transformed in images of body sections, in a transversal plane [7]–[9]. The CT is extremely useful since different parts of the body absorb the x-rays in different ways, making it easy to observe an anomaly. For example, since bone absorbs x-rays well, and better than tissues for most levels of radiation, in the image it will appear white. On the contrary, air does not absorb well x-rays, thus lungs, for example, are dark. Other tissues, like muscle, or even blood have different absorption levels to x-rays, and normally appear in shades of grey. Thus, when a patient has a tumour or a blood clot, this area appears in a different shading that the circulating tissue, making it easy for doctors to detect it [9]. That is the case of oncologic patients.

Over the years, there has been a big evolution in the field of CT scanners (Figure 2.3). The first CT scanner was installed in September 1971, at the Atkinson Morley's Hospital, but due to the small opening in the scan, it could only produce images of the head. At that time, with only two slices, it would take almost five minutes to do the scanning, which would result in an image of 80 x 80 pixels, with each pixel as 3 x 3 mm. It was only two years later, in 1973, that the first commercial CT scanner was made available, and but then, the scanning time was only 20 s [10]. The first whole body CT scanner was developed in 1974, at Georgetown university by Ledley [5]. In the following years, the evolution of CT scanners was mainly due to an increase in the number of detectors, which helped to reduce the time of scanning and improve image resolution [5], [10]. Until the 90's, the detectors and thus the CT scanners were acquired in a transaxial direction, while nowadays they are done axially, with manufacturers building the detectors in rows, in order to be able to scan several slices for each rotation [5].

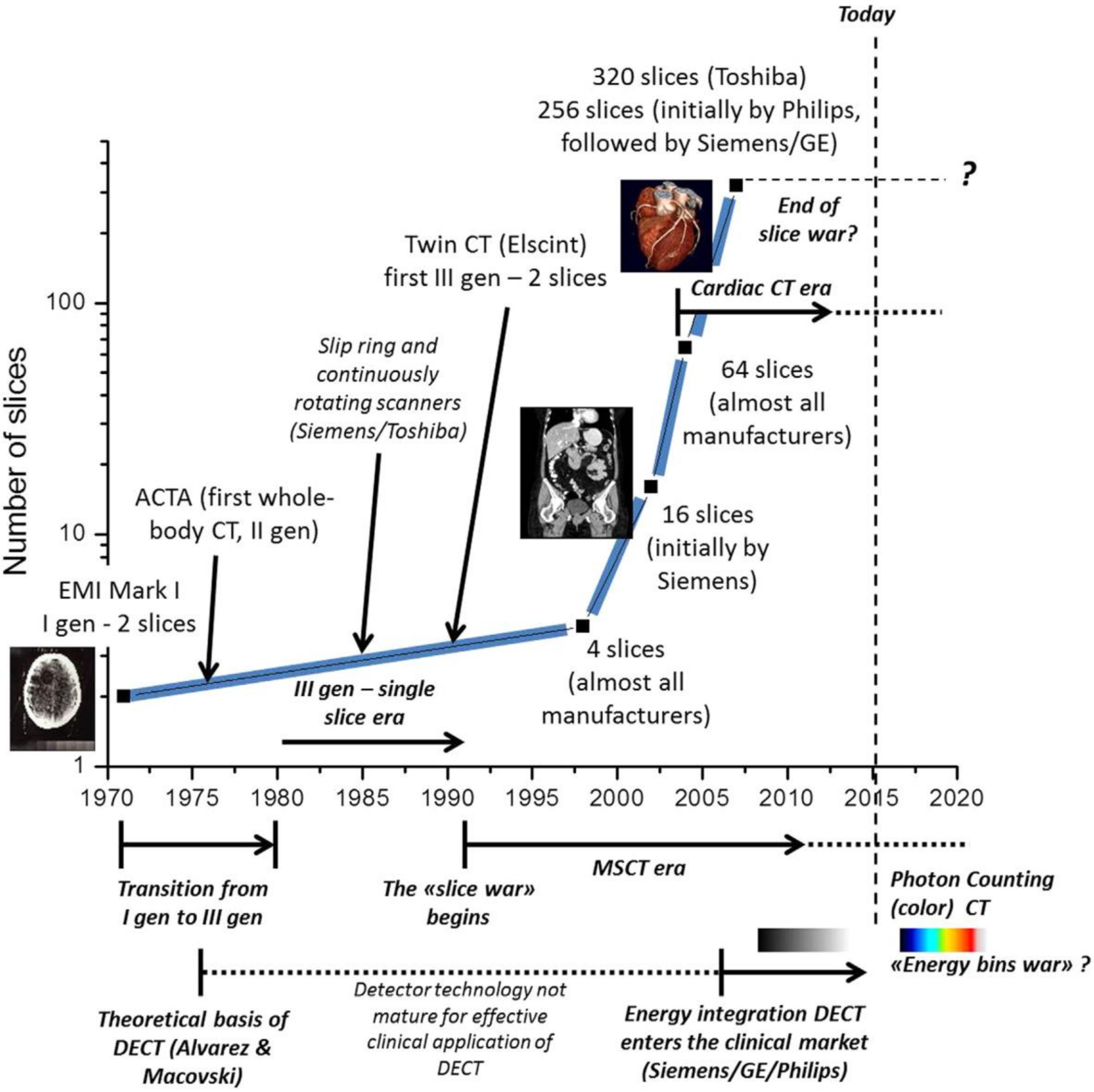

Figure 2.3: Evolution of CT scanners [5]

While in the beginning, only 2-slices CT scanners were available, in the past ten years manufacturers launched in the market scanners with 8, 16, 32, 64, 128, 256 and even 320 slices! Although these changes improved greatly the time and quality of acquisition (Figure 2.4), it can bring disadvantages related to patients' dose. Thus, researchers are now not as concerned in increasing the number of slices in the scanners, but focusing instead in reducing the dose of radiation received by patients, and the costs related with this industry [5].

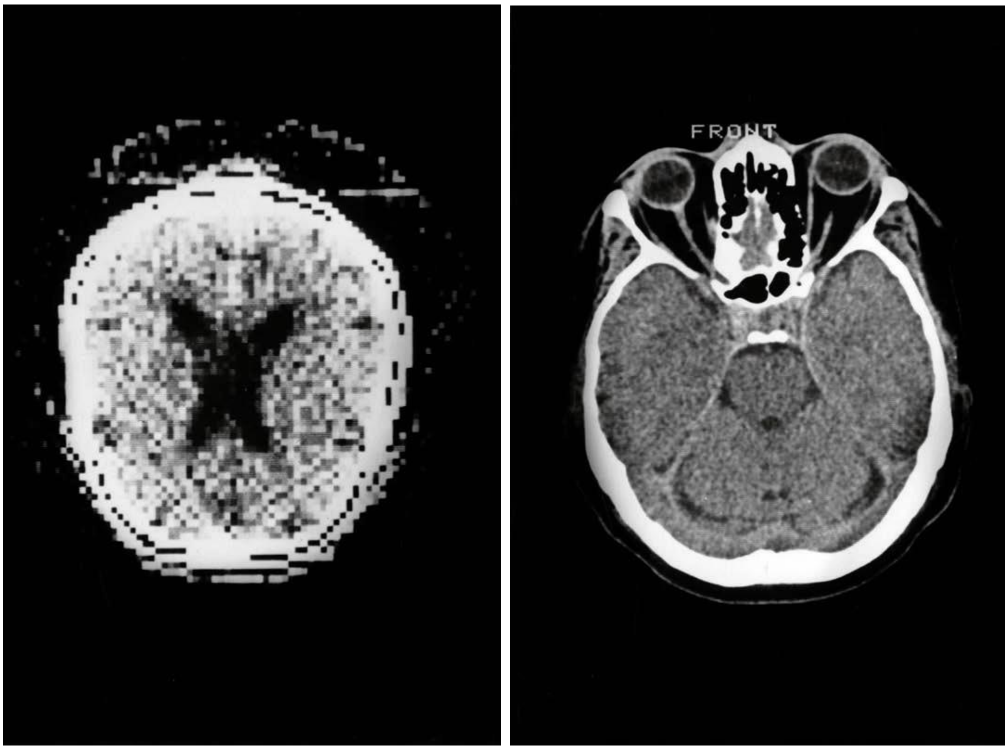

Figure 2.4: Cranial CT evolution: 1974 (left) VS 1983 (right) [11]

Nowadays, CT scans are able to the acquisition in hundred milliseconds, with an image of 2048 x 2048 pixels [10], which allows doctors to obtain images with much more quality, as seen in Figure 2.5.

Figure 2.5: A dual energy scan with the SOMATOM Definition Edge, University of Eriagen Nuremberg, 2014[11]

2.3 The methodology

According to Lacerda [12], the methodology framework of a research must not be understood as a bureaucratic act. Instead, it consists in choosing and justifying a method of research that allows:

i) To answer to the problem of research;
ii) To be evaluated by the scientific community;
iii) To point out procedures that strengthen the results of the research.

These steps should be seen as necessary procedures to assure impartiality, rigor and reliability of the results.

In this work we will use the Design Science Research methodology, which has as a main goal to study, research and investigate the artificial (phenomena created by man), and its behaviour. This way, Design Science Research consists in a rigorous process of projecting artefacts in order to solve problems, evaluate what has been estimated or what is functioning, and to communicate the obtained results [12], [13]. This methodology has been previously used in healthcare with success [14].

Every scientific methodology is defined by a group of rules and procedures, upon which research is based. The design research methodology is based on the following six steps [12], [13]:

(i) Problem identification.
The research has to demonstrate knowledge of the current state of the art and the relevance of the identified problem
(ii) Definition of the objectives for a solution.
Gather the objectives of the solution for the problem in question and acknowledge what is possible.
(iii) Design and development.
Creation of artefacts (model of evaluation)
(iv) Demonstration.
Demonstrate the use of the artefact to solve the problem

(v) Evaluation.

Observe and measure how well the artefacts support the solution to the problem.

(vi) Communication.

Communication of the new knowledge obtained by the research in terms of dissertations or journal articles.

According to Herbert Simon [15], an artefact is the organization of the components of an internal environment that attain certain objectives in a determined external environment. Thus, they can be models, methods, or instances [12].

Following this methodology, for this thesis, the artefacts considered will be the two methods used: scenario planning and multicriteria decision analysis.

3. Methods

3.1 Scenario Planning and MCDA

Life is about choices. Every day people are faced with numerous questions and tasks that force them to make a decision. Most of these decisions imply a simple yes or no answer, or an easy choice to make. What colour should I wear today? Do I want coffee? Or tea? And so on and so on.

Sometimes it is not as simple to formulate an answer or come up with a solution to a certain problem. This is something that happens frequently in management, where there are multiple objectives or alternatives that can sometimes be contradictory. These alternatives normally have to be selected based on more than one criterion [16].

With the increase of available information, it is not strange to observe a rising number of alternatives and criteria, that the Decision Makers (DMs) need to select, sort and classify, which means that making a decision might become a complex problem, and therefore take some time and effort [17].

Due to demographic changes, financial pressures, medical and technological developments, and policy changes, healthcare provision is suffering pressure for changing quickly. Given the ageing population and consequent budget pressures, already it is felt a strong pressure for more efficient healthcare systems. Governments and healthcare providers all over the world are looking for ways to cope with booming healthcare costs, that occur at the same time of cuts in governmental budgets [18].

The assessment of healthcare interventions is a very challenging task: from the investment and authorization, to the reimbursement and prescription, all facts must be taken into consideration. The different effects, either beneficial or not, and the fact that these effects might have greater value in a certain disease, or in one where there is no treatment, are also elements to take into consideration when making the evaluation of a healthcare intervention [19].

Also, uncertainty is one of the emerging constants in the modern world. The world is growing more complex. In fact, our social systems are growing so complex that they are beginning to defy understanding. In result, our systems of problem solving also become more complex [20]. However complexity also means higher resilience.

Nowadays, there is a relentless pressure on costs in all public decision making. We have entered a world where irreversible consequences, unlimited in time and space are now possible, and where the implications of solutions being formulated may take decades to be understood [20].

Besides pressure on costs, public perception is becoming more and more important. When it comes to uncertainties and risks, acceptability depends on whether those who bear the losses also receive the benefits. When this is not the case, the situation is often considered unacceptable. As a result, possibility is often accorded the same significance as existence in a stakeholder’s view [20].

But with the changing world, responsibility has also become less clear. Questions like “Who has to prove what? Who is responsible morally? And who is responsible for paying the costs?” are becoming the plague of planners, making many public decisions subjective in nature [20].

For all these reasons, we know now that decision making and planning processes operate in an uncertain reality. Thus, we need decision support tools to help us, like:

- Risk analysis;
- MCDA;
- Planning frameworks that are realistic and useful, like scenario planning;

3.2 Scenario Planning

Traditional planning processes are generally deterministic in practice, and rely on a forecast of a single most likely alternative future, that is usually attached to the present. While this was an acceptable practice in the past, when change was not as rapid and the social context was not as complex, nowadays we cannot rely on that since dependence on a single forecast might translate into an adversarial decision process because there are always legitimate differences in views of an uncertain future [20].

If there is little uncertainty and the consequences of being wrong are minor, any decision making method will do. But when uncertainty is high and the consequences of being wrong are grave, then we must consider other options like scenario planning, as it is an effective tool for strategic decision making under uncertainty [20].

This method is able to capture a whole range of possibilities in rich detail if properly applied [21]. A manager can build a series of scenarios to help to compensate for the usual errors in decision making, by identifying basic trends and uncertainties [22]. By expanding their imagination to a wider range of possible futures, managers can take advantage of the unexpected opportunities that come along [14], [22].

Scenario planning is a method that imagines possible futures that can be applied to a great range of issues [22]. Developed in the latter part of the 20th century in order to deal with the uncertainty that confronts modern decision makers, scenario planning is not forecasting and does not predict the future [14], [20].

This method was introduced by Herman Kahn, at the RAND Corporation in the 1950s/1960s, as to develop strategies for uncertain futures for the military of the US government [18],[20]. But it is the Royal Dutch Shell that is credited with popularizing and modernizing the use of scenario planning for strategic planning in the early 1970s [20],[22].

As said before scenario planning is not forecasting. In fact, this method is rooted in the suggestion that all forecasts are wrong. We can say that scenarios are plausible descriptions, but not predictions, of a future that an organization should be aware of, in order to adapt their strategic development [18].

Thus, scenario planning aims to build stories for the future that can contribute to the better understanding of the external environment in which an organization is operating and to support strategic decisions and anticipate difficulties [14], [20]. If one finds the meaning of the words, it will find that "Scenario" literally means an outline or synopsis of a play [20].

A strategic decision is defined as "a decision that forces the organization to ponder its very existence, independence, mission, and main field of activity" [18]. And each scenario is regarded as a "strategic case"[14].

If scenario planning is compared to other planning methods, like contingency planning, sensitivity analysis, and computer simulations, several differences will be found. For instance, while contingency planning examines only one uncertainty, as it presents a base case and an exception or contingency, the scenarios explore the joint impact of various uncertainties, which stand side by side as equals. Sensitivity analysis examines the effect of a change in only one variable, keeping all others constant. This makes sense when moving one variable at a time makes small changes. However, if considering change as a larger change, then the other variables will not stay constant. Scenarios keep up with this, as they change several variables at the same time. They try to capture the new states that will develop after major shocks or deviations in key variables. Thirdly, scenarios are more than just the result of a intricate simulation model. Instead they attempt to interpret that result by identifying patterns among the possible results a computer simulation might create. Therefore, scenarios represent more than objective analysis, as they include subjective explanations [22].

In a nutshell, scenario planning tries to capture all possibilities, by stimulating decision makers to consider changes they would not consider before [22].

The uncertainties are addressed by defining different scenarios for each relevant future state of the world. One can define scenarios as: “Developed by blending data and analysis with intuition and creativity, scenario plots must ‘hang together’ like a well-crafted novel, stretch the imagination without going outside the bounds of believability, and consistently address issues that are critical to decision makers” [20].

Each scenario is described in a narrative story style, with memorable names so that DMs can understand and identify how the different possible futures could end up in if managers ignore and disregard them. The narrative should be clear and concise, to help DMs and stakeholders to understand that particular future [20].

In traditional planning processes, only one of the four futures is identified as the most likely and then all resource management options would be evaluated against it. On the contrary, scenario planning considers all the options. Rather than choosing the plan that performs best if only one future state of the world is recognized, it is the plan that performs best across all futures that is considered the best plan [20]. In traditional planning, if the future turns out different than the most likely forecast the efficacy of the management options is compromised. With scenario planning this does not happen, as the plan chosen is the one with the best overall performance against all scenarios [20].

Although scenario planning can be used to make any type of decision, this method is more valuable when applied to corporate strategic planning [22].

Schoemaker [22] believes the two more common mistakes in decision making are underprediction and overprediction of a certain change. He believes that scenario planning offers a common ground between these two possibilities, as it help us to expand the array of possibilities that we can see, while not letting us enter the world of science fiction.

By dividing knowledge into 1) things people believe to know something about, and 2) things that are considered uncertain or unknowable, can simplify the work. Of course, nothing is set in stone, but not everything can be under uncertainty, or it would not be able to move forward. The challenge is to separate the components we are confident about from those that are largely uncertain [22].

The purpose of scenario planning is not to cover all possibilities, but to restrict them. No one wants to account for all the possible outcomes of each uncertainty, therefore the goal is to simplify them [22].

For that Schoemaker [22] proposes a 10-step process to develop scenarios:

1. Define the scope – The first step is to set the time frame and scope of the analysis;
2. Identify the major stakeholders – Define who will have an interest in the decision being made, and who will be affected by it;
3. Identify Basic trends – Define which trends will affect the problem (political, economic, social, technological, legal);
4. Identify key uncertainties – The uncertainties should also be divided in the categories: political, economic, social, technological, legal;
5. Construct Initial scenario themes – Build an initial scenario;
6. Check for consistency and plausibility – Check if the trends are compatible with the chosen frame, and if scenarios combine outcomes of uncertainties that go together;
7. Develop Learning scenarios –Name the scenarios;
8. Identify research needs – See if further research should be made;
9. Develop quantitative models – Analyse the scenarios again;
10. Evolve towards decision models – Build the final scenarios;

In a nutshell, the scenarios must cover a wide array of possibilities and highlight competing perspectives, while keeping focus on the interlinkages and internal logic of each future.

3.3 Multicriteria Analysis

Multi-Criteria Decision Analysis can be useful to support the evaluation of the scenarios [20]. MCDA consists of a group of methods that work as a tool to help DMs sort problems with conflicting objectives or multiple criteria [17]. These methods use a structured and logical approaches to resolve the problem in question, by comparing different alternatives [16], [23]. In order to do this, it is necessary to weight in each criterion, and normalize/scale them, so that they can be ordered and evaluated for each alternative [24], [25].

We can say that Multiple Criteria Analysis is very useful for analysing these types of problems, due to several reasons [26].

1. We can use multiple criteria;
2. Mixed data can be used;
3. Everyone can be involved;
4. MCDA has feedback mechanisms to analyse the consistency;

Besides these factors, MCDA is especially useful because we can separate the decision elements and track down the decision-making process, making it easier to communicate and explain the decisions made.[26]

"In an uncertain world the responsible decision maker must balance judgements about uncertainties with his or her preferences for possible consequences or outcomes." [27]. The process of MCDA can be divided in 5 steps: [27]

1. Pre-analysis – The problem is identified and the alternatives are selected;
2. Structural analysis – The problem is structured in a qualitative way, that is organized in a decision tree;
3. Uncertainty analysis – Probabilities are assigned ;
4. Utility or value analysis – Utility values are assigned to the consequences associated with paths through the tree. The decision maker must assign numbers to consequences (such as u'_i to C'_i and u''_j to C''_j) in such a manner that he feels that

$$(a' \textit{is preferred to } a'') \leftrightarrow \left(\sum_{i=1}^{m} p'_i u'_i > \sum_{j=1}^{n} p''_j u''_j \right)$$

5. Optimization analysis – The decision maker calculates his optimal strategy;

At each tip of the tree there is a consequence C that describes the impact of that position. The decision maker is called on not only to rank the consequences at the tips of the tree but also to evaluate the strengths of his preferences and his attitudes toward risk [27].

It is likely that objectives will conflict with each other in that the improvement achievement with one objective can only be accomplished at the expense of another. An objective generally indicates the "direction" in which we should strive to do better [27].

To be useful to the decision maker, a criterion should be both comprehensive and measurable. A criterion is comprehensive if, by knowing its level in a particular situation, the DM has a clear understanding of the extent that the associated objective is achieved. A criterion is measurable if it is reasonable to obtain a probability distribution for each alternative and to assess the decision maker's preferences for different possible levels of the criterion [27]. A comprehensive criterion should be relevant to the alternative under consideration. In many cases, choosing a criterion will not be difficult if the objective is clear [27].

Let's assume a MCDA problem with *m* alternatives and *n* decision criteria [28]. The weights reflect the relative importance of each decision criterion, and these are usually normalized by making their sum equal to 1 ($\sum_{j=1}^{n} w_j = 1$). Given the specific performance value $a_{j,k}$ of each alternative *k* *(k=1,2,…,m)* in terms of each criterion *j* *(j=1,2,…,n)*, the overall performance of each alternative *k* can be calculated as follows [29]:

$$P_k = \sum_{j=1}^{n} w_j a_{j,k}, k = 1,2, \dots, m$$

We assume that input can be obtained from several individuals, where each individual *i* may list and rank the *n* criteria that contains only n_i criteria he or she deems to be relevant ($n_i \leq n$). Thus, a list of n_i prioritized (ranked) criteria is given by each individual *i*, who gives each criterion *j* a rank $r_{i,j}$, ($r_{i,j} = 1, \dots, n_i$) [29].

Before starting to consider approaches, it is necessary to have input from the stakeholders. This means collecting information about the problem, and the different alternatives, and criteria [26]

Multi-Criteria Decision Analysis can be divided into two groups: Multiple Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM) [16], [30]. Depending on the number of DMs, methods can be classified as single or group decision making methods [25], [30].

If there is a defined number of alternatives, then MADM is used. If on the contrary, there is an infinite number of alternatives, MODM is used. In MODM, the conflicting objectives are optimized and subjected to a group of defined constraints, by a mathematical programming model [16].

In this study, we will use MADM methods. MADM prioritizes alternatives in order to make a decision. Since each alternative is characterized by multiple attributes/criteria, these are evaluated and ordered by each method [16].

Since it first started being used in the 1950s, MADM methods have been developed by several researchers, which resulted in methodologies based on different approaches. If considering the attribute information processing, there is non-compensatory and compensatory processing models. The first ones do not allow trade-offs between attributes, meaning that a disadvantage in one attribute, cannot atone for an advantage another attribute. This means that comparisons have to be made attribute-by-attribute. Compensatory models allow trade-offs. Although these models might be more demanding in a cognitive way, they provide solutions that are closer to the optimal outcome [16].

MADM methods can also be based on an outranking approach. In these methods, also called preference aggregation based approaches, the DMs can express a strict preference or indifference when comparing one alternative to another, for each criterion. Two of these methods can be highlighted: 1) ELECTRE - the elimination and choice translating reality method, and 2) PROMETHEE – the preference ranking organization method for enrichment evaluation method [16], [23]

The ELECTRE was first mentioned in 1966 by Benayoun, Roy and Sussman. The ELECTRE classify preferred alternatives and non-preferred ones by establishing outranking relationships, and using concordance and discordance indices and threshold values to analyse the outranking relations among the alternatives [16], [23], [31]. It can analyse quantitative and qualitative data [30].

PROMETHEE was developed by Brans in 1982. Although it also uses the outranking principle, PROMETHEE is easier to use and less complex. It is suited for problems with a finite number of alternatives that are to be ranked with respect to several conflicting criteria. We can classify six criteria functions: usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area, and a Gaussian criterion[16], [23].

Other methods can also be used that have their own mathematical foundation, or are based on an utility function. This means that these methods synthesize all information into a unique parameter. Some call these the Performance Aggregation based approaches[23].

One of these methods is AHP – Analytical Hierarchy Process, proposed by Saaty in 1976. AHP converts subjective assessments of relative importance to a group of scores or weights. It is considered a quantitative comparison method, because it selects the preferred alternative by using pairwise comparisons of the alternatives based on their relative performance against each criterion. This results in an arrangement of the important components of the problem organized in a hierarchically structure, like a family tree, which makes it easier to capture the preferences of the DMs [16], [23], [26].

Pairwise comparisons (PC) filter the different criteria into a series of one-on-one comparisons regarding the significance of each indicator relative to the criterion that it describes. Each indicator from under a criterion is compared with all the others indicators under the same criterion, so that they can be ordered according to their relative importance. PC is very useful because it can measure ordinal and cardinal data, and can be analysed for consistency, through a consistency index, that indicates where there is a great inconsistency among the responses, making the analysis more reliable and accurate [26].

The TOPSIS – Technique for order preference by similarity to ideal solutions is also a method which has its own mathematical basis. It was developed in 1981, by Hwang and Yoon, and it is a utility-based compensatory approach, that uses distance-based to quantify and compare the preferences of the alternatives over the set of attributes. The algorithm used by TOPSIS rank the alternatives in a straightforward way, that can be pictured in a graph. This is a MADM method usually used when dealing with information on a cardinal scale [16].

These are just a few methods of MCDA. Each one has stronger and weaker factors, which include: Type of data, weights typology, threshold values, compensation degree, uncertainty and sensitivity analysis, robustness, and software support [23].

Data can be either quantitative or qualitative. If it is qualitative, the information is reduced to point scales. This is one of the advantages of MCDA methods, since it doesn't apply restrictions to the type of data being analysed [23].

Weights typology can be distinguished between coefficients of importance and trade-offs. If the weights are considered trade-offs, meaning that they can be accepted among the criteria, this will have implications in the aggregation procedure, since the scaling of criteria and the weights are now connected and dependent on each other, therefore when one changes, the other has to follow accordingly. If we consider the weights as importance coefficients, it means they indicate the voting power of the criterion, thus contributing to the building of the outranking relation. Importance coefficients are independent from the measurement scale of the criteria, and are representative of non-compensatory methods [23].

Depending on if we have a performance or preference aggregation method, we can have different degrees of compensation. Performance aggregation methods, like AHP, assume complete compensation among the criteria. The aggregation of all the criteria in a unique value that implies full compensation among them means that a bad performance in some criteria can be offset by a good performance in others [23].

Uncertainty is usually used in two occasions: 1) when weighting the criteria, and 2) when assessing the performance of the alternatives. The sensitivity analysis helps us to distinct the treatment of uncertainty at the input and at the output stage. If using the AHP methods, we can use the inconsistency index to indirectly measure the uncertainty of the weighting of the criteria. The sensitivity analysis is applied on criteria weights at the output stage [23].

All these methods can be aided by different software.

4. Development of the Methodology

This chapter presents the methodology followed in this dissertation. Firstly, in section 4.1, the identification of the problem is presented, as well as the possible solutions. Then, in section 4.2, the scenario planning analysis is implemented, followed by the multicriteria analysis in section 4.3.

4.1 The identification of the problem

Instituto Português de Oncologia de Lisboa currently holds two CAT scanners in their inventory, both of 16 slices. One of the two equipments, acquired in January 2009, will end its life span on 31st December 2016. This means that after this date the manufacturer will not be able to assure the replacement of the machine's parts. If the hospital decides to keep this machine, then they face two scenarios:

1) the machine has no problems and there is no need for substitution of its parts, or

2) there is a problem with a machine's part that the manufacturer cannot solve, and the hospital ends up with only one machine running, and needs to do the rest of the exams at another hospital until another machine is bought, which might take months. The risk associated to the functioning of the machine and its parts will grow every year, as it is more probable that the machine might have a

problem, and that the manufacturer no longer has the component needed to replace.

This equipment is of extreme importance to the hospital, since both machines perform over 35.000 exams a year (Table 4.1), i.e around 100 exams per day. Each exam that the hospital cannot perform in its facilities and needs to be done in another hospital has the cost of 42,5€.

Table 4.1: TC Exams performed at IPO-L

IPO-L	**Quantity**		**Variation**	
Exam	**2015**	**2014**	**Δ**	**(%)**
TC Scan (2)	37.664,00	38.747,00	-1.083,00	-2,80

IPO-L's decision makers now face three options:

1) Keep the old machine, with the increase risk of failure in the near future
2) Or acquire a new CAT scanner, either by:
    a. Direct acquisition
    b. Leasing contract

If the Hospital decides to acquire a new CAT scanner, then it will be a scanner of 128 slices. The hospital chose the 128 slices scanner as the model to replace since it will provide a better quality in image, and therefore a better diagnostic, as well as producing a lower dose of radiation for the patient.

4.2 Scenario planning

The first part of the analysis is based on scenario planning methodology, as to better understand the environment in which IPO-L is operating.

The first thing to do is to define the time frame for the scenarios, which can depend on several factors: from the rate of technology change to political elections. For the following project we will consider a five year time frame. The life cycle of a CAT scanner is around 8 years, so anything beyond eight years might not be applicable, and five years is a period long enough to present several changes.

To understand how each scenario will play out, and who, and how it will affect, we must identify and define the major stakeholders in the situation.

According to the Agency for Healthcare Research and Quality, stakeholders are defined as “persons or groups that have a vested interest in a clinical decision and the evidence that supports that decision” [32]. Thus, it can be said that a stakeholder is any person or party who provides, receives, manages or pays for healthcare. For this work, the stakeholders were organized in 4 main groups: Providers, Payers, Employers, and Patients, as seen in Table 4.2 [19].

Table 4.2: Major Stakeholders of the problem

Providers	Includes doctors, nurses, etc. Their main focus in the accuracy of the diagnostic, in order to recommend an appropriate therapy, which can then result in the optimal health result. They want to do the best examination with the most accurate and advanced treatment possible. For them, this should always be the case, even if the patient’s care provider does not cover the treatment payment.
Payers	Focus on cost-effectiveness. For them it is necessary to have a clear and accurate diagnostic, with the minimum amount of tests and treatments. Can be insurers, health care institutions and policymakers.
Employers	Their main goal is to minimize costs and optimize the service of employees and machines. They want to keep their costs at the minimum value possible, and for patients to only seek them when care is needed. They also want for patients to follow their instructions, in order to recover quickly and reduce the possibility of a relapse in the future. Patients should make the effort to reduce the risk of health problems – no smoking, no fast food, exercise regularly.
Patients	Want skilled workforce, associated with compassion, clear communication, and prompt service. They want a wide offer of solutions, and want the employer or their care provider (insurance) to fund the majority, or the totality, of the treatment.

It is important to acknowledge that uncertainty is present in any firm’s life and that manager’s make a huge effort to minimize the risks associated to it. In order to gain an insight if the most relevant trends of the macro environment in which IPO-L is incorporated, a STEEP analysis was executed. In doing so, the driving forces with the highest impact and the highest uncertainty in terms of direction and speed of evolution were selected.

The STEEP analysis is done by focusing on the driving forces or trends, which are the fundamental sources of future change. The trends can be divided into 5 groups: Social, Technological, Economic, Environmental, and Political. By identifying these trends, it is possible to enhance the ability to imagine future scenarios and understanding future events. We can also classify their impact to IPO-L in terms of positive or negative, depending if they bring opportunities or challenges, respectively.

Social trends (Table 4.3) can affect the demand for a company's product, and how the company operates.

Table 4.3: Social Trends

Social		
Trend	**Description**	**Impact**
S_1 – Ageing population	An ageing population has greater needs for medical treatment, meaning the long term prospects for healthcare facilities are good. More demand for services for the aged.	Positive
S_2 – Age distribution	Being an expert hospital in oncology, means that the hospital must have a business model that will suit the young, the adults and the ageing population. Caring for everyone regardless of age is an initiative that will give the hospital a positive image and improve business.	Positive
S_3 – Health Consciousness	Everyone wants to stay healthy and have a reasonable standard of living.	Positive
S_4 – Cancer	The hospitals will have more customers subscribing for medical care. In this case customer retention will also be high since oncologic patients are obliged to do several check-ups.	Positive
S_5 – Connectivity & Internet	Internet is now a major part of people's lives, and the way in which business operate. This means that the hospital has new ways to keep in touch with patients, and thus improving their communication.	Positive
S_6 – Patient awareness, changing expectations	More pressure on customer service, increased need for education and more price transparency	Positive

Technological trends (Table 4.4) do not necessarily involve technical equipment, and can be new approaches to problems and new ways of thinking. They can determine barriers to entry, and affect the efficiency, costs and quality.

Table 4.4: Technological trends

Technological		
Trend	**Description**	**Impact**
$\boldsymbol{T_1}$ – Research & Development	The hospital should also invest more on R&D on the latest patient care development. This will give them a competitive edge against hospitals which have not yet introduced the practice.	Positive
$\boldsymbol{T_2}$ – Fast rate of change in technology	Increase in price, not being able to keep up with the changes	Negative
$\boldsymbol{T_3}$ – Online health platforms	The hospital can advertise some of its services online by creating health forums. This way, customers can easily access health information and making informed decisions.	Positive
$\boldsymbol{T_4}$ – Online Diagnosis	Possibility to diagnose a patient regardless of where they are. The online diagnosis mechanisms brings a positive change to the hospital	Positive
$\boldsymbol{T_5}$ – Mobile healthcare	The hospital can take advantage of the trend and bring patients closer to its services by taking care of their need through the use of mobile technology.	Positive
$\boldsymbol{T_6}$ – Social media	New digital opportunities	Positive
$\boldsymbol{T_7}$ – Customized treatments	Directed to patient communications	Positive

Economic trends (Table 4.5) have an impact in the way business operate and make decisions. They also represent the financial resources available.

Table 4.5: Economical trends

Economical		
Trends	**Description**	**Impact**
E_1 – Economic growth	Industry highly dependent of the economic growth	Positive and Negative
E_2 – Rates	Healthcare is highly correlated with rates	Positive and Negative
E_3 – Outpatient Services	Working with community providers to increase referrals, adding new services. Expanding existing treatment areas.	Positive
E_4 – Ageing Health infrastructure	Low level of investment results in systems in desperate need for modernization to overcome the challenges that have arisen over the years.	Negative
E_5 – Responsive to economic change	Changes in economy may result in the changes in staff.	Negative
E_6 – Global economic crisis	Reluctance of consumers to spend on healthcare	Negative
E_7 – Reduction in individual disposable income	Increased pressure on pricing, however the market it likely to grow due to aging population	Negative

Table 4.6: Environmental trends

Environmental		
Trends	**Description**	**Impact**
En_1 – Green Industry	The use of technology, equipment and resources that are friendly to the environment will reduce the impacts of global warming.	Positive
En_2 – Sustainability	The long term use of green technology on medical resources will lead to sustainability of resources.	Positive
En_3 – Waste management	Disposal of wastes is a sensitive issue.	Negative
En_4 – Growing environmental agenda	Identify opportunities to market	Positive
En_5 – Management for Carbon storage	The hospital must recognise the benefits of using green technology to reduce carbon footprints and minimize waste.	Positive

Political trends (Table 4.7) can affect the performance and the options open to the organisation. They represent the degree to which a government intervenes.

Table 4.7: Political trends

Political		
Trends	**Description**	**Impact**
P_1 – Cyber Terrorism	Medical databases hold sensitive data of patients.	Negative
P_2 – Government Regulations	The government's policy has allowed private health care industry to play an important role in health.	Negative
P_3 – Public Health Decline	The public healthcare has been reported to be in decline.	Positive
P_4 – Local Taxation and finance	The government heavily imposes taxes on hospitals and this has a negative effect on the overall revenue of the hospital.	Negative
P_5 – Growing political focus and pressure on healthcare	More pressure on pricing	Negative
P_6 – Harmonization of healthcare across Europe	Reference pricing, exposing prices across borders	Positive & Negative

For a better understanding a diagram was set on which all trends are ranked from the lowest to highest impact/uncertainty, as seen on Figure 4.1. Zero means lowest impact/uncertainty, while ten means highest impact/uncertainty. These values were attributed by considering how each trend would influence IPO-L individually.

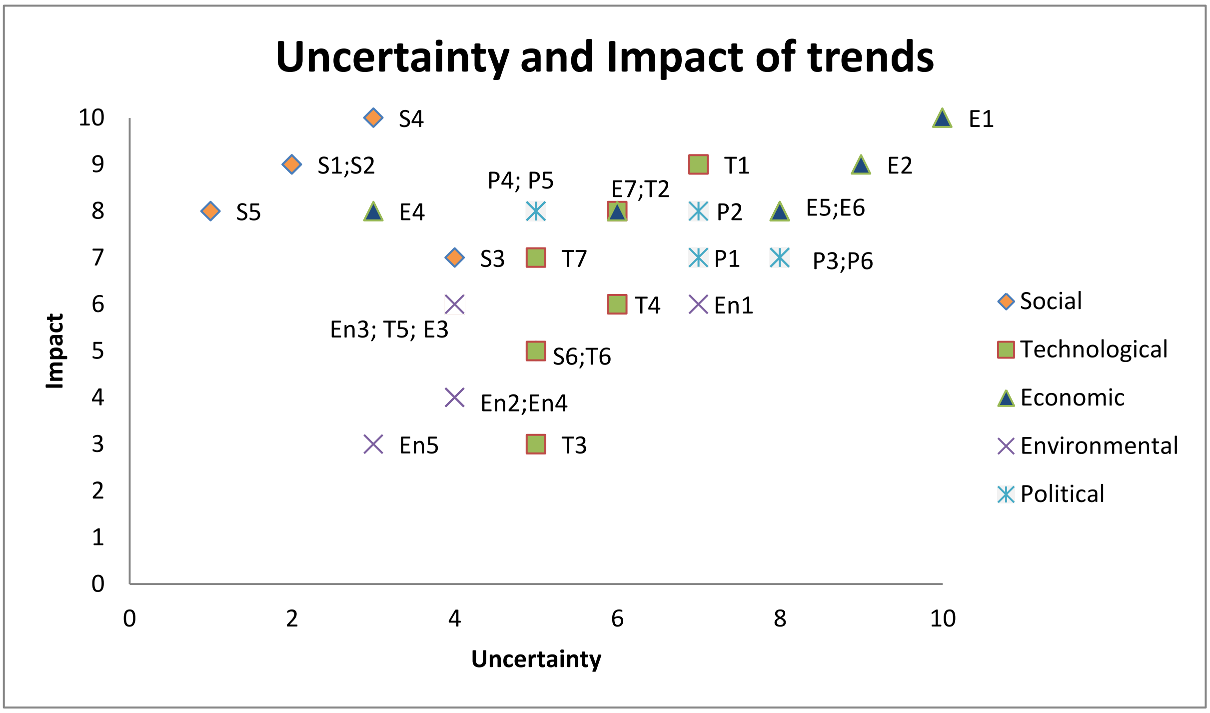

Figure 4.1: Trends Diagram

This way identify key uncertainties that will affect the issue at hand can be identified. The uncertainties are also divided in the six categories: political, economic, social, technological, legal and industry.

Table 4.8: Key uncertainties

Uncertainties	
Social	
S4 – Cancer: There will be a probable increase in the population affected by this disease, but medical breakthroughs might also mean a cure for cancer.	
Technological	
T1 – Research & Development	Associated can create an even bigger impact on the healthcare industry. From drugs, machines, genetic manipulation, etc
T2 – Fast rate of change in technology	
Economical	
E1 – Economic Growth	The biggest uncertainties and the ones that can cause a bigger impact in the industry.
E2 – Rates	
E5 – Responsive to economic change	

E6 – Global economic crisis	
Environmental	
En1 – Green industry	Can transform the way the world uses technology.
Political	
P2 – Government Regulations	Regulations are firmly in place, and there is no way around them. But with the change in government, so can come the change in legislation.
P6 – Harmonization of healthcare across Europe	A big uncertainty in the near future. With the immigration crisis, plus the economic recession, it could cause a big impact in the healthcare industry.

The initial scenario themes are now ready to be constructed, since the trends and the uncertainties are defined. The top two uncertainties will be selected and crossed, in order to create a graph with the different scenarios.

The goal is to select the trends that not only have the maximum impact, but also are the most uncertain in terms of direction and speed of evolution. Since the majority of the most key critical uncertainties are related with economic and technologic factors, it was decided to group these uncertainties by creating two global critical uncertainties, which have the highest impact and/or highest uncertainty to influence IPO-L' long-term strategy. These two global critical uncertainties are the economic situation and medical breakthroughs. Thus, a matrix with three different scenarios was developed.

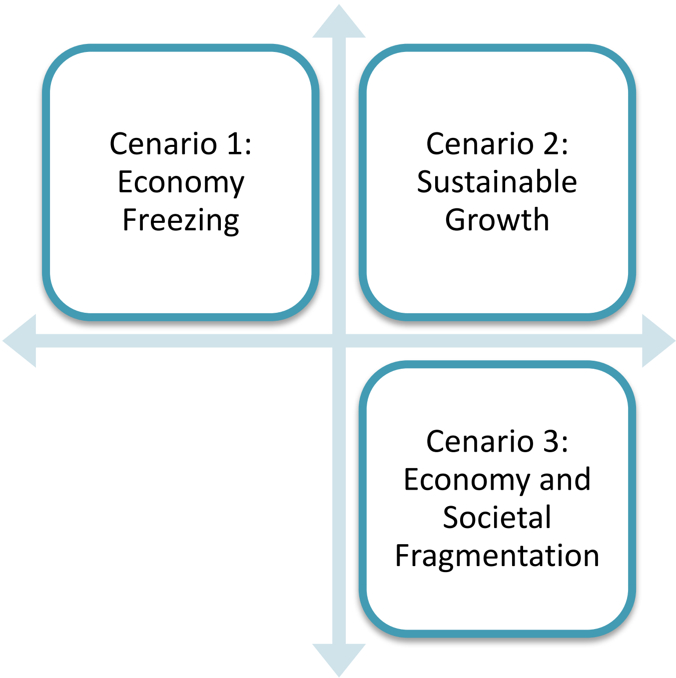

Figure 4.3: Scenarios Matrix

Scenario 1 – Economy Freezing

Characterized by a continuing mild recession, associated with an increase in medical costs. The population keeps getting older, and a rise in chronic illnesses is observed. Hospitals and clinics have lack of personnel, as management is more focused on costs and life cycle, leading to an increase in outsourcing.

Scenario 2 – Sustainable Growth

Economic boom does not mean a decrease in health care costs. On the contrary, these increase and are associated with repeated medical breakthroughs, including the cure for cancer, and improvement in genetic modification. Although with an ageing population, the concern about healthy lifestyle increases. Hospitals are more efficient, and adapt a patient oriented business model, which includes healthcare home delivery.

Scenario 3 – Economy and Societal Fragmentation

The aggravation of the economic crisis translates into a bigger economic recession, which leads to a bigger income differential and the disruption of the classes. The government starts to exert more control on healthcare provision. There is a drain of doctors and personnel, causing low efficiency, low level of innovation, and an aggregation of healthcare providers.

4.3 MCDA Evaluation

In order to better understand the structure of the MCDA analysis, and evaluate the problem at hand, first some notation must be defined.

The different alternatives will be given by:

$A_i - Alternative\ i\ to\ the\ problem$

$i = 1, \dots, N$

$N - number\ of\ alternatives\ to\ the\ problem$

While the criteria will be set as:

$C_j - Criterion\ j\ to\ evaluate$

$j = 1, \dots, M$

$M - number\ of\ criteria\ available$

Since the problem definition was already defined in the previous sections, the first step in the MCDA analysis is the explanation of the criteria, as seen in Table 4.9. In the case of IPO-L, the criteria are mainly related with economic factors, since the goal of the hospital is to keep providing a quality service, but by minimizing their costs and optimizing the use of the machine. The investment cost, the maintenance and operational cost will all be grouped in the same criterion.

Table 4.9: Criteria used in MCDA

Criteria	Description
C_1 – Costs	Includes investment, maintenance cost, and operational cost
C_2 – Quality	Evaluates the operational capacity of the equipment, its efficacy and quality of diagnostic
C_3 – Organizational impact	Human resources, …
C_4 – Operational Risk	Evaluates the possible risk in which the machine stops working due to technical problems

The different alternatives to the problem are explained in Table 4.10:

Table 4.10: Alternatives to the problem

Alternative	Description
A_1 – Keep the old machine	Keep the old machine. Finish paying the amortization until 2018, as well as a maintenance contract.
A_2 – Direct acquisition of a new machine	Replacement of the old machine by one of 128 slices. Direct acquisition with 2 years of warranty, and a contract of maintenance.
A_3 – Leasing contract for a new machine	Replacement of the old machine by one of 128 slices. Leasing contract with everything included. 2 options: a) monthly rent for 60 months b) monthly rent for 84 months

In order to be able to compare the criterion that represents the costs of the different alternatives, the present value (PV) of the each one was calculated (Table 4.11-4.15), since we can only compare cash flows at the same point in time. The formula for the present value is given by:

$$PV(A_i) = \frac{C_i}{r}\left(1 - \left(\frac{1}{1+r}\right)^n\right)$$

Where C_i is the yearly cash flow to pay, r is the discount rate (in this case 3,25% - value provided by the management team at IPO-L), and n is the number of periods.

Table 4.11: Cost Analysis for Alternative 1

	2017	2018	2019	2020	2021
Initial Investment	0 €	0 €	0 €	0 €	0 €
Maintenance + Operational Costs	70.000 €	70.000 €	70.000 €	70.000 €	70.000 €
Amortizations	38.496 €	38.496 €	0 €	0 €	0 €
Send to exterior	*	*	*	*	*
PV	391.698,86 €				

*In the previous case the number of exams to be sent to the exterior is dependent on the operational risk of the machine, thus it will not be included in this cost analysis.

Table 4.12: Cost Analysis for Alternative 2

	2017	2018	2019	2020	2021
Initial Investment	349.000 €	0 €	0 €	0 €	0 €
Maintenance + Operational Costs	115.000 €	70.000 €	70.000 €	70.000 €	70.000 €
Amortizations	0 €	0 €	0 €	0 €	0 €
PV	699.902,00 €				

Table 4.13: Cost analysis for Alternative 3 - a)

	2017	2018	2019	2020	2021
Initial Investment	0 €	0 €	0 €	0 €	0 €
Maintenance + Operational Costs	0 €	0 €	0 €	0 €	0 €
Amortizations	85.900,32 €	85.900,32 €	85.900,32 €	85.900,32 €	85.900,32 €
PV	390.605,86 €				

Table 4.14: Cost analysis for Alternative 3 - b)

	2017	2018	2019	2020	2021	2022	2023
Initial Investment	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Maintenance + Op. Costs	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Amortizations	63.314,76 €	63.314,76 €	63.314,76 €	63.314,76 €	63.314,76 €	63.314,76 €	63.314,76 €
PV	390.778,69 €						

The Present Values for the different alternatives can be compared in the following table:

Table 4.15: PV of the different alternatives

$\boldsymbol{PV(A_1)}$	391.699 €
$\boldsymbol{PV(A_2)}$	**699.902 €**
$\boldsymbol{PV(A_{3a})}$	390.606 €
$\boldsymbol{PV(A_{3b})}$	390.779 €

From table 4.15, it can be concluded that Alternative 2 is the less desirable concerning the criterion of cost, since it has the highest present value, and thus it means a higher cost for the hospital.

Regarding the criterion of Quality, we can compare the technical specifications for both machines that are being considered:

Table 4.16: Technical Specifications of CAT Scanners

	Siemens SOMATOM Sensation 16 [33][34]	**CAT 128 Slices** [35]
Detector	Ultra Fast Ceramic with adaptive array detector	Ultra Fast Ceramic (UFC)
Number of acquired slices	16	128
Rotation time	Up to 1.5 s	Up to 0.3 s
Temporal resolution	-	Up to 150 ms
Generator power	60 kW	80, 100 kW
kV steps	80, 100, 120, 140 kV	70, 80, 100, 120, 140 kV
Isotropic resolution	-	0.33 mm
Cross-plane resolution	-	0.33 mm
Max. pitch	-	Up to 1.5; up to 192 mm/s coverage
Table Load	Up to 200 Kg	Up to 307 kg
Gantry opening	70 cm	78 cm
Dose	-	Reduce radiation dose up to 60%
Features	z-Sharp technology, STRATON x-ray tube, CARE Dose4D, High speed volume scanning, Proprietary z-UHR technolgy[36]	FAST CARE technology and Single Source Dual Energy ,z-Sharp technology, STRATON x-ray tube, half the time, half the dose

Since Alternative 1 has the technical specification of a Siemens SOMATOM Sensation 16, and Alternatives 2, 3a), and 3b) have similar technical specifications of a CAT of 128 slices described in Table 4.16, it can be concluded that Alternatives 2, 3 a) and 3b) are equally preferred when compared to one another, and more preferred when compared to Alternative 1.

Regarding the criterion of Organizational Impact, the impact of the different alternatives is relatively similar. This happens since the alternatives will not demand changes or sacrifices in the organizational structure of the hospital. This will probably also be the criterion that will have less weight in the overall evaluation of the criteria.

Regarding Operational Risk, although no official numbers are provided, it is known that the risk of Alternative 1 is much higher than any other Alternative, as it was explained above. Thus, it can be concluded that this will be the least desirable Alternative regarding this criterion. While Alternative 2 has a much smaller risk, since it will be protected by a two-year warranty and a maintenance contract with spare parts guaranteed, Alternatives 3a) and 3b) carry no risk, since everything is covered in the leasing contract. Therefore, both alternatives are the preferred ones regarding this criterion.

For this case, the Analytic Hierarchy Process method will be used. As previously said, this method is based on $n \times n$ matrix, where the lines and columns are the n criteria evaluated for the case.

After defining the alternatives and the criteria, an hierarchy tree can be built, based on De Lima's study [17], as seen in Figure 4.4.

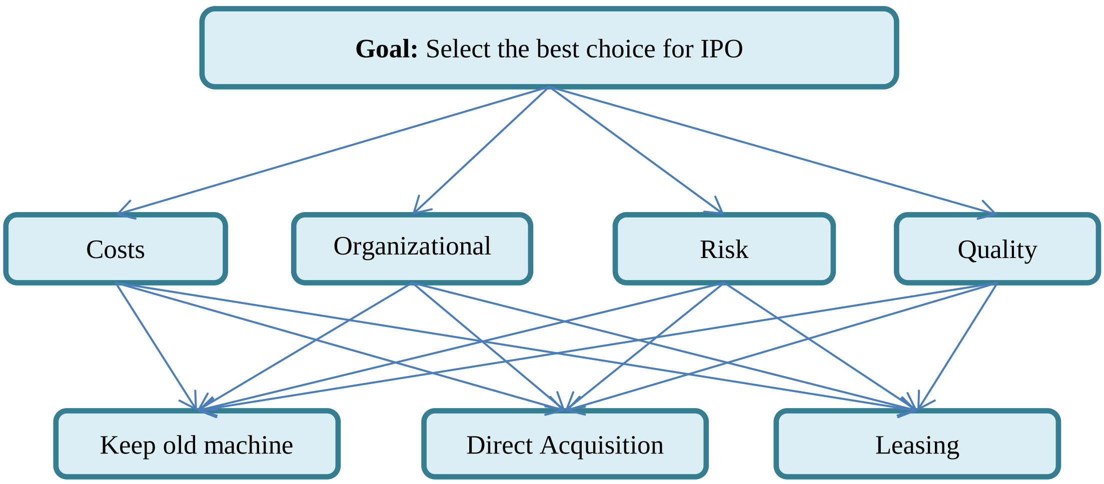

Figure 4.4: Choice hierarchy composition

As to compare the different criteria for the different alternatives to the problem, the criteria must be in the same gauge, thus they must be normalized. In order to that, there must be created a scale for comparison. Since the AHP method is being applied, the pairwise comparison scale will be used, as seen in Table 4.17 and Table 4.18:

Table 4.17: Pairwise Comparison Table [24], [37]

How important is A relative to B?	Preference Index Assigned
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9

Table 4.18: Scale for pairwise comparison [24]

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	Equal	Moderately	Strongly	Very Strongly	Extremely
Less Important/Preferred					More important/Preferred			

Now, the pairwise comparison matrix (Table 4.19) can be built based on the preference and importance of the criteria:

Cost is "extremely more important" than organizational impact (9), "very strongly more important" than quality, and "moderately to strongly" more important than operational risk.

Operational Risk is "strongly" more important than quality, and "strongly to very strongly" more important than organizational impact.

Quality is "moderately" more important than organizational impact.

Table 4.19: Pairwise Comparison Matrix for the criteria

	Costs	Quality	Organizational Impact	Operational Risk	Sum
Costs	1	7	9	4	21,00
Quality	1/7	1	3	1/5	4,34
Organizational Impact	1/9	1/3	1	1/6	1,61

Operational Risk	1/4	5	6	1	12,25
Sum	1,50	13,33	19,00	5,37	

The next step is to transform the pairwise comparisons matrix into a set of normalized scores that represent the relative importance of each weight of each criterion. The normalization is done by completing the following steps:

1) Sum the numbers in each column of Table 4.19, and
2) Divide each entry by the previous sum and sum each row (Table 4.20)
3) Calculate the average value of each row (Table 4.21)

Table 4.20: Normalized Scores of the Criteria

	Costs	Quality	Organizational Impact	Operational Risk	Sum
Costs	0,66	0,53	0,47	0,75	2,41
Quality	0,09	0,08	0,16	0,04	0,37
Organizational Impact	0,07	0,03	0,05	0,03	0,18
Operational Risk	0,17	0,38	0,32	0,19	1,04

The average value for each criterion corresponds to their normalized weight. The criterion with the highest average score is the most important one, in this case the cost, followed by the operational risk.

Table 4.21: Consistency Analysis of the Criteria

	Average Score	Consistency Measure	CI	CR
Costs	0,60	4,48	0,13	0,14
Quality	0,09	4,01		
Organizational Impact	0,05	4,09		
Operational Risk	0,26	4,38		

In order to analyse the consistency of the values, the consistency measure, the consistency index (CI), and the consistency ratio (CR) will be calculated [38]. The consistency measure can the found through Excel by using the function =MMULT(), which is basically a function that multiplies matrixes.

The consistency index is given by the following equation [38]:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Where λ_{max} is the sum product of the average score values with the sum of each column, and n the number of criteria.

The consistency ratio tells the decision maker how consistent he has been when making the pairwise comparisons. In practice this value should be 0,1 or below to be considered acceptable. The CR is given by [38]:

$$CR = \frac{CI}{RI}$$

RI is a random index, which can be found in Table 4.22 [38]:

Table 4.22: Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

Once the scores for the criteria have been found, the focus turns to the level 2 of the hierarchy tree (Figure 4.4), where each alternative must be evaluated regarding each criterion.

The same methodology applied above is used for the following calculations, in which each alternative is ranked for each criterion. Thus, four matrixes will be developed (Table 4.23, 4.26, 4.29), one regarding each criterion, where each alternative will be pairwise compared against every other alternative relative to the same criterion.

Regarding **Costs**, Alternative 1 is “moderately less” preferred than Alternatives 3a) and 3 b), but is “very strongly to extremely” more preferred than Alternative

2. Alternatives 3a) and 3b) are equally preferred, and are both "extremely" preferred than Alternative 2.

Table 4.23: Pairwise Comparison Matrix for the Alternatives regarding Costs

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	1	8	1/3	1/3	9,67
A_2	1/8	1	1/9	1/9	1,35
$A_{3a)}$	3	9	1	1	14,00
$A_{3b)}$	3	9	1	1	14,00
Sum	7,13	27,00	2,44	2,44	

Table 4.24: Normalized Scores of the Alternatives regarding Costs

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	0,14	0,30	0,14	0,14	0,71
A_2	0,02	0,04	0,05	0,05	0,15
$A_{3a)}$	0,42	0,33	0,41	0,41	1,57
$A_{3b)}$	0,42	0,33	0,41	0,41	1,57

Table 4.25: Consistency Analysis of the Alternatives regarding Costs

	Average Score	Consistency Measure	CI	CR
A_1	0,18	4,12	0,06	0,06
A_2	0,04	4,01		
$A_{3a)}$	0,39	4,19		
$A_{3b)}$	0,39	4,19		

Regarding **Quality**, Alternative 1 is "strongly" more preferred than Alternatives 2, 3a) and 3 b). Alternatives 2, 3a) and 3b) are equally preferred.

Table 4.26: Pairwise Comparison Matrix for the Alternatives regarding Quality

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	1	1/5	1/5	1/5	1,60
A_2	5	1	1	1	8,00
$A_{3a)}$	5	1	1	1	8,00
$A_{3b)}$	5	1	1	1	8,00

Sum	16,00	3,20	3,20	3,20	

Table 4.27: Normalized Scores of the Alternatives regarding Quality

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	0,06	0,06	0,06	0,06	0,25
A_2	0,31	0,31	0,31	0,31	1,25
$A_{3a)}$	0,31	0,31	0,31	0,31	1,25
$A_{3b)}$	0,31	0,31	0,31	0,31	1,25

Table 4.28: Consistency Analysis of the Alternatives regarding Quality

	Average Score	Consistency Measure	CI	CR
A_1	0,0625	4,00	0	0
A_2	0,3125	4,00		
$A_{3a)}$	0,3125	4,00		
$A_{3b)}$	0,3125	4,00		

Regarding **Organizational Impact**, all alternatives are equally preferred, so they all have the same impact. Although there is no need to perform these calculations, they were executed as to prove the former statement..

Table 4.29: Pairwise Comparison Matrix for the Alternatives regarding Organizational Impact

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	1	1	1	1	4,00
A_2	1	1	1	1	4,00
$A_{3a)}$	1	1	1	1	4,00
$A_{3b)}$	1	1	1	1	4,00
Sum	4,00	4,00	4,00	4,00	

Table 4.30: Normalized Scores of the Alternatives regarding Organizational Impact

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	0,25	0,25	0,25	0,25	1,00
A_2	0,25	0,25	0,25	0,25	1,00
$A_{3a)}$	0,25	0,25	0,25	0,25	1,00
$A_{3b)}$	0,25	0,25	0,25	0,25	1,00

Table 4.31: Consistency Analysis of the Alternatives regarding Organizational Impact

	Average Score	Consistency Measure	CI	CR
A_1	0,25	4,00	0	0
A_2	0,25	4,00		
$A_{3a)}$	0,25	4,00		
$A_{3b)}$	0,25	4,00		

Regarding **Operational Risk**, Alternative 1 is "very strongly" less preferred than Alternative 2 and "extremely" less preferred than Alternatives 3a) and 3 b). Alternatives 3a) and 3b) are equally preferred, and are both "moderately to strongly" preferred than Alternative 2.

Table 4.32: Pairwise Comparison Matrix for the Alternatives regarding Operational Risk

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	1	1/7	1/9	1/9	1,37
A_2	7	1	1/4	¼	8,50
$A_{3a)}$	9	4	1	1	15,00
$A_{3b)}$	9	4	1	1	15,00
Sum	26,00	9,14	2,36	2,36	

Table 4.33: Normalized Scores of the Alternatives regarding Operational Risk

	A_1	A_2	$A_{3a)}$	$A_{3b)}$	Sum
A_1	0,04	0,02	0,05	0,05	0,15
A_2	0,27	0,11	0,11	0,11	0,59
$A_{3a)}$	0,35	0,44	0,42	0,42	1,63
$A_{3b)}$	0,35	0,44	0,42	0,42	1,63

Table 4.34: Consistency Analysis of the Alternatives regarding Operational Risk

	Average Score	Consistency Measure	CI	CR
A_1	0,04	4,01	0,08	0,09
A_2	0,15	4,14		
$A_{3a)}$	0,41	4,27		
$A_{3b)}$	0,41	4,27		

Now that all scores have been found, the final weighted average for each alternative and their final score can be calculated. This calculation is done by a linear additive model, where the criteria weights are multiplied by the scores regarding each alternative for each criterion (Table 4.35), and afterwards summed. The final result (Table 4.36) is a value between 0 and 1 where the weights indicate the trade-offs between the criteria [23]. The alternative with the highest score is the one that should be chosen.

Table 4.35: Relation between the different Alternatives and Criteria

		Criteria			
		Cost	Quality	Organizational Impact	Operational Risk
		0,60	0,09	0,05	0,26
Alternatives	A_1	0,18	0,06	0,25	0,04
	A_2	0,04	0,31	0,25	0,15
	$A_{3a)}$	0,39	0,31	0,25	0,41
	$A_{3b)}$	0,39	0,31	0,25	0,41

Table 4.36: Final scores for the Alternatives

Alternatives	Final score
A_1	0,13
A_2	0,10
$A_{3a)}$	0,38
$A_{3b)}$	0,38

5. Results and Discussion

This chapter is intended to present the relevant results of this work, which aims to decide if IPO-L should, or should not, replace their old 16 slices CAT scanner for a new one of 128 slices.

First, the application of the scenario planning methodology resulted in 3 different scenarios, in a time scope of 5 years. The scenarios were built based on the trends involving the healthcare industry (moreover the impact on exams demand), and thus IPO-L, and also the uncertainties surrounding this problem.

The three scenarios were aligned in accordance with the two biggest uncertainties: economic situation and medical breakthrough. The designed scenarios can be found in the following figure, succeeded by their description.

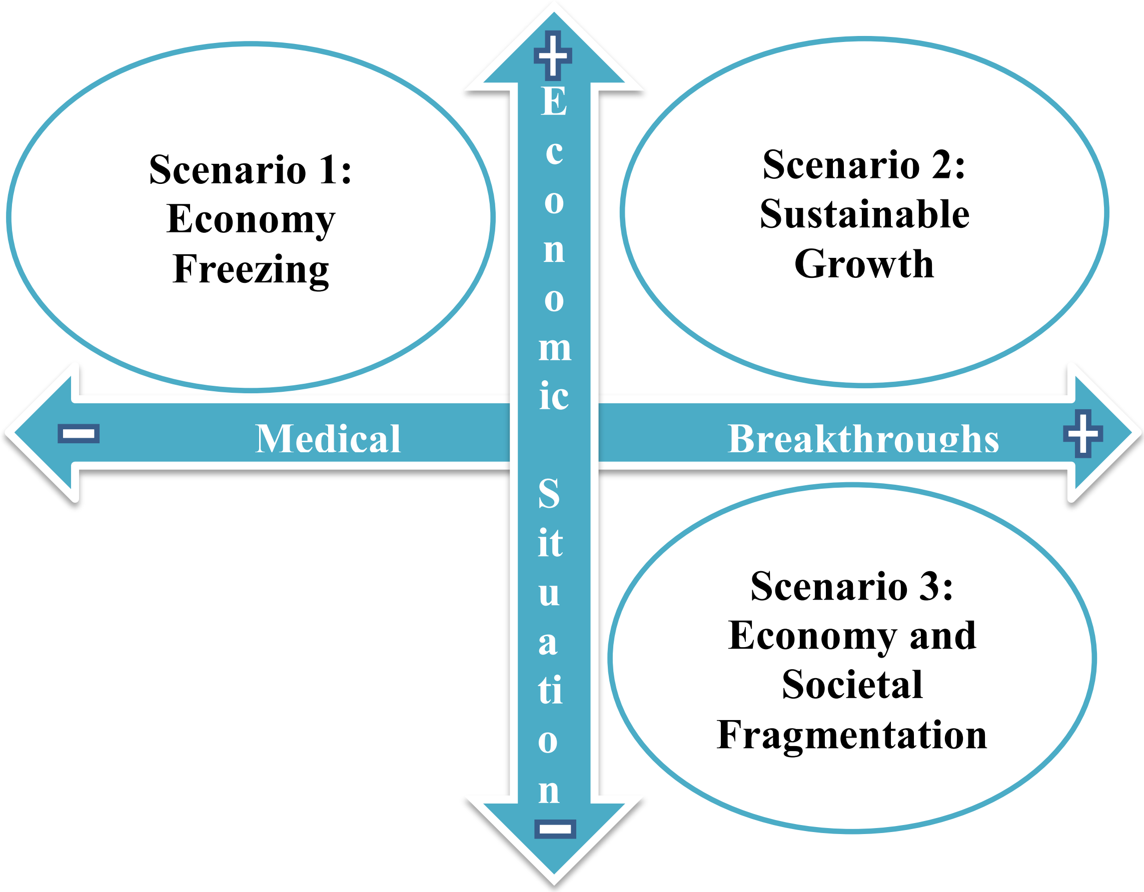

Figure 5.9 Constructed Scenarios

Regarding Multicriteria Decision Analysis, the different criteria were evaluated and weighted against each other, using the Analytical Hierarchical Model and a Linear Additive Model.

However, before the start of the MCDA, the present value of the costs of each alternative was also calculated, in order to better evaluate the criterion of cost (Table 5.1).

Table 5.1: Present Value of the Alternatives

$PV(A_1)$	391.698,86 €
$PV(A_2)$	699.902,00 €
$PV(A_{3a})$	390.605,86 €
$PV(A_{3b})$	390.778,69 €

A brief comparison between the two types of TAC Scans was also conducted, as seen in Table 5.2:

Table 5.2: Technical Specifications of CAT Scanners

	Siemens SOMATOM Sensation 16 [33][34]	**CAT 128 Slices** [35]
Detector	Ultra Fast Ceramic with adaptive array detector	Ultra Fast Ceramic (UFC)
Number of acquired slices	16	128
Rotation time	Up to 1.5 s	Up to 0.3 s
Temporal resolution	-	Up to 150 ms
Generator power	60 kW	80, 100 kW
kV steps	80, 100, 120, 140 kV	70, 80, 100, 120, 140 kV
Isotropic resolution	-	0.33 mm
Cross-plane resolution	-	0.33 mm
Max. pitch	-	Up to 1.5; up to 192 mm/s coverage
Table Load	Up to 200 Kg	Up to 307 kg
Gantry opening	70 cm	78 cm
Dose	-	Reduce radiation dose up to 60%
Features	z-Sharp technology, STRATON x-ray tube, CARE Dose4D, High speed volume scanning, Proprietary z-UHR technolgy[36]	FAST CARE technology and Single Source Dual Energy ,z-Sharp technology, STRATON x-ray tube, half the time, half the dose

Regarding the AHP methodology for the Multicriteria Decision Analysism the following data were obtained:

Table 5.3: Relation between the different Alternatives and Criteria

		Criteria			
		Cost	Quality	Organizational Impact	Operational Risk
		0,602233369	0,091287156	0,045641527	0,260837948
Alternatives	A_1	0,177343612	0,0625	0,25	0,037051046
	A_2	0,036372497	0,3125	0,25	0,147592619
	$A_{3a)}$	0,393141946	0,3125	0,25	0,407678167
	$A_{3b)}$	0,393141946	0,3125	0,25	0,407678167

This resulted in the following final scores for each alternative:

Table 5.4: Final Scores for the Alternatives

Alternatives	Final score
A_1	0,133582
A_2	0,10034
$A_{3a)}$	0,383039
$A_{3b)}$	0,383039

According to this methodology, the best alternative is the one with the highest overall final score. Thus, it can be said that the leasing contract is the preferred option for IPO-L's decision makers.

After careful consideration of the results, IPO-L should replace their old CAT scanner for a new one of 128 slices, in a leasing contract. Although the final scores of $A_{3a)}$ and $A_{3b)}$ are the same, the Present Value of A_{3a} is slightly inferior. Since the goal of the hospital is to minimize their costs, the DMs should opt for Alternative $A_{3a)}$, as its final score and present value are the more valuable in this case. Also important to take into account that the leasing contract for A_{3b} lasts for a longer period of time, which can be affected by more uncertainty as we have seen by the different proposed scenarios.

This option does not possess almost any operational risk, since it has a guaranteed service for the period of the contract, which includes maintenance and substitution of machine parts, with no additional cost.

6. Conclusion

Decision-aiding methodologies have been gaining importance in the last few years, mainly due to the constant change that the world is being subject to, and the uncertainty that surrounds it.

Thus, it is understandable that the major players in each industry are starting to use these methodologies to make better decisions and to anticipate problems and unforeseen events that might happen in the future.

This work was carried out with the goal of supporting Instituto Português de Oncologia decide if they should replace or not one of their computerized axial tomography. In order to solve this decision two different methods of decision-aiding were used: scenario planning and multicriteria decision analysis. While the scenario planning methodology allowed us to study the environment in which IPO-L is located, and anticipate certain events that might condition their practices, the multicriteria decision analysis uses different criteria to study each option is the best.

After conducting the analysis we found that IPO-L should replace their CAT of 16 slices for one of 128, with a leasing contract. This option does not carry as much risk as the others, and leaves the uncertainty on the side of the manufacturer, and not on the management team of the hospital.

It can thus be said then that the objectives defined in the first chapter of this work were achieved.

Although I found this project very interesting, I believe that the hospital should be more careful with the process of acquisition of technology. One appealing example is the one of the CAT that needs replacement. Although he machine had a life cycle of only eight years, meaning that after the 31 December 2016 the manufacturer will not assure the existence of machine’s parts for substitution, the hospital made a contract, where they will be paying for the machine until 2018. This means that they will be paying for something that is no longer valuable. Thus, acquisition contracts must be carefully drafted, and the criteria carefully evaluated.

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