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Development of a Multicriteria Decision Aiding Model for the Allocation of Physicians' Working Time

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Abstract

Health care managers are constantly facing the challenge of making decisions on how to best deploy scarce resources. Such decisions are likely to be complex and are often characterised by the existence of multiple objectives, which render difficult to make fully informed decisions. In the context of clinical departments of public hospitals, scarcity of human resources demands the allocation of physicians to the different activities to be properly managed, so as to meet the department's objectives while preserving service quality. Although there is an extensive literature on operations management and scheduling methods, these approaches fail to account for all the features that are necessary in the allocation of physicians.

This thesis aims to develop a methodology to inform the allocation of physicians to the different activities that take place in the Neurology department of the Western Lisbon Hospital Centre (WLHC). The methodology comprises an algorithm for the generation of allocation alternatives and a resource allocation model based on the principles of Multicriteria Decision Analysis (MCDA) and Portfolio Decision Analysis (PDA). The model was built through a socio-technical approach of interaction between a facilitator and the decision maker, the Chief Director of the Neurology department. The methodology made use of MATLAB for generating alternatives, whilst the construction of the evaluation model was performed in M-MACBETH. The analysis of efficient allocation profiles was performed in the PROBE decision support system.

The generated alternatives were appraised according to the evaluation model. The applications of the created model were illustrated by means of hypothetical scenarios, characterised by a set of constraints on the collective allocation of physicians. For the different scenarios, results suggested possible modifications in the distribution of physician amongst the different activities. The applications have shown that such approach may, in fact, have the potential to support the allocation of human resources in a context of multiple objectives and complex internal organisation. Furthermore, the methodology has revealed to be flexible, allowing the adaptation to variations in resources, activities and scenarios of analysis.

Keywords: Physician allocation, Neurology department, multicriteria model, portfolio decision analysis

Resumo

A escassez de recursos é uma constante nos sistemas de saúde actuais, exigindo a tomada de decisões no sentido de maximizar o benefício obtido com a utilização dos recursos disponíveis. No entanto, estas decisões ocorrem frequentemente sob influência de múltiplos objectivos que limitam a percepção do decisor no processo de tomada de decisão. No contexto dos serviços clínicos hospitalares, a escassez de recursos humanos exige que a alocação de profissionais médicos seja executada de forma a garantir o cumprimento dos objectivos operacionais contratualizados, preservando simultaneamente a qualidade dos cuidados de saúde prestados. Apesar de existir uma extensa documentação bibliográfica no âmbito da gestão de operações, tais abordagens não permitem considerar todos os factores envolvidos na alocação de médicos.

Esta tese propõe-se a desenvolver uma metodologia de apoio à decisão na alocação de profissionais médicos às diferentes actividades desenvolvidas no contexto do Serviço de Neurologia do Centro Hospitalar de Lisboa Ocidental. A metodologia compreende um algoritmo para geração de alternativas de alocação e um modelo de afectação de recursos apoiado nos princípios da Análise Multicritério de Apoio á Decisão e na Análise de Portfolio. O modelo foi construído através de uma abordagem socio-técnica de interacção entre um facilitador e o Director do Serviço de Neurologia. O desenvolvimento da metodologia baseou-se no programa MATLAB para implementação do programa de geração de alternativas, enquanto a construção do modelo multicritério de avaliação foi executada com auxílio do *software* M-MACBETH. Por fim, a análise de portfolio foi desenvolvida com o *software* PROBE.

As alternativas geradas foram avaliadas de acordo com o modelo multicritério construído. As aplicações deste modelo foram demonstradas através de cenários ilustrativos, caracterizados por um conjunto de restrições definidas ao nível da alocação global dos médicos às diferentes actividades. Para os diferentes cenários, os resultados indicaram possíveis alterações na distribuição das horas de trabalho dos médicos. As aplicações seleccionadas demonstraram que uma abordagem deste tipo tem, de facto, potencial para apoiar a alocação de recursos humanos num contexto de múltiplos objectivos e estrutura interna complexa. Desta forma, a metodologia revelou-se flexível, podendo adaptar-se a variações nos recursos existentes, actividades desenvolvidas e cenários de interesse.

Palavras-chave: Alocação de médicos, Serviço de Neurologia, modelo multicritério, análise de portfolio

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List of Abbreviations

B/C	Benefit-to-cost ratio
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
CUA	Cost-Utility Analysis
CVA	Cerebrovascular Accident
DALY	Disability-Adjusted Life Year
DC	Differentiated Consultation
DRG	Diagnosis-Related Group
EC	External Consultation
ED	Emergency Department
EEG	Electroencephalography
EMG	Electromyography
EPE	Entrepreneurial Public Entity
GBS	Government Business Sector
GDP	Gross Domestic Product
GP	General Practitioner
HEM	Hospital de Egas Moniz
HSC	Hospital de Santa Cruz
HSFX	Hospital de São Francisco Xavier
IC	Internal Consultation
ICER	Incremental Cost-Effectiveness Ratio
MCDA	Multicriteria Decision Analysis
MCO	Multicriteria Optimisation
MoH	Ministry of Health
MRI	Magnetic Resonance Imaging
NHS	National Health Service
PAS	Public Administrative Sector
PBMA	Program Budgeting and Marginal Analysis
PDA	Portfolio Decision Analysis
PLC	Public Limited Company
QALY	Quality Adjusted Life Year
RHA	Regional Health Administration
VFT	Value-Focused Thinking
VfM	Value for Money
WHO	World Health Organisation
WLHC	Western Lisbon Hospital Centre

1. Introduction

1.1. Motivation

Health care provision in developed countries has been experiencing an increasing demand over the recent decades, mostly as a result of the overall aging of populations and the constant advances in technological fields that, despite generating significant health gains to the population, inevitably render medical treatments more and more expensive. However, resources destined for health care fail to keep up with such tendency, giving rise to scarcity in available resources. This insufficiency imposes the need for making decisions on which provision fields should be supplied at the cost of others, so as to best meet population needs and policy objectives, and thus make the best use of the available resources. In this sense, health care resources comprise not only capital budgets, which are preferentially addressed in resource allocation problems, but also physical (infrastructural) and human resources. Although it is crucial to correctly manage all sorts of resources, there has not been given much relevance to the allocation of human resources, namely to the distribution of physicians' competences amongst the different activities of health services.

Physicians working in a clinical service of a certain medical specialty are required to divide their working time by the different activities that take place inside the service, of which inpatient care and ambulatory consultations are examples. This distribution is often made by periodic scheduling procedures and requires the department's responsible to make decisions about the service levels for the different activities. The allocation of working time is often characterised by multiple objectives, such as the achievement of the contracted targets and the maintenance of quality levels, and these may not be properly considered at the time of making decisions. Furthermore, when the number of physicians is insufficient to cover the demand, some type of prioritisation must occur, so as to decide which activities are to be carried out and which will not be performed.

Despite the recurrence of such situations of scarcity in human resources, there seems to be a lack of methodologies to inform decision makers on how to deploy human resources in a context that requires accounting for multiple objectives. Although this issue has been approached in the scope of operations management and scheduling methods, these methodologies seem to fail in accounting for all the features that are required for the decision maker to develop an appropriate understating of the problem at hands. In this sense, a systematic and progressively constructed methodology for priority setting can, in fact, be useful to assist decision makers in handling the complexity inherent to the process of allocation of working time. The identification of such necessities drove forward the development of this thesis.

1.2. Scope

The aim of this thesis is to develop a methodology to help allocating the working time of physicians in the Neurology service of a hospital centre located in Lisbon, which has been undergoing major human resource scarcity over the past years. Such methodology is considered to be of significant importance to ensure proper utilisation of human resources, especially in face of growing pressures for the achievement of operational objectives and the current restructuring measures that are being implemented. The development of a supporting tool to the whole process of allocation of physician working time intends to inform the priority setting process and highlight the activities that may represent a greater contribution to the achievement of the objectives, which potentially leads to an improvement of the benefit outcome. On the other hand, such decision aiding tool can in fact grant transparency to the decision making process, for the purpose of explicitation and discussion with relevant stakeholders and, ultimately, validation of the resource allocation process itself.

1.3. Thesis Outline

The first and present chapter aims to provide an insight on the motivation underlying the development of this thesis, as well as on its objectives and purposes. The second chapter concerns the characterisation of the context in which the methodological framework was developed, namely regarding the features of the Neurology service of the Western Lisbon Hospital Centre, whilst integrated in the public network of the National Health Service. Along with this description, the service's current condition is also presented, so as to identify the main issues that constitute the groundwork of this thesis. Next, the third chapter presents the results of a bibliographical review conducted in order to survey the existing methods that address resource allocation and working time distribution problems, providing the required theoretical basis for the development of this work. Chapter 4 presents the methodological framework developed for the purpose of this thesis, with the description of the main assumptions, features, required inputs and expected outputs, as well as the scope of application. The fifth chapter presents the results of applying the methodological framework to the case study of the Neurology service, regarding the created evaluation model and the generated alternatives. Chapter 6 then shows the results of applying the developed the model to the generated alternatives in the current situation of the Neurology service. In chapter 7, the results are discussed in order to identify the main conclusions of this work, which are in turn present in chapter 8. Likewise, this chapter also presents possible guidelines for future development and improvement of this type of methodology.

2. Context and Case Study

Before introducing the work developed on this thesis, it is essential to provide an insight on the context in which this work has arisen, namely regarding the Portuguese National Health Service (NHS) and the Neurology service integrated in a hospital centre. The context is complex and encompasses many characteristics that will assume relevance in the development of this thesis, hence the importance and extension of this chapter. In this section, the organisational context of this work is described, as well as the case study in which the methodology will be applied.

The first sub-section presents the NHS, as a network of health care providers managed by the Ministry of Health (MoH). The recent reforms in the NHS are also addressed, provided their influence on the characterisation of the present context. Section 2.2 briefly describes the general structure and operation of the Western Lisbon Hospital Centre (WLHC), in which the Neurology department is integrated. Next, section 2.3 presents the common features of a general Neurology department, as a hospital functional unit. Section 2.4 then provides a description of the Neurology department of the WLHC, presenting most of the information that will originate the methodological assumptions and will necessarily be used in the development of the resource allocation model. Finally, section 2.5 sums up the main considerations that are drawn out from the description of the context and case study, serving as the basis for the start off point of this thesis.

2.1. Overview of the National Health Service

2.1.1. Brief History of the National Health System

The information contained in this subsection was obtained from the MoH, namely from a document published in the website, [1]. Until the beginning of the 20th century, health care was delivered by charity and religiously affiliated institutions, whose actions were mainly directed to the poor, as the Government did not assume social responsibility for the health condition of the population. This situation persisted until the middle of the 20th century, when the health condition of the population reached a concerning level, and the Government then acknowledged the need to revert such situation.

In spite of the successive improvements in health care resources from the 1950 decade, it was not until 1971 that the citizens' right to health provision was stated, as the Government assumed the responsibility to ensure the compliance of this right. In the years between 1971 and 1979, existing hospitals were taken over by the government and the Portuguese Constitution (1976) materialised the population's right to health provision. The Portuguese NHS was then officially created in 1979, by means of the decree-law nr. 56/79. The created NHS is a structured entity, with administrative and financial autonomy, ranging from primary care to differentiated care in hospitals. In the years following the creation of the NHS, measures were adopted to improve management of resources and the efficiency of care provision. Namely, Regional Health Administrations (RHA) were created, in order to overcome the great complexity of allocating resources throughout the whole NHS. The MoH was created afterwards, in 1983.

As today, health expenditure was already taking over the public budget, increasing the awareness towards the usage of health care funds and, later on, leading to the introduction of entrepreneurial management principles. Moreover, the Government performed the 2nd Constitutional Revision, introducing moderating taxes to regulate the access to health services. Until the end of the 20th century, major changes in the structure of the NHS were related to the definition of partnerships with private health care entities, progressive decentralisation of decisions and resources, and focus on training of health care professionals.

At the beginning of the 21st century, the structure of the NHS had been quite modified comparing to its original frame. In fact, decentralised regulatory bodies had been created, managing the integrated functional units for health care provision. These functional units, linked through patient referral and interchange systems, provided the infrastructures for health care provision of subsets of the population, although the coordination at the national level had to be maintained. From the year 2000 onwards, several further reforms have been approved and implemented, which had impact at the national level and, naturally, in the actual operation of the hospital centre. These particular reforms are dedicated a later section.

2.1.2. The National Health Service

The NHS consists of a set of public health care provision entities and has the mission of providing health care to the whole population. Most of the information contained in this section was gathered from the extensive review of the national health system made by Barros and Simões in 2007 [2]. The NHS is one of the three main insurers of the Portuguese health system, along with profession-related insurance schemes (subsystems) and voluntary health insurance. Approximately 80% of the population of the continental territory refers to the NHS in the first place [3]. The health system is composed both of public and private health care providers, with complex relations between them and with patients. The MoH is the Government department responsible for coordinating these relations and the agreements respecting financing flows and heads the organisational chart that characterises the NHS's administrative structure.

Delivery of Health Services within the NHS

It is important to provide a general idea of the different health care delivery entities composing the NHS, in order to understand the services that are related to the WLHC. These services have distinct objectives and act integrated to constitute a comprehensive health care network. The separation of health provision fields is made regarding the type of patients and care provided and these fields are articulated in order to cover the different patients' needs.

Patients are advised to establish the first contact with the primary care centres, where they can be consulted by a general practitioner (GP). The GP performs general health care services concerning mainly the maintenance of the patient's health in non-acute situations and acts as a gatekeeper, establishing the link between primary care centres and hospitals by means of the referral process. Patients are forwarded to a specialty consultation in a hospital, following the referral pathways. The referral system is defined for the different medical specialties. In what concerns the Neurology department, the operating referral network was published in 2001 [4].

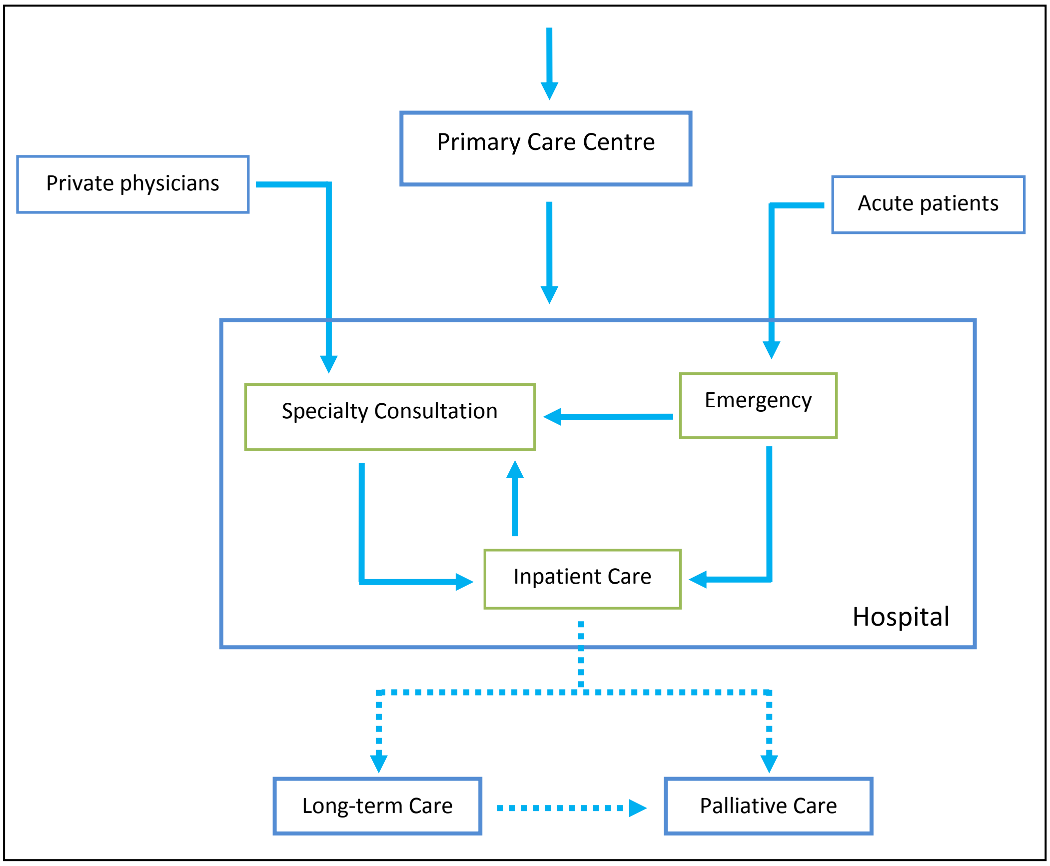


Figure 1. Summarised patient pathways between the main NHS services. All arrows represent patient flows, and dashed arrows correspond to situation-dependent pathways.

The flow of patients in hospitals is rather complex. Specialty consultations receive patients from primary care centres and patients with acute health condition that attend the emergency department (ED), as well as patients referred from private physicians. These consultations aim to provide specialised care to patients whose condition so demands and patients may be followed up in posterior ambulatory consultations, admitted as inpatients or discharged. However, the waiting lists for obtaining specialty consultations may result in a very large delay, aggravated by the referral of patients coming from private physicians, and also the bypass of primary care centres, provided that a significant fraction of the population does not have an assigned GP (10,8% in June 2006) [5]. Given the multiple pathways leading to specialty consultation, it is expectable that the great patient affluence to this hospital sector gives rise to issues related with difficulties in access due to large waiting lists. As for inpatients, these are admitted in a hospital if their health condition requires continuous monitoring. Upon discharge, patients may be referred to be followed in specialty consultations or, in case of.

The long-term care and palliative care services aim to provide specialised care for patients with chronic illnesses and high disabilities. These services are yet rather underdeveloped within the NHS, as their action does not meet the population needs. In face of the poor services provided in the sector of long-term and palliative care, the MoH has created the National Network of Integrated Long-term Care (NNILTC) [6]. The latest report on the development of the NNILTC shows evidence of significant improvement in the provision of long-term care [7], which plays a fundamental role in the follow-up of disabled patients that no longer need inpatient care in a hospital. However, in the actual condition of the NHS, there is still a lack of proper response to these needs, leading to the retention of patients in hospital wards. Even though this situation is not dependent on the physicians' action, it obviously influences the provision of care to inpatients.

As one could infer from the brief description of the NHS, public health provision entails a complex structure, with many interrelated entities that need proper coordination. In what concerns hospital operation, patient flow comes from various services and requires coordinated activities between and within hospitals. This has obvious implications at the management level, mainly related to the multiplicity of tasks that are carried out within the hospital and within each medical specialty. In a situation of insufficient resources to perform all the desired activities, the complexity becomes a main obstacle in the process of prioritising activities.

2.1.3. Recent reforms in the NHS and the new hospital statutes

As mentioned in the previous sections, the NHS has undergone significant restructuring at the organisational and operational level. It is important to put emphasis on the recent reforms that have been or are being put into practice, namely since the year 2000, as they are fundamental to characterise the case study of this thesis is inserted. Most of these reforms have direct or indirect implications in the hospital centre, namely regarding the modifications in the management model and the creation of the hospital centre itself.

Prior to the year 2000, the expenditure in health care had been increasing, as in most of the OECD countries [8]. This tendency of growth of health expenditure may be associated with several factors, such as the reimbursement and physician remuneration schemes, and also the type of care provided (ambulatory *vs*. inpatient care), amongst others [9]. Despite the significant health improvements of the population, questions have been raised regarding the under-utilisation of resources to produce the observed health gains, that is, that the inadequacy does not lie in the level of expenditure, but in the general waste of resources [10, 11]. This served as an impetus to the more recent health care reforms, whose main guidelines were the increase in care effectiveness and resource efficiency.

Since the year 2000, several measures have been approved, and some implemented. The set of policies developed to implement the health care reforms are mostly based on the principles of cost containment and efficiency improvement, health gains, quality of care and equity amongst the population. One important aspect of these reforms is their focus on various sectors of the NHS, as they comprise various levels of health care provision, where primary care, hospital care and palliative care, as well as pharmaceutical services are most the most affected [2]. Amongst all the recent reforms, it is more adequate to focus on the particular reforms that are most relevant to the hospital centre. These are briefly presented in the next table (Table 1).

Table 1. Policy measures most relevant to the hospital centre [2].

Policy Measure	Main Objectives
Provide hospitals with entrepreneurial-like statutes (2003 onwards)	Implement purchaser-provider split; cost containment
Merge hospitals management team (2003 onwards)	Increase efficiency (make use of scales and scope economies)

The new hospital statutes: PLC, EPE and PAS

The transformation of hospitals into public limited companies (PLC), in 2002 [12],constituted the first approach to implement a corporative management model in the public hospitals of the NHS, in the context of the set of recent reforms. The large magnitude of this measure (transformation of 34 hospitals into 31 PLC) required the creation of a specialised functional group– Mission Unit (*Unidade de Missão*), under the authority of the MoH, whose strategic vision was to "develop, through an economically sustainable process, a network of public corporative units, focused on the provision of excellence health care to patients and in the development of the health care professionals" [13].

The main features of the PLC hospital model are as follows [14]:

- The hospital capital is entirely public, provided by the Government;
- Autonomy is granted both at the financial and administrative level;
- Financing model based on the actual effective production, with elimination of traditional "subsidies" and implementation of individual labour contracts (*contratos - programa*);
- Independent management boards, accountable for the hospital operation and achievement of objectives.

The new financing model is a central feature of the new hospital statute and results in the formal division of the purchaser (Government) and the provider (hospital). In this framework, the individual labour contracts are established, creating a contractual relationship between purchaser and provider and determining the responsibilities of both parts during the forthcoming period. The allocation of funds is thus performed according to the individual labour contracts, which are based on the hospital capacity and the case mix index - related to the average severity of pathologies. Furthermore, along with the implementation of the referred contracts, the new statutes also comprise an integrated policy for training of medical professionals and definition of incentives, so as to ensure that the new hospital model can be provided with the required human resources. These policies are thus based on the principles of effectiveness, efficiency and meritocracy [15].

The measures applied to the hospitals have direct repercussions at the level of clinical departments. In the case of the Neurology Department, specific objectives are defined, regarding the different activities of the department, making use of a range of indicators. As a result, there is a focus both on quality of care provided and on operational efficiency, and the management of the Neurology department is strongly based on the labour contracts. This obviously has a strong impact on the whole process of allocating physicians, as will be noted at the time of applying the developed methodology. In effect, the structuring of the decision aid model will be quite influenced by such aspects, due to the great tendency to steer the Neurology department's objectives towards the production of performance evidence.

The allocation of resources amongst hospitals makes use of the Diagnostic-Related Group (DRG) system to adjust prospective budgets. The DRG system is based on a method of cluster analysis and aims at the classification of patients according to their hospital expenditure, or alternatively, according to the associated hospital tangible products. Each category is clinically coherent and comprises patients with similar levels of resource consumption [16]. The creation of DRG is fully implemented throughout the NHS hospitals and required the collection of extensive patient information, which also improved the information systems. In practical terms, the DRG system serves as a basis for the case mix model to adjust the budget allocated to a hospital [17]. On the practical level, the DRG system and the case mix model produce an index that provides information on the types and severity of pathologies that a given hospital deals with during its operation, in respect to other hospitals [18].

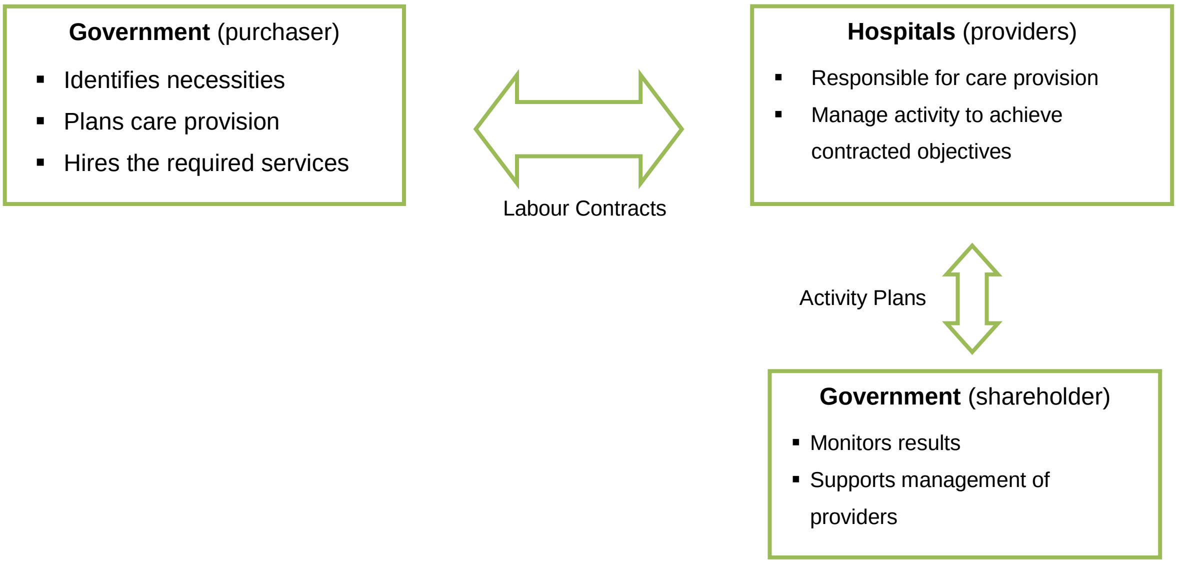


Figure 2. Explicitation of the purchaser-provider split in public hospitals [15].

The new PLC statute presented a significant change in the management policy of the NHS hospitals. It is important to also refer to the monitoring of policy results, as an important stage of the implementation process. For this purpose, the MoH created a committee to execute the field work to assess such results – CAHSA (*Comissão para a Avaliação dos Hospitais Sociedade Anónima)*. The committee produced a report, concluded in December 2005, with an extensive analysis of the PLC hospitals performance. The main conclusions stated that PLC hospitals produced evidence of efficiency improvement, mainly driven through increase in production without compromising the quality of the provided services. However, there still lacked awareness for cost and resource containment, as improvements in efficiency are driven by increase in production rather than reducing expenditure for the actual production. Furthermore, the system demands that the roles of the bodies involved in the purchasing and control of health services are clearly defined. The report claims for better control systems to monitor operation and timely identify flaws, so as to better utilise the potential of the PLC hospitals to improve the efficiency in care provision [19].

In the year of 2005, the Government considered that the public hospitals, then entitled with the PLC statute, should be converted into Entrepreneurial Public Entities (EPE), integrating the Government Business Sector (GBS), subject to its specific juridical law, which would better suit the managerial paradigm necessary to ensure the maintenance of the global hospital policy. The Government has thus determined the transformation of a series of public hospitals, formerly with the statute of anonymous societies (S.A.), into EPE’s by means of the decree-law nr. 93/2005 [20]. On the practical level, the new EPE statute did not have significant impact in the management of hospitals. The major differences lie in the process of creation and the impossibility to declare bankruptcy. Furthermore, the capital remains property of the Government, excluding the possibility of privatisation (leastwise without law revision) [19].

The transformation of hospitals into EPE’s occurred progressively, increasing the number of hospitals with this statute. The hospitals that were not endowed with the EPE statute (and had not previously become PLC hospitals) were designated PAS Hospitals (hospitals belonging to the Public Administrative Sector). Although both EPE and PAS hospitals integrate the management policies underlying the individual labour contracts, EPE hospitals are conducted under the laws of the private sector, whilst integrated in the GBS [21].

Creation of Hospital Centres and changes in management strategies

Besides the transformation of hospital statutes, it is important to refer to the creation of hospital centres. In such measure, some hospitals joined efforts in the provision of specialised care, based on the concept of horizontal integration, in which there is a single entity that is responsible for the management of different organisations that provide the same level of care (in this case, multiple hospitals) [22]. Given the geographical proximity and high level of specialisation of several hospitals, their integration into hospital centres aimed to create units with broader scope of care provision, eliminating supply redundancy and pursuing economies of scale. Furthermore, horizontal integration takes advantage of the complementarity of specialised clinical services offered by the different hospitals [23].

The creation of the hospital centre had direct implications in the management strategy of the integrating hospitals, as it was necessary to create a single entity responsible for the management of the hospital centre. An administration board has been nominated, whose coordinating and supervising actions cover all of the three hospitals. The board is composed of the president, the executive members, a clinic director and a nursing director, and operates under the supervision of a single fiscal. The different sectors of the network were grouped according to the type of services they provide, such as the sector of Medical Activity Services (*Serviços de Acção Médica*) and the sector of Support to the Medical Activity Services (*Serviços de Apoio à Acção Médica*), with further subdivision at lower levels within the different departments [24].

The implemented management model distinguishes three key management levels - strategic, intermediate and operational. This structure improves the differentiation of management roles, relying the strategic planning on the administrative board, keeping the goal setting and control processes within the internal management programs. Such management structure is coordinated, with decentralised management assigned to intermediate – level bodies, in order to handle the complex operation of the hospital centre [25]. In the present case study, management occurs at the operational level, as there is a direct coordination of care provision and the multiple activities performed within the Neurology department.

2.2. The Western Lisbon Hospital Centre

Following the measures and directives incorporating the NHS recent reforms, the hospital centre was officially created by the decree-law nr. 233/2005, with the integration of three public hospitals located in the western Lisbon area: Egas Moniz Hospital (HEM), São Francisco Xavier Hospital (HSFX), and the Santa Cruz Hospital (HSC), with the designation of *Centro Hospitalar de Lisboa Ocidental* – Western Lisbon Hospital Centre (WLHC) [26].

The WLHC serves the western region of the Lisbon metropolitan area. The municipalities of Lisbon, Oeiras and Cascais represent the direct catchment area of the health care services. Although the municipalities of Amadora and Sintra are referred to the Amadora-Sintra Hospital, some services of specialised care are provided in the WLHC. Therefore, the hospital centre’s catchment area comprises two levels of care delivery: direct referral and differentiated care. As for the municipality of Lisbon, only five civil parishes belong to the catchment area: Ajuda, Alcântara, Santa Maria de Belém, Santo Condestável and São Francisco Xavier. Table 2 lists the demographic profile of the WLHC catchment area [25].

Table 2. Population in the catchment area of the WLHC.

	Municipality	Population
Direct Referral	Lisbon*	67.809
	Oeiras	162.485
	Cascais	17.555
Differentiated Care	Amadora	175.534
	Sintra	371.118
	Total	948.501

*In respect to the 5 municipalities in the catchment area of the WLHC.

The population served by the hospital centre is rather extent, either by direct referral or differentiated care. The dimension of the facilities and the affluence of patients are therefore quite considerable. The hospitals' locations are geographically close, although the HSC hospital is relatively more distant. There are several communication routes between the hospitals, although most of them are subject to high traffic affluence, especially during rush hour periods, and the course from one hospital to another can become rather time-consuming. This fact is particularly relevant when neurologists are required to provide consultations to other clinical departments whose infirmaries are located in the HSC.

Figure 3. Map of the western Lisbon metropolitan area, with the location of the three hospitals.

As a process of horizontal integration, the creation of the hospital centre required the articulation of the different services, so as to establish and maintain a solid relationship of cooperation between the hospitals, and therefore enable an efficient sharing of resources and patients. Some of the medical specialties are practiced at just one hospital, whilst others have their activities spread over the hospital centre, depending on the distribution of competences, knowledge and facilities. Hence, some clinical departments and hospital sectors have been shifted or centralised in one hospital, with special emphasis to the ED, now operating solely in the HSFX hospital. It is important to consider the issues related to the location and distribution of the hospital services, as there may be some drawbacks. For instance, the hospital centre’s ED has been centralised in the HSFX hospital, which brings advantage in the sense that there is less dispersion of resources and cooperation is facilitated, and the service may also benefit from economies of scale. However, this centralisation implies that physicians from other hospitals have to move away from their original workplace, which constrains their working schedule, as they cannot perform other activities if their actions are not being requested in the ED.

The coordination of the three facilities has presented a major challenge in the creation of the WLHC. The resources and facilities involved in the process demanded the creation of information systems, so as to enable proper coordination within the hospital centre and with external entities. Furthermore, the role of the information systems is closely related to the centralisation of clinical departments, as it is necessary to overcome the geographical separation of services. The creation of an electronic clinical record for inpatients and outpatients is probably one of the most significant examples of such information systems.

The 2006-2008 triennium was mostly an adaptation period, during which the implementation of the new directives of the hospital centre has been put into practice. As written in the official annual statement of accounts and management report of 2008, once the process of centralisation of resources and services has been concluded, it is then necessary to take full advantage of all of the potentialities of the hospital centre. After these three years of adaptation, the administration reinforces the intention to maintain the development of the hospital centre in the central issues – accessibility and quality of care, efficiency, financial sustainability, alignment with the NHS objectives, and finally the improvement of physical and technological infrastructures [25].

2.3. The Neurology Department

2.3.1 The Neurology medical specialty

The Neurology medical specialty consists of a post-graduate field of medicine aiming at the study, diagnosis and treatment of all categories of diseases concerning the central, peripheral and autonomic nervous systems. The field of study comprises the main neurological anatomical components and the peripheral nervous communication pathways. Physicians acquire specific post-graduate knowledge, approaching specific fields such as neuropathology and neuroradiology [27]. It is frequently considered one of the most challenging medical specialties [28], as the diagnosis is mostly elaborated through the combination of the patient’s medical history with a series of systematic examinations.

Neurological disorders have a global impact on the world population’s health, although the burden of disease associated with these disorders has been rather underestimated in the past. This issue was mostly due to the fact that early studies focused on mortality rates, not considering the disabilities associated with this type of pathologies, which are extremely significant [29]. Furthermore, the actual burden of disease greatly surpassed the available resources, especially in poorer countries, and these resources were not likely to keep up with the tendency of increasing demand, as a consequence of global ageing of the population [30, 31]. Although neurological disorders have greater impact in developing countries, these disorders still present a significant burden of disease in developed countries, which stands for Portugal as well [32]. Neurological disorders combine both high prevalence on the world population and high disability potential [33]. The repercussions at the hospital level are felt as high demand levels for both first and follow-up consultations.

2.3.2. General Features of the Neurology Department

This section is based on specific literature, in order to provide an overview of the scope and general features of the neurology medical specialty. Namely, two books were consulted – Harrison's Principles of Internal Medicine [34] and Adams and Victor's Principles of Neurology [28]. Although the information contained in these textbooks is highly specific and is mainly directed to medical professionals, they provide the relevant information for the purpose of this brief description.

The medical approach to patients with neurological diseases can be generally divided into two groups – objective examination and use of complementary diagnosis methods. The first group is related with the clinical examinations that consist in direct analysis performed on the patient by the physician, regarding both motor and cognitive condition. Such examinations require a significant level of experience, acquired after systematically performing these tests, so as to develop appropriate sensibility and acuity. Therefore, the interns' learning process requires supervision by more experienced neurologists, which can be quite time-consuming. The learning and supervising processes have significant implications in the resource allocation process. Namely, intern supervision is integrated in the department's regular activities, which become more time consuming than if performed solely by a neurologist, and inevitably have a negative influence on the operational performance of the department. Moreover, this negative influence is aggravated by the financing policies, based on objective operational data, traduced greater pressure to produce performance evidence.

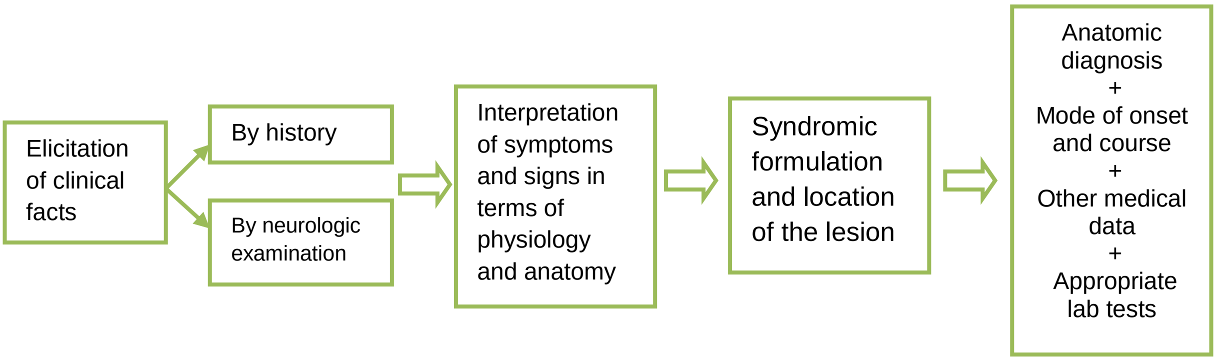


Figure 4. Steps in the diagnosis of neurological disorders [28].

Figure 4 outlines the general process of elaboration of diagnosis of neurological disorders. Some of the stages take place in consultations or complementary exams, but the interpretation of symptoms and formulation of a diagnosis assume major importance in the process. Besides, evaluation of clinical conditions might require meetings and discussions with other physicians, either neurologists or other medical specialists. Once more, despite being essential to the provision of care, such backstage work represents an activity that does not contribute, at least directly, to produce performance evidence. In this sense, one must also consider this balance, as it would be pointless to arbitrarily increase the number of consultations without assuring that physicians have enough time to evaluate the respective patient clinical processes in order to formulate coherent and substantiated diagnoses.

Neurologists also make use of complementary methods and techniques, which play an important role in the formulation of diagnoses, especially in this particular medical specialty. Nevertheless, clinical examinations should not be put aside in the diagnosis process, as relying too much on the costly complementary exams without paying the required attention to the objective symptoms may result in erroneous conclusions. Complementary exams firstly include the use of medical imaging techniques that provide useful information, as they can produce clear anatomical images of the desired areas to detect structural anomalies, as well as functional images for metabolic and functional mapping. Imaging techniques surpass the great limitation of inaccessibility of the main neurological structures, and the possibility to enhance contrast or target specific molecules or tissues allows the identification of signs that otherwise would not be detectable at plain sight. Computed tomography, magnetic resonance imaging (MRI), positron emission tomography and angiography are examples of imaging techniques recurrently used in neurology departments. Recommendations for the use of medical imaging techniques are documented in the literature regarding their efficiency, efficacy and adequacy for different groups of diseases, providing guidelines to help physicians decide which complementary exams would most likely serve one specific case. In spite of the usefulness of these exams, they often require large investments in installation and operation. In the WLHC, as well as in several other hospital facilities, the operational capacity of imaging techniques is quite reduced, thus demanding a wise utilisation, For instance, MRI is a central technique in the diagnosis of neurological disorders, yet only recently (May 2010) the first MRI scanner - with 1.5 T magnetic field - was installed in the hospital centre. Although the new scanner is outdated and does not cover all the desirable requirements, it represents an important contribution to the hospital's response to the exigencies of multiple medical specialties. The possibility to perform exams with the hospital's resources reduces the number of exams performed in private entities, therefore reducing the dependency on external entities [35].

Apart from the medical imaging techniques, complementary exams based on the detection of electric potentials, the most important being the electroencephalography (EEG) and the electromyography (EMG), are also frequently used. EEG and EMG techniques are much less complex and expensive than standard imaging techniques such as MRI, which is quite suitable for analysing brain activity in a large number of situations without involving large expenditure. EEG analyses the electrical activity in the brain, and is used, for instance, in cases of seizures or monitoring of brain activity. On the other hand, EMG analyses the electrical activity in muscle tissue with use of surface or intramuscular electrodes, assessing the activation of muscle units. EMG is particularly important in neuromuscular disorders. Both EEG and EMG require interpretation, for which proper experience is needed, giving rise to constraints to the allocation of physicians to the different activities.

In addition to the previously mentioned techniques, it is worth referring that neurologists can also make use of other types of exams, such as genetic tests, most of them performed in external private entities. These exams become rather costly, gaining relevance as a portion of the overall expenditure and therefore narrowing the available budget.

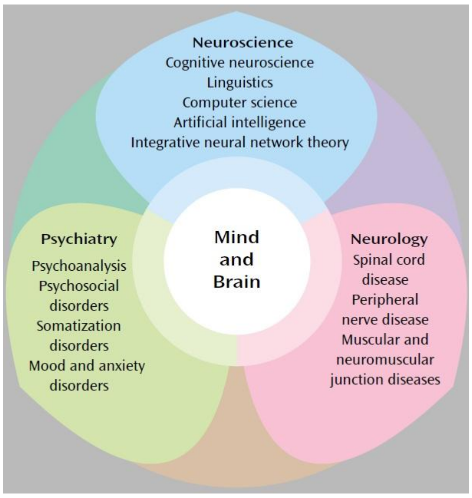


Figure 5. The relationship of Neuroscience, Neurology and Psychiatry and their subtopics [36].

As in many medical fields, neurologists work in close cooperation with other medical specialties, typically neurosurgeons, psychiatrists and radiologists, since many disorders are related to multiple medical specialties. In fact, while neurosurgery has a defined area of action in correlation with neurology, the separation between neurology and psychiatry is not as clear. In 2002, J. Martin emphasised the need for cooperation between these medical disciplines that is required for further progress in unravelling neurological disorders [36]. For that reason, the intricacy of the neurology specialty derives both from the intrinsic complexity of the disorders comprised in the scope of action and from the multifaceted relationship with other medical specialties. The need for cooperation between medical specialties demands that diagnoses are formulated with the participation from the relevant medical fields. In practice, this is traduced in conducting meetings for discussion and evaluation of clinical cases whose diagnosis requires knowledge from multiple medical fields or requires sharing different points of view amongst neurologists. These sessions have two facets, as they serve the purpose of elaboration of diagnosis, while strongly contributing to the knowledge of the participating physicians. Given the relevance of such meetings, these must be considered as activities requiring the allocation of physicians' working time. Then again, pressure for maintaining productivity levels arises, demanding an appropriate trade-off between operational performance and the efficacy of diagnoses.

2.4. The Neurology department in the WLHC

This section presents the Neurology department of the WLHC, regarding the objectives, resources, facilities and activities. The operational data is presented, when relevant, so as to demonstrate the current condition of the different divisions and highlight outstanding problems. The description is mostly based on the Annual Report of Activities of 2009 and Plan of Activities for 2010 [37], issued by the Neurology department, as well as on the Summary of the Action Plan [38] and on data gathered for the purpose of this thesis.

2.4.1. Overview of the WLHC Neurology Department

The neurology clinical department operates mainly in the HEM hospital, where most of the facilities are located. The clinical department is managed by a Chief Director, Dr Mário Veloso, who monitors the unit's operation and interacts both with the administration board and the personnel working in the clinical department.

Mission and Strategic Objectives

The Neurology unit is, by nature, a public care service that aims to achieve excellence in the provision of health care services. In this sense, the Neurology department has developed strategic guidelines, to serve as groundwork for the definition and implementation of operational strategies that aim at the progressive improvement of performance. The Plan of Activities for the 2009-2011 triennium materialises such management approach. This triennial document serves as a base to the Annual Plans of Activities that are typically issued every year, and more importantly, the explicitation of motivations and objectives promotes the engagement of all working physicians [39].

The Plan of Activities states the strategic objectives, of which the most significant are:

- Provide quality care services;
- Achieve client and staff satisfaction;
- Achieve the objectives stated in the labour contract;
- Establish a framework to enable Department growth and development;
- Promote and implement the delivery of highly specialised care;
- Address specific areas of Neurology through the creation of functional units, such as the Programme for Study of Sleep Disorders;
- Become a reference in terms of care delivery, as well as in educational and scientific activity;

The explicitation of the strategic objectives establishes the directives according to which the department's operation should be driven and are at the base of definition of operational objectives. These, in turn, represent tangible references to the monitoring of activity and assessment of performance. For that reason, operational objectives are defined for the different services of the Neurology department.

Facilities

The Neurology department makes use of 13 consultation rooms in the HEM hospital, which have to be shared with other hospital departments. Therefore, utilisation of consultation rooms needs periodic scheduling. Despite the fact that, presently, consultation rooms are not fully occupied, the limitation in the number of rooms may present a constraint in the maximum number of consultations.

The ward is also located in the HEM hospital, with a capacity of 16 beds distributed amongst 8 rooms. One of the inpatient rooms is equipped with a video-EEG instrument and the associated monitoring facilities, which only allows the execution of one exam at a time. The existence of two equipments in this room would allow the simultaneous performance of the video-EEG exam (requiring the presence of one neurophysiologist) would allow a better utilisation of the facilities.

The Neurology department does not have an independent ED. Instead, emergency care is delivered in the WLHC centralised ED, located in the HSFX, where physicians remain when working on an emergency shift. As for the performance of complementary exams such as EEG and EMG, these are carried out in the department's laboratories in the HEM. The EEG laboratory currently has 2 fixed acquisition systems. The acquisition of portable equipment, destined for Holter-EEG exams, is in process and yet not available. The EMG laboratory has 2 systems available for these exams. However, the availability of human resources with the required knowledge is not sufficient to allow the operation of the two EMG equipments, leaving one of these inactive.

Finally, the department also has a division in the HEM destined to serve as a day hospital, whose activity is scheduled in articulation with the other activities, both for outpatients and inpatients.

Human Resources

The human resources involved in the delivery of health services in the Neurology unit are quite extensive, comprising physicians, nurses, laboratory technicians, amongst others. Many activities, such as complementary exams, could not be carried out without the intervention of specialised staff, but the purpose of this thesis demands that some aspects are simplified to prevent the excess detail from overwhelming the whole resource allocation process. For that reason, emphasis will be put on the working neurologists.

At the time of development of this thesis, 16 neurologists worked in the Neurology department. From these physicians, 4 of them were interns of the postgraduate programme. In recent years, the number of physicians has been suffering a progressive reduction, which obviously has hindered the department's operation. In fact, this reduction has had repercussions across the whole Neurology department.

Although these physicians work within the same hospital department, it is important to emphasise the fact that, as in many medical specialties, each physician is highly specialised in certain pathologies and techniques. As a result, the allocation of physicians to the different activities must account for the specific profile of each physician. In fact, one may expect the effectiveness of care provision to be positively related to the specialisation of a physician in a given medical field, mainly due to the high level of knowledge that is required for most activities. In order to attend for the high specificity underlying these activities, restrictions in the assignment of physicians to activities arise, so as to ensure that a physician assigned to an activity possesses the required qualifications.

The areas in which physician specialisation must be considered as a constraint to resource allocation regard mostly the differentiated consultations and the performance of EEG, EMG and echo-doppler exams. Provided the fact that each physician would not be able to develop specific knowledge of all neurology subfields, physician resources become heterogeneous and, thus, care provision makes use of both complementarity and specificity of medical knowledge amongst physicians. At this point, the central issue to be retained is that specialisation of physicians will have to be accounted for in the resource allocation process, in which the referred constraints will have to be traduced.

2.4.2. Health care delivery in the Neurology department

Provision of care to patients in the Neurology department is organised in different activities or functional units, creating the basis for the desired level of specialisation. The internal organisation regards the type of care provided, such as ambulatory or inpatient care, and also the heterogeneity of pathologies. Furthermore, proper articulation between these activities must be enabled. In the following subchapter, the internal organisation of the Neurology department is described.

Inpatient care

The ward is the facility where inpatients are lodged, when the physician finds that there is a significant risk of the patient needing immediate intervention. Unlike ambulatory care, in which patient consultations are scheduled, the attendance of inpatients is managed by the physicians themselves, according to the severity of illness, the associated risk factors and eventual changes in clinical condition. Therefore, physicians' activity in the ward is quite flexible. On the other hand, the amount of time spent on inpatient care is rather variable, depending on the complexity of the pathology, as well as on the stability of the patient's condition.

The provision of care to inpatients is performed both by neurologists and interns. The discharge process may be delayed because physicians lack time to continuously monitor inpatients, as these patients are less likely to require urgent attention and consequently their discharge may only be declared when neurologists have less work load. On the other hand, discharge of inpatients may also be conditioned by the lack of solutions for patients with high physical dependence, as they would immediately be readmitted, although their permanence in a ward is not justified in practical terms. Despite these significant implications, this matter lies out of the scope of this work.

Inpatient care plays a significant role in the training of interns. Ideally, each intern would have the opportunity to analyse different clinical profiles and discuss these with supervising neurologists. In other terms, this learning process requires that clinical evaluation is deeply studied and repeated, resulting in the extension of the time needed to deliver the required care to a patient. In section 2.3, issues were raised in regard to the training of physicians for the elaboration of diagnosis, in which clinical examinations required experience and supervision. Similarly, intern training for observations in the ward decreases the efficiency of care provision and thus has a negative impact on the operational results. Resource allocation must account both for the efficiency level and proper training of interns.

The monitoring of the ward's operation is based on a series of indicators, which observe the achievement of the desired performance levels and identify matters that may require attention. Conversely, other indicators provide information on the quality of care provided. Table 3 presents relevant indicators for the ward.

Table 3. Relevant Performance Indicators for the Ward.

	Actual Jan/Nov 09	Goal Jan/Nov 09	Achievement (%)	Goal Jan/Nov 10
Discharged patients	306	301	101,7	300
Occupation Rate (%)	85,72	83,9	102,2	80
Average Length of Stay (days)	14,14	13,2	107,1	14,0
Mortality Rate (%)	0,6	--	--	--

In terms of operational performance, the relevant indicators were mostly achieved in respect to the stated goals, in except for the average length of stay, in which a percentage larger than 100% indicates that this value was not sufficiently reduced. A possible explanation for the non accomplishment of this objective may be related with the physicians' time scarcity, as their condition is likely to be less urgent and there may be a tendency to dedicate the available time to the more urgent issues. Furthermore, the aforementioned issue related to the discharge of disabled patients due to the lack of response from the NNILTC also influences this parameter.

The ward does not present a significant drawback in terms of performance indicators. However, the issues related to the educational activities integrated in inpatient care still stand, even if they are not directly reflected in terms of these indicators. This situation evidences that monitoring the clinical department condition focusing only on these performance indicators may lead to an incomplete understanding of the global condition. For that reason, it would be useful to consider a trade-off comprising all of the aspects that traduce the department's objectives.

Ambulatory Care – External Consultation

A significant proportion of the care provided by the Neurology department is delivered through ambulatory consultations, corresponding to the specialty consultation represented in **Figure 1**. Patient referral is processed through an electronic system created in 2008 (*Consulta a Tempo e Horas*), an integrated system for management of the access to first consultations of medical specialties of NHS hospitals [40].

The Neurology department has implemented a highly specialised system for EC through the creation of differentiated consultations (DC), each referring to a specific group of pathologies. Each type of DC is provided by specialised physicians, according to their experience and personal training. Upon reception, consultation requests are sort out and assigned to the corresponding consultation group, consistent with the description of the clinical condition included in the request.

Presently, besides regular consultations, the Neurology department operates 6 types of DC, as follows:

- Movement Disorders, e.g. Parkinson's Disease;
- Demyelinating Disorders, e.g. Multiple Sclerosis;
- Cognitive Disorders, e.g. Alzheimer's Disease;
- Neuromuscular Disorders, e.g. Myasthenia Gravis and Polyneuropathy;
- Epilepsy;
- Sleep Disorders, e.g. Parasomnias;

The chief director is responsible for receiving and processing the electronic requests, scheduling the EC to the different physicians. When a patient's condition is not clearly suitable for a specific group of pathologies, a regular consultation is scheduled, thus performing a total of 7 types of EC. It is important to point out that the creation of such system is in line with the department's objective to provide highly specialised care. First consultations represent a minor proportion of the total number of consultations. Follow-up consultations correspond to attending of patients being followed in ambulatory care. Given the chronic tendency of many neurological disorders, it is expectable for follow-up consultations to be prevalent over first consultations, even if a significant portion of them serve only for routine procedures. Typically, follow-up consultations are requested by patients and scheduling is managed according to the urgency and current patient load. In such context, the waiting time for follow-up consultations is not taken into account as a relevant indicator.

The time available for EC, either regular or specialised (for both first and follow-up consultations), is typically defined *a priori*. In other words, the allocation of physicians' working time to consultations is firstly established, and then the requests for consultations are received and scheduled according to this predefined allocation. As for the response to patient demand, the total time allocated for EC is not very flexible, as these are articulated with other departments that require use of EC rooms. Instead, response to patient demand occurs through the modification of the time allocated to the different types of EC, within the total time destined for

Neurology EC. However, this flexibility may not be sufficient to effectively reduce the waiting time, as these changes usually occur only when the situation reaches critical levels, and may not consider possible impacts on other activities.

In what concerns operational performance, the department has established a series of indicators related to the EC activity, which regard mainly the number of performed consultations and the relative proportion of first and follow-up consultations. For this purpose, DC are not considered. The payment of EC (in the scope of labour contracts) also varies between the two referred categories, being higher in first consultations.

Table 4. Relevant Performance Indicators for External Consultations.

	Actual Jan/Nov 09	Goal Jan/Nov 09	Achievement (%)	Goal Jan/Dec 10
Total number of EC	11934	10472	114,0	12000
Nr of 1st Consultations	2752	2723	101,1	2760
Nr of follow-up Consult.	9182	7749	118,5	9240
% 1st Consult/Total	23,1 %	26,0 %	88,7	23,0 %

The EC division has achieved the majority of the contracted objectives in 2009, namely in respect to the number of first and follow-up consultations. However, the proportion of first consultations is below the contracted value, which is probably a result of the reduction in the number of physicians. The reason for this is related to the fact that, as neurological disorders have a rather extent time span, the reduction of human resources results in a higher number of patients per physician. Hence, the necessity of regular follow-up consultations has caused the number of first consultations to decrease. The contracting of a proportion of first consultations represents an incentive, and it is only considered when at least 85% of the contracted value is achieved. The achievement of these operational targets is rather significant in the scope of the new financing model and labour contracts.

The waiting time for a first consultation is also an issue to be taken into account. The creation of DC has introduced some heterogeneity in the waiting time, depending on the required type of consultation, as demand is variable amongst different DC. The waiting time is not directly comprised in the financing policy, but is still considered an important parameter to the assessment of the department’s quality.

In EC, several issues must be considered in the allocation of physicians’ working time. There seems to be a conflict between first and follow-up consultations, and their respective purposes must be considered. As there is a high demand level for first consultations, associated with long waiting lists, it would be expectable that these would be privileged over follow-up consultations, also because payment for first consultations is higher. Furthermore, first consultations also contribute to the reduction of the waiting time. On the other hand, payment for follow-up consultations is lower, and these move the department’s performance away from the target ratio. However, as mentioned before, treatment of neurological disorders tends to be rather long, if not chronic, requiring a proper accompaniment of outpatients in follow-up consultations, which may also be seen as a factor of quality. In this sense, both first and follow-up consultations must be subject to a trade-off, considering both operational and quality issues. It is important to keep in mind that the Neurology department is, by nature, a public care provider, and the entrepreneurial approach to the department management must not be imposed over the department’s fundamental objectives.

Internal Consultation

Internal consultations (IC) refer to the observations performed to inpatients of other medical departments. For this purpose, physicians have to meet these patients in the corresponding ward. The requests for IC are typically processed once a week and attended according to their urgency and availability of physicians. As the Neurology department is integrated in a hospital centre, IC comprise inpatients located also in the HSFX and HSC hospitals. The IC for medical departments located in the HSFX are usually performed when a physician is working on the ED, when two neurologists are present. The articulation of IC in the HSFX with ED shifts thus minimises the number of courses between hospitals, reducing the time expenditure. Conversely, IC performed in the HSC forces neurologists to go there on purpose, requiring a carrier to transport the neurologist from one hospital to the other. In fact, IC in the HSC represent great time expenditure, due to the distance and availability of a carrier. Furthermore, IC are typically requested with urgency, and may involve cancelling scheduled activities, such as EC.

Internal consultations are not comprised in labour contracts and the Neurology department does not receive any compensation for the time spent on this activity. In other terms, the IC activity does not contribute to any aspect in terms of the department’s operational performance. This fact may suggest that IC should have a low priority in resource allocation. However, it is essential to consider the nature of the present context, as a public hospital, and the provision of quality care is one of the department’s main objectives, regarding patients from the whole hospital centre. In this sense, provision of care to inpatients of other medical departments should be seen not only in the scope of the Neurology department, but also as a contribution to the quality of care provided by the WLHC entity.

The allocation of resources to IC takes into account both the capacity to respond to the requests and also the waiting time. Normally, the waiting times involved are much lower than those of external consultations. Table 5 shows the number of IC performed in 2008 and 2009. This numbers do not include the IC of the HSFX.

Table 5. Number of Internal Consultations performed by neurologists in the WLHC.

	Jan/Oct 08	Jan/Oct 09	Variation (%)
Total number of IC	351	236	-32,8

The number of performed IC has been progressively decreasing, which is attributed mainly to the reduction in the available human resources. As a result, internal consultations are currently ensured when there are two neurologists working in the ED, and there may be a lack of response to more urgent requests. The Neurology department acknowledges that IC is a service that requires most attention due to its current situation.

Emergency Department

Emergency care is delivered by means of the ED located in the HSFX to patients with acute health conditions enter the ED by themselves or are brought by the emergency transporters. Given the urgency of most patients, medical care is provided *in situ*, which demands the presence of multiple physicians from different medical specialties. Neurologists working in this division are organised in a rotating shift system. Each regular shift has the duration of 12 hours, plus 3 hours in extraordinary regime. Each physician is typically assigned one shift a week. Physicians working on a Sunday shift have the right to take one day off in the following week. Depending on the scheduling, each shift may have one or two neurologists present in the ED. However, the annual report stated that in shifts with just one neurologist there is an excessive workload for a single physician, apart from the fact that it is almost impossible to provide care to inpatients of the HSFX. This situation is aggravated in the case of absence for holidays or scientific meetings, and it has happened that temporary workers were hired in order to ensure coverage of all ED shifts.

The neurologists' action in the ED is also integrated in a programme destined to provide specialised care do patients suffering from a CVA. For this purpose, a functional unit – CVA Unit – has been created. Neurologists attend these patients and are responsible for their monitoring when thrombolytic therapy is administered. However, the CVA Unit suffers from great scarcity and dispersion of human resources, and lacks proper coordination, as there should also be cooperation with other medical fields. The CVA Unit demands for a proper framework in order to properly utilise the existing resources. For that reason, the CVA Unit is not considered as an independent service, given its current situation.

The ED is an important division of the Neurology department, yet there are no operational indicators considered in this activity. The allocation of physicians to this activity essentially aims to cover all the required shifts. Furthermore, efforts are made in order to enable shifts with two physicians and allow the attending of HSFX inpatients. However, ED shifts represent a large portion of the total working time, which has obvious implications in the department's operation.

Laboratories – EEG and EMG exams

Complementary exams take place in the Neurology department, namely in the EEG and EMG laboratories, which represent the majority of performed exams, although the physicians specialised in these areas are working in a reduced schedule - 28 and 17 weekly hours, respectively. Therefore, this area is suffering from a severe scarcity of specialised resources, unable to respond to the solicitations of other divisions of the Neurology department, namely EC and the ward. The reduction in the laboratories' capacity implies that more exams are requested to external entities, significantly increasing the monetary expenditure. Apart from EEG and EMG exams, echo-doppler exams are also performed. These exams are administratively associated with the Imagiology unit, although the consumption of human resources falls back on the Neurology department.

The payment of performed EEG and EMG exams depends on the circumstances of the respective requests. While the payment for exams requested by the ward and EC is included in the corresponding DRG group, the exams requested from other activities within the Neurology department and from other hospital departments are paid unitarily. Such fact will be relevant when considering the income from the different services.

Table 6. Number of EEG and EMG exams.

	Jan/Nov 08	Jan/Nov 09	Variation (%)
EEG exams	840	1053	25,4
EMG exams	758	303	-60,0

Table 6 shows that the EEG laboratory has increased production, while the number of performed EMG exams has greatly decreased, as a consequence of the reduction in specialised human resources. Furthermore, the reduction of EMG-specialised physicians is not coherent with the creation of a DC destined for neuromuscular diseases, which is expected increase the demand for this type of exams. This fact reduces the flexibility of resource allocation, in the sense that, in order to keep acceptable levels of performed exams, these physicians do not have remaining time to dedicate to other activities. The main objective of these laboratories is, thus, to maximise production to best respond to patient demand, minimising the resultant costs of requesting these services to external entities. As for the echo-doppler exams, it is necessary to maintain acceptable production levels, given the relevance of these exams, even if there is not any material compensation for the time expenditure.

Day Hospital

The day hospital is the division of the Neurology department in which assisted therapies are administered and routine complementary exams, such as lumbar punctures, are performed. The day hospital operates in articulation with other activities, mainly EC and the ward. Most of the therapies are administered by specialised technicians, so that physicians do not need to monitor patients during the whole treatment. Instead, physicians' action in the day hospital is mostly related to the emission and verification of prescriptions and the performance of complementary exams. Generally, this activity does not consume great amounts of time, in comparison with other divisions.

Table 7. Number of sessions performed in the Day Hospital.

	Actual Jan/Nov 09	Goal Jan/Nov 09	Achievement (%)	Goal Jan/Dec 10
Number of sessions	743	327	227,2	600

The day hospital service is also encompassed in the labour contract. The numbers presented in Table 7 show that the objectives were surpassed, although it is expectable that this will result in higher expenditure, especially concerning pharmaceutical products. A possible reason for the exceeding of the contracted objectives may be related to the fact that assisted therapies integrate numerous patient follow-up protocols, and therapies must be administrated in order to ensure the quality of care.

Epilepsy Surgery Programme

The Neurology department has organised a multidisciplinary programme directed to patients suffering from epilepsy. The aim of this programme is to constitute an integrated system for the evaluation and selection of candidates electable for surgery. The programme involves complex procedures for the assessment of patient condition. There are multiple medical teams involved, as the programme requires a strong cooperation between medical fields and between hospitals, in order to articulate the required human resources. Given the importance and positive impact of this programme, financing policies are distinct from those of the other services. The process of patient evaluation requires spending a large amount of human and financial resources, and only a portion of the evaluated patients are in fact operated. Nevertheless, the Epilepsy Surgery Programme has largely contributed to the reputation of the WLHC, as a reference care provider, especially in the scope of Neurology.

The successful interventions have produced evident health gains, which drove the programme's development forward [41].

The programme has a strong component based on the Neurology department, and demands close cooperation with other fields, mainly neurosurgery. Typically, the first selection takes place in epilepsy DC, in which potential candidates are identified. A large number of complementary exams are requested, from which the video-EEG is an example. This exam consists of a long duration signal acquisition, with the EEG system coupled with the video recording. The video-EEG exam itself does not require the presence of a physician, as monitoring is performed by a technician during signal acquisition. However, the analysis of the exams' results is rather time-consuming. In addition, this analysis demands a high level of experience.

The Epilepsy Surgery programme entails complex features that have a significant impact in the consumption of physicians' working time. Furthermore, efforts to maintain the programme's operation may not produce the desired results, given the fraction of patients that effectively receive surgery. Nonetheless, a proper equilibrium should be established, weighing the positive impact in terms of reputation and health gains, yet assessing the consequences of leaving other activities unattended.

2.4.3. Clinical Research and Academic Activities

Scientific and Research Activities

Scientific activities are a common practice in the Neurology department. In fact, the annual Plans of Activities establish a number of scientific activities – either publications or presentations – to be developed each year, integrating the contracted services. Presently, 25 scientific activities are contracted for a yearly period, and are developed either by interns or attendants. The high level of medical specialisation in the Neurology department also provides an environment that renders these scientific activities possible.

In the context of the Neurology department, which is primarily a care provision service, scientific activity has to be integrated and articulated with other services. The department's operation is often the groundwork for the development of scientific activities, with patients as study subjects. Evidently, the background work necessary for the preparation of scientific publications or presentations is quite significant, distributed amongst working and non-working hours. Nonetheless, it is important to retain that scientific activities contribute to the achievement of contracted objectives, yet their development is not clearly isolated from other activities and may be difficult to consider these activities separate from the aforementioned care provision activities.

Educational Activities for Attendants

Physicians, namely attendants, are in a constant learning process, as medical knowledge is shared. Most of the performed activities somehow contribute to these learning processes, with meetings being one of the most significant. Meeting sessions occur between physicians from the Neurology department and also from other medical fields, in which clinical cases are discussed and physicians express their point of view, so as to develop further insight on each clinical case. In such discussions, physicians acquire knowledge and experience, which is a rather important issue. Some of these meetings may serve to discuss inpatient discharge notes, as a means to monitor the quality of the service. In this sense, physician meetings represent a significant component of the educational activities amongst graduate professionals.

Apart from the sessions, postgraduate physicians also participate in scientific meetings. Given the importance of these conferences, each physician is given 15 days per year to participate in such events, in which the physician must ensure the availability of another physician to prevent services to be left uncovered.

Educational Activities for Interns

During internship, postgraduate students - interns - go through a long educational process for the development of the required experience and knowledge. Supervision and support are provided by more experienced attendants, and should cover most of the department's activities. Training is usually integrated in the department's different activities, mainly inpatient care. Although intern supervision and training require the spending of physician's working time, these are essential to ensure the availability of qualified professionals in the future. Although the benefits produced by these educational activities are not as tangible as the operational evidence produced in other activities, they should be properly considered when analysing the distribution of human resources.

2.5. Analysis of the Neurology department's condition

The previous sections of this chapter have described the Neurology department of the WLHC, as a public care service operating in a hospital centre. At this point, it is important to highlight the most important aspects to be taken into account in the elaboration of the proposed methodology regarding the resource allocation process.

2.5.1. Multiplicity of Objectives

The Neurology department, as a public service provider, has stated multiple objectives, presented in section 2.4.1, which constitute the guidelines that drive the department's operation. As one could observe, the nature of these objectives is quite varied. Firstly, there is the intention to provide a complete and quality health care service, promoting both patient and staff satisfaction. However, it is also necessary to consider the fact that the entrepreneurial approach to the department's management, in line with recent reforms requires the department's operational performance to be also considered, by means of a series of indicators. On the other hand, focusing solely on the achievement of the contracted goals may not always yield the best results in terms of service quality and patient satisfaction, as these criteria are likely to be disregarded from an economical point of view. Furthermore, the Neurology department also aims to provide highly specialised care, adopting an internal structure that is not considered for contracting issues, but still renders the department's organisation more complex. As for scientific and educational activities, these also integrate the contracting policy, but still demand for a close articulation across the activities. These issues are likely to claim for a considerable portion of physicians' working time and may become incompatible with maintaining care delivery in the department's divisions.

The simultaneous consideration of all the department's objectives is likely to be complex and may present a source of problem, as these objectives are quite varied in their nature, and may even be conflicting. Likewise, one may observe that considering concrete objectives, such as operational evidence, and also quality factors – that can be difficult to express in tangible terms – may surpass the manager's capacity to fully consider the extent of the problem. In this sense, it would be useful to consider a methodological approach to assist the manager in accounting for all the objectives.

2.5.2. Multiplicity of Care Provision Activities

The internal structure of the Neurology department comprises several activities with specific features that need to be properly articulated. The variety of activities is quite significant, which adds complexity to the process of assigning physicians to activities, whilst taking into account all the department's objectives. Furthermore, the particular features of each activity give rise to the need to consider different aspects upon analysing the condition of a given division. The same is to say that when it is necessary to compare the condition of different divisions, one must consider different parameters and must be able to perform relative judgements based different types of information. For that reason, it would be practical to establish a framework in which such heterogeneous information can be expressed in similar terms, so as to overcome the complexity of considering such trade-offs.

The multiplicity of activities also gives rise to issues related with the qualifications required to perform activities. As mentioned before, the specificities underlying each activity demand physicians to possess a high level of specialisation. The available human resources may be considered as heterogeneous in the sense that each physician is characterised by a particular qualification profile that does not cover all the activities of the Neurology department and must be respected in the allocation of neurologists to the different activities. This process may become too complex, given the number of activities and physicians involved.

2.5.4. Scarcity of Human Resources

The condition of the Neurology department demonstrates that the available human resources are insufficient to ensure the maintenance of all the necessary - or desirable - activities. The impossibility to cover all internal consultations requests and the difficulty to provide an adequate training to interns are examples of situations that evidence that the department is currently facing a condition of human resource scarcity. Furthermore, the pressures for cost containment also result on management policies that avoid the hiring of more physicians. In such circumstances, it is not expectable that the department's current condition will be resolved through an increase on the available human resources. In fact, the Annual Report of Activities intensely emphasises the insufficiency of resources, demonstrating that presently the department's activities are secured with great effort from all medical professionals. In such context, one might consider two arising issues.

The first aspect is related to the efficiency of resource utilisation, regarding the production resulting from the current distribution of resources. Considering the nature of the present context, as a public health care service with integrated scientific and educational activities, the assessment of efficiency levels may provide a biased notion of the department's condition, as efficiency parameters may not be adequate to also evaluate all the outcomes, both in terms of production and in terms of scientific activity.

The second issue is related to the distribution of the available human resources amongst the different activities and may provide a better insight of the problem than the approach to efficiency parameters, given the nature of the context. Variations in the distribution of human resources imply evaluating the impact of placing human resources in a given division and, at the same time, observe the consequences of leaving other activities with fewer resources. Either way, the condition of resource scarcity demands efforts to be made so as to best use the available resources.

2.5.4. The Decision Problem

The description of the WLHC Neurology department provided insight on the organisation of care provision activities and on the department's current condition. The analysis of such information allows the formulation of the concrete decision problem. The Neurology department is characterised by a set of resources - in this case physicians – to be assigned to the different activities. Given the current availability such resources, and in face of the exigencies of patient demand, it is evident that these resources are not sufficient to carry out all the necessary activities. Thus, in such condition of resource scarcity, decisions must be made in order to establish which activities should be assigned resources at the cost of others. Hence, this constitutes a resource allocation problem, an issue that arises in all health care services [42].

The resource allocation problem in the Neurology department is characterised by a high internal complexity, regarding both the delivered services and the specific qualifications of physicians. As a result, resource allocation decisions have to account for a large number of aspects, which are likely to overwhelm the process and render impossible for the decision maker to account for the impact of resource allocation decisions in their full extent.

The complexity of the problem suggests the need to take on a methodology to assist the resource allocation process, providing a better understanding of the global problem without leaving important features unattended. For this purpose, a bibliographic review was conducted, in order to identify the methodologies existing in the literature. The literature review is presented in the next chapter, analysing the existing methods that address resource allocation problems. However, the consulted literature did not provide a complete solution for the present case study. In this sense, the chief director of the Neurology department, who is responsible for making most of these decisions, has raised the challenge of developing a methodological framework for this purpose. This thesis will address this challenge, with the conception and development of a methodology based on relevant literature and encompassing the particular features of the problem.

3. Literature Review

The Neurology department is currently characterised by a resource scarcity situation, as previously described. This chapter aims to present the results of the bibliographic research conducted to identify methods addressing resource allocation problems that have been documented in the literature. These methods will be presented and discussed, so as to analyse the extent to which they may contribute to solving the resource allocation problem in the Neurology department. Despite the multiplicity of available methodologies that address resource allocation problems in varied points of view, none of these provides a suitable solution for the present case study, therefore demanding for the development of a methodology for this purpose. Nevertheless, the existing literature provides the theoretical foundations necessary for the development of a new methodology.

Before presenting the methodologies, it is worth to refer to some aspects concerning resource allocation problems. Firstly, these problems may arise from a variety of contexts. As a result, the existing methodologies are based on diverse information and yield different results. Notwithstanding the multiplicity of resource allocation problems, it is important to establish the basic notions underlying the development of these methods. A resource may refer to different attributes, and in most cases financial resources are the central factor of scarcity. In other instances, resources may also refer to an organisation's capacity and also to specialised human skills. In general terms, resources are required to carry out some sort of activity inside an organisation, which are in turn usually referred as projects. In spite of the nature of the resources, projects must not be considered separately, as choosing a project implies that fewer resources remain available [43].

The bibliographic review was mainly based on the literature available in online databases, such as PubMed[1], ISI Web of Knowledge[2] and ScienceDirect[3]. These databases were searched using queries such as "*resource allocation in health care*", "*hospital resource allocation*", "*decision analysis in health care*", "*human resource allocation*" and "*physician scheduling"*. The results were explored with the tools available in the referred databases, so as to extend the scope of the search. At the end, the number of results was rather extent, and these were selected according to their relevance. Given the scope of analysis, it was decided to leave non-economic methodologies, such as allocation based on history and cost-of-illness studies, since these fall out of the scope of the problem of allocating physicians.

3.1. Methods based on economic principles

Methodologies based on economical principles include a wide range of approaches, sharing a common key goal, which is the minimisation of cost and the maximisation of the benefit outcome. However, the means for handling costs and calculate benefits highly differ amongst the methods.

[1] Available at http://www.ncbi.nlm.nih.gov/pubmed
[2] Available at http://www.isiknowledge.com
[3] Available at http://www.sciencedirect.com/

3.1.1. Economic Evaluation

Resource allocation in health care has been often addressed through the application of economic principles. This type of approach is extensively documented in the literature and addresses a wide range of resource allocation problems in health care. Although most of the existing literature on economic evaluation techniques refers to the allocation of financial resources to health care programmes, interventions or technologies, the explicitation of these methods will make use of the general concept of resource, in order to identify the principles underlying the methods. In general terms, an economic evaluation may be defined as "*the comparative analysis of alternative courses of action in terms of both their costs and consequences*" [44]. These costs refer to the resources required to carry out a specific action, and the consequences regard the outcomes from this action. This definition implies that economic evaluation entails the assessment of both the costs and the consequences in face of those of other alternatives under consideration. [44]. Accordingly, economic evaluation studies are classified according to the type of information considered in the analysis.

In Cost-Effectiveness Analysis (CEA), consequences of the different alternatives are expressed in a single dimension such as life years gained [44], considering methods of sensitivity analysis to assess the impact of uncertainty on the results of economic evaluations [45, 46]. CEA may be suitable for problems in which the decision maker considers a limited number of options and is able to extract information from the measure of outcomes. The difficulty to explicitly consider trade-offs between different measures of the outcomes has caused CEA to be less applied, as other economic evaluation techniques are being more accepted [44].

Cost-Utility Analysis (CUA) differs from CEA in the evaluation of outcomes, as these are assessed in terms of an utility-based unit of measurement [44, 47]. Multiple parameters may be accounted for in the measurement of outcomes, making use of the multi-attribute utility theory. Based on these theoretical foundations, methods were proposed for the evaluation of health states in specific conditions, such as developed by Torrance et al. [48]. Currently, measurements of health states are typically expressed in terms of Quality Adjusted Life Years (QALY) or Disability Adjusted Life Years (DALY), which account for both the duration and the health condition along the forthcoming life years. The quality or disability indexes result from standardised measurements of health or disease conditions, associated to utility-based values, and descriptive collections of health state measurements have been developed in the past decades. Though, there are still concerns on the validity of such information databases [49]. In a CUA study, the comparison of consequences yields the health gains expected from an option over another and the results are typically expressed in terms of costs per QALY or DALY gained.

Additionally, in Cost-Benefit Analysis (CBA), consequences are expressed in monetary terms, assigning these values to possible health outcomes. The concept of willingness to pay is typically encountered in this method and corresponds to the value that people would be prepared to pay in order to achieve or avoid a given health outcome [44].

The analysis of results makes use of the notion of incremental cost-effectiveness ratio (ICER) of two resource allocation options. The ICER provides information on the cost of an additional unit of the outcome and may also be expressed in a cost-effectiveness plane. The parameters in which outcomes are expressed will depend on the type of economic evaluation performed [44].

Although economic evaluation studies have had a large contribution in allocating resources in the health care sector, these methods are not suitable for the present case study. The first drawback is related to the multiplicity of services delivered within the Neurology department of the WLHC. This number is extensive, which would require a large number of evaluations in terms of cost and outcomes. Furthermore, the methods used to assess outcomes in economic evaluation would not be adequate for the activities in the Neurology department. While it would be possible to evaluate, for instance, the health gains from a day hospital session, such measurement would not capture the outcomes of scientific and educational activities. Also, outcomes obtained from different activities would be expressed using different measures and require a common basis for comparison. In this sense, methodologies based on economic evaluation lack features required to address the allocation of physicians and, thus, do not provide an adequate solution for the Neurology department.

3.1.2. Program Budgeting and Marginal Analysis

One of the drawbacks also pointed out to the use of economic evaluations is that opportunity costs are not considered. Opportunity costs provide information on the forgone benefit of the options left unfunded when allocation decisions are taken. Also, the concept of margin is not considered. From these two concepts, methodologies based on program budgeting and marginal analysis (PBMA) were developed and have been used in several health organisations [50, 51]. The key principle of PBMA derives from the idea that resource allocation in health care should not continuously claim for additional resources (as in the case of economic evaluation), as scarcity will always exist [52]. Similar methods have been developed, such as macro-marginal analysis [53].

The PBMA approach comprises several stages that constitute guidelines for the resource allocation process. In brief, these stages involve firstly the definition of the scope of analysis, the assessment of the existing resources and activities and the constitution of an advisory panel, which elicits the criteria according to which the options will be evaluated and identifies a prioritised list of the resource allocation options that are to be considered. These options are then rated according to the criteria using qualitative or quantitative scales, assigning scores to the different options. Typically, scores range from 0 to 100 and are multiplied by the weight of the respective criteria in order to obtain global scores that allow direct comparison between options. The last stages of the PBMA method involve the analysis of the options' scores, determining whether resources should be reallocated between them, and continue an iterative process to identify additional options that are worth such analysis until no further gains can be obtained. Lastly, the advisory panel is responsible for discussing results with a wider range of stakeholders and elaborate policy recommendations [54].

The PBMA framework provides insight on several features of resource allocation in health care that may be applicable for the allocation problem of the Neurology department. Namely, the consideration of multiple criteria according to which options are evaluated is an important aspect that will arise in the Neurology department, as one could infer from the stated diversity of objectives. In effect, it is established that prioritisation and resource allocation decisions in health care must consider multiple criteria [55]. The rating of options is also a relevant issue in such methodology, as a necessary process to achieve an overall rating of options that allows direct comparison of options.

However, in order to apply such features to the resource allocation problem of the Neurology department, the stages of the decision making process would require further development. The elicitation of criteria is often complex and may require the use of specific approaches to achieve such purpose. As PBMA has developed mostly on the allocation of financial resources to health services and programs, the criteria involved in such processes may be shared by different contexts and thus require less effort on this matter. Nevertheless, although the principle of considering multiple decision making criteria still stands, the definition of decision making criteria in the Neurology department would require a more specific approach. The rating of options according to the criteria and the definition of the corresponding weighting coefficients may also lack additional improvement. Assigning scores to the options requires the existence of a system that enables the valuation of options according to the criteria, which can be rather difficult in more intangible criteria. The rating of options by decision makers may lead to a biased evaluation. Also, the weighting process should be carefully performed, so as to avoid partial judgements.

Despite the limitations of PBMA methodologies, the principles of considering multiple criteria, rate options according to the criteria and assign weights to these criteria are applicable for the context of the Neurology department. However, PBMA does not provide a solution for the problem, therefore demanding the development of a more specific methodology.

3.2. Optimisation Methods

The principles underlying optimisation methods have common aspects to those based on economic principles. As in varied approaches, the central objective is to maximise the benefit and, thus, optimisation should not be considered as incompatible with economic techniques. Instead, these can be used in complementarity.

Principles of Optimisation

Most of the times, resource allocation problems are characterised by a level of complexity that renders impossible for the decision maker to account for all the variables and trade-offs existing within the decision making context. In order to overcome such complexity, these problems are often tackled by means of mathematical modelling, in which the decision making context is represented by a set of parameters, constraints and variables, making use of computing technology to process the required amount of information. The use of such programming methods integrates in the field of optimisation. The general form of optimisation problems is as follows [56]:

$$\begin{aligned} &minimise\ f_o(\boldsymbol{x}) \\ &subject\ to\ f_i(\boldsymbol{x}) \leq b_i, \quad i = 1, \dots, m \end{aligned} \tag{1}$$

In the previous equations, f_o denotes the objective function, f_i represents the set of constraints, the constants b_i define the constraint bounds and, lastly, $\boldsymbol{x}$ denotes the vector $\boldsymbol{x} = [x_1 \quad \cdots \quad x_n]$. The objective function is the mathematical expression that defines the problem and integrates the variables x_i, as well as context-specific parameters. The objective function typically represents total cost or benefit; in the latter, the aim is to maximise the objective function. On the other hand, the possible values of $\boldsymbol{x}$ correspond, in practice, to the different options under consideration Through diverse programming techniques, optimisation methods analyse the set of possible alternatives for resource allocation and intend to determine the best solution out of this set, according to the defined objective function [56].

The nature of the objective function f_o determines the subfield of optimisation the broad range of methods. In health care resource allocation, objective functions are often expressed as a linear combination of the decision variables present in the vector $\boldsymbol{x}$ in equation (2). The problem constraints are also expressed as linear equalities or inequalities. The optimal solution is thus determined by the maximisation of minimisation of the objective functions, within the limits of the constraints. In some cases, the decision variables may be limited to integer values. Such problems are addressed through integer programming methods [57].

Multicriteria Optimisation

The field of multicriteria optimisation (MCO), also known as multiobjective optimisation, is characterised by the integration of multiple, conflicting objectives in the objective function to be maximised or minimised. In such problems, the objective function to be optimised is represented by a vector of functions $f_{o,k}$, each one corresponding to a criterion. A typical approach for solving such problems consists in the scalarisation of the vectorial objective function by means of a weighted sum [58]:

$$f_o(\boldsymbol{x}) = \sum_{k=1}^{N} w_k f_{o,k}(\boldsymbol{x}) \tag{2}$$

In equation (3), the coefficients w_k represent criteria weights. The objective function is thus represented as a scalar value to be optimised, which reduces the computational workload of such methods. In the context of resource allocation problems, the objective function typically represents the overall benefit of a given allocation option. Thus, each function $f_{o,k}$ represents the benefit obtained from a given option in criterion k. The field of MCO comprises various particular techniques for defining the objective functions, decision variables and constraints of the mathematical models. In general terms, the brief description of the MCO approach hereby presented represents the main principles and formalisms inherent to the methodologies comprised in this scope.

Goal Programming

The goal programming approach is integrated in the field of MCO, as a variant of linear programming, and has been used in the scope of resource allocation problems. The central concept of goal programming lies in the definition of objective functions by means of goals to be achieved. Such approach derives from the premise that decision makers aim to achieve a set of goals as closely as possible, instead of trying to maximise or minimise objective functions. In practical terms, the objective functions are modelled in such a way that the deviations from the respective target values penalise the overall objective function. System and goal constraints are also defined, in order to achieve a mathematical formulation of the problem. The field of goal programming comprises several variants, whose major differences are found mostly in the definition of the objective functions and handling of the deviation penalties. These methods may also rely on utility functions to model preferences [59].

Goal programming techniques have been applied in the context of resource allocation in hospitals, for instance, in the organisation of shift hours [60] and the definition of case mix and volume of acute an acute care hospital [61]. The principles underlying the mathematical modelling of resource allocation problems are in line with those of MCO, yet differing mostly in the way of stating objectives in the model formulation.

Contributions of Multicriteria Optimisation

The MCO methodology might be suitable for the present case study in some of its basic principles. Firstly, it is able to encompass the multiplicity of objectives that characterise the Neurology department, and such can be of different nature. However, these functions would be required to yield the benefit outcome of a given option in each criterion, so that the overall scalarised objective function is expressed in common units. Also, the possibility to define weights for the criteria enables the possibility to consider the decision maker's preferences, as criteria may not have equivalent impacts on the overall objective function. However, some aspects are not covered in the scope of MCO methodologies and would require further detailing in the allocation of neurologists. Criteria elicitation and determination of weights are likely to be complex tasks and require deeper elaboration, which is an aspect already pointed out to PBMA. Although goal programming approaches definition of criteria in terms of goals to be achieved, such measures might not be possible in more certain criteria.

Despite the utility of the central principles of MCO, namely the possibility to consider multiple objectives and define weights for criteria, the approach does not cover all the necessary aspects in the context of Neurology department.

3.3. Scheduling Methods

As the current decision problem concerns the allocation of working time, it is important to refer to the field of scheduling. In general terms, scheduling consists of decisions concerning allocation of limited resources to tasks over time, so as to optimise one or more objectives. The aim is to determine the time intervals in which resources are to be assigned to different tasks that are competing for the same resources [62].

The definition of scheduling problems also requires modelling the context in mathematical terms, though in a perspective that is different from the characteristic objective functions in optimisation methods. The mathematical framework is related to the general features of operations management and logistics, requiring the establishment of parameters such as the duration of activities, start time and finishing time. According to the parameters defined for a specific problem, scheduling methods yield the sequence of processes that optimises an objective function. As a result, the solutions establish both the distribution of resources amongst different activities and the order according to which the allocation takes place [62].

The formulation of scheduling problems also includes the definition of an objective function. In simple scheduling problems, this function represents a criterion to be maximised or minimised. However, most of the contexts require the definition of multiple criteria, as was the case of MCO. The central idea of multicriteria scheduling problems is similar to that of MCO, which is the minimisation or maximisation of an objective functions that incorporates the set of criteria, weighted by the respective coefficients [63]. Scheduling methods have provided interesting approaches in allocating health care resources, as for instance, the flexible scheduling of patient appointments to use a CT-scanner [64].

Contributions of Scheduling Methods

The scheduling approach is widely used in addressing resource allocation problems, specifically when it is necessary to determine both the distribution of resources amongst different areas and the sequence in which this distribution occurs. However, solutions yielded by scheduling methods determine the sequence in the time domain according to which the allocation of resources – in this case, physicians – to the different activities. Such solutions are not adequate for the purpose of this work, namely for the reason that the activities that are carried out within the department require a certain level of flexibility in terms of their sequence. For instance, it would be difficult to establish start and end times for inpatient care, as this would depend on external variables such as the evolution of the patients' clinical condition. Unexpected variations of inpatients' clinical condition would require the adaptation of physicians' schedule in order to timely attend urgent patients, even if adaptive mechanisms were to be incorporated. Hence, the nature of the activities at stake would not be adequately captured. The use of scheduling methods to address resource allocation in the Neurology department is thus not likely to be suitable for the purpose of this thesis.

3.4. Multicriteria Decision Analysis

Decision analysis has been experiencing a progressive growth in the recent decades, as a field within Operations Research. The primary principles of decision theory are based upon probability calculus and on multi-attribute utility theory. The scope of decision analysis has been branched into different approaches, regarding the means of handling uncertainty and accommodating multiple objectives. In this sense, Phillips proposed a taxonomy of seven model types that aims to elucidate decision makers on matching such methodologies to different types of real problems [65]. The scope of decision analysis has been differentiated towards a greater focus on handling multiple objectives, introduced by Keeney and Raiffa in 1976 [66]. The next paragraphs will present an overview of the main features of multicriteria decision analysis, and it is important to refer that the basal principles of decision analysis aim at the maximisation of the benefit outcome and the minimisation of costs, similar the economic principles pointed out in section 3.1. Though, for the purpose of this work, decision analysis is addressed separately from economic methodologies, notwithstanding these similarities.

Decisions with Multiple Objectives

In almost every organisation, resource allocations decisions are characterised by multiple objectives, which often become in conflict, and therefore demand the trade-offs are considered along the decision making process [67]. Such conclusion is typically valid in public organisations [68], and may be expected to stand true in the context of a public hospital, such as the WLHC. The existence of multiple criteria brings significant complexity to the process of decisions making. Furthermore, when there are numerous options under consideration, decision makers are not able to attain full understanding of all the details of all options, as their perception capability has natural limitations [69]. In this sense, multicriteria decision analysis (MCDA) has introduced a constructive approach that aims to aid decision makers through the process of considering multiple criteria and evaluate numerous options in order to enable informed decisions.

The development of MCDA methodologies was introduced by Keeney and Raiffa in 1976 [66], an approach focused on structuring the objectives of an organisation and also in the evaluation of alternatives. The authors firstly establish some terminological notions for the process of structuring objectives, starting by the definition of areas of concern, which should provide a formal specification of these objectives, so that multiple points of view are comprehensively considered. However, the specified areas of concern frequently do not provide a means to inform the extent to which a given option meets the organisation's objectives. These are further explored in order to define more specific objectives that can, in fact, indicate the degree to which an option contributes for the organisation's objectives. These objectives provide a means to assess, with the required detail, such contribution, even if these are conflicting. The point is to determine which features the decision maker is required to account for upon evaluating alternatives. The resulting structure of objectives may be able to give the decision maker a better insight on the decision problem, so as to properly handle the complexity arising from the multiplicity of objectives [66].

Traditionally, decision analysis was mostly based on alternatives, aiming to identify the criteria that allowed an adequate distinction of the alternatives under consideration, an approach usually designated as alternative-focused thinking. Later on, Keeney proposed a shift in the paradigm of modelling objectives, placing the focus of structuring objectives in the organisation's values and strategic objectives [70], giving rise to value-focused thinking (VFT). Keeney proposed that structuring objectives should be performed according to the organisation's values and strategic objectives. In this sense, such approach advocates that focusing on values may enable the creation of better alternatives. The VFT approach is, therefore, a stronger principle with greater potential for aiding decision making processes, and promoted the improvement of multiple MCDA techniques.

Evaluating Alternatives

Following the process of structuring objectives, the decision making process involves the appraisal of the set of alternatives under consideration. The structuring of objectives presented in the previous paragraphs provides the groundwork for evaluating options according to different objectives, which in turn are assigned attributes. However, in most decision problems, these attributes are expressed in measures of different nature, which are not easily comparable and render the interpretation of trade-offs quite more complex. In this sense, MCDA makes use of the multi-attribute utility theory to enable the definition of scales of measurement in terms of utility values, for each criteria to which has been assigned an attribute [71]. The use of utility values results in the definition of a value function that captures the decision maker's preferences in respect to the different criteria [72]. To determine the overall value of a given option, the MCDA framework typically relies on the additive model that demands respect for mutual preference independence:

$$V_j = \sum_i w_i v_{ij} \tag{3}$$

In equation (3), V_j represents the overall value of alternative j, i is the weight assigned to criterion i, and v_{ij} corresponds to the value of alternative j according on criterion i. This overall score provides information on the extent to which an alternative contributes to the set of objectives elicited in the earlier phase of structuring objectives, according to the decision maker's preferences. Hence, MCDA performs the evaluation of alternatives through the decomposition of the problem in simpler tasks that analyse the decision maker's preferences in a constructive manner.

Portfolio Decision Analysis

The appraisal of the set of options under consideration provides a means to properly inform decision maker's on the impact of a given alternative according to the established evaluation criteria. Still, resource allocation decisions involve the selection of multiple alternatives that provide the highest overall benefit without exceeding a limited budget of resources. Such problem is rather complex and is likely to surpass the decision's maker capacity to consider all possible combinations of alternatives. This issue is generally referred to as the knapsack problem, already mentioned in the scope of multiobjective combinatorial optimisation. MCDA establishes a framework for selecting a portfolio of options, i.e., a set of alternatives that makes best use of the available resources. This method relies on the definition of a priority index for the selection of alternatives, given by their ratio of their benefit to the respective cost. Should uncertainty be considered, it must be accommodated in the benefit through probability weighting [69]. The priority index is usually illustrated by means of the Value for Money (VfM) triangle:

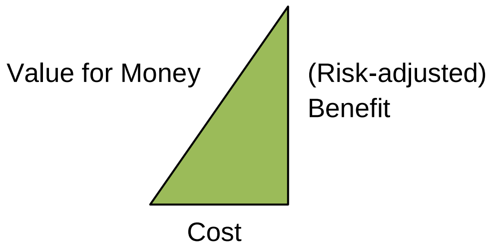


Figure 6. Illustrative representation of the Value for Money principle [65].

The VfM principle, schematically represented in Figure 6, provides the aspect according to which options are to be integrated in the portfolio. It is important to note that VfM is interpreted as the benefit that is expected to be obtained from a unit of resources, which can be either financial or non-financial. The selection of alternatives according to the VfM index forms the Pareto-efficient frontier, providing the highest possible benefit for a given budget constraint. If the options were to be selected in decreasing order of benefit, the total benefit outcome would fall below that of the normative VfM principle [69].

The MCDA approach to resource allocation provides the principles and tools necessary to ensure the best outcome that can be obtained from the available resources. This methodology relies on the structuring of objectives and appraisal of options, as presented earlier in this section. Hence, MCDA provides an integrated framework for resource allocation, involving multiple stages that comprise several tasks, in order to overcome the great complexity of these problems in organisational contexts.

Contributions of MCDA

The scope of action of MCDA methodologies is rather broad, as it provides essential principles for aiding decision makers throughout complex resource allocation problems, yet granting flexibility to accommodate the features of a particular context. Also, the process enables transparency of the whole structuring and evaluating process by explicitly expressing preferences and criteria. MCDA has had significant developments in multiple topics, as the trend seems to point towards VFT, organisational processes and real options, amongst others [73]. In addition, software tools have been developed, so as to facilitate the application of these methodologies and systematise the approaches. Equity and HiPriority are examples of such tools, although there are some differences in the underlying type of MCDA procedure [74].

The applications of these resource allocation techniques are extensively found across the literature, both in the public and private sector, addressing a broad variety of problems. As for the health sector, such methods have been adopted to address capital allocation [75], prioritisation of health care programmes [76] and health policy making [77].

MCDA approaches for resource allocation may, in fact, provide suitable principles for handling the complexity arising from the multiplicity of objectives existing in the context of the WLHC Neurology department. The VFT approach to structuring objectives should be advantageous for such context, as a public health service with strategic and operational objectives. Furthermore, as these objectives concern different aspects, evaluation criteria are likely to be expressed in different attributes that may be difficult to compare, so as to consider properly trade-offs. Hence, the definition of utility functions may provide a helpful means of modelling preferences and enable an informed appraisal. Such features were already pointed out in PBMA, yet MCDA enables further insight through the application of the VfM principle and the possibility to integrate an optimisation method to maximise benefit.

Nevertheless, it is important to note that some aspects of human resource allocation in the Neurology department still require a methodology to be developed, as for instance the creation of alternatives. The general methods found in the literature typically establish alternatives as well-defined projects or courses of action, which are to be evaluated and are assigned a cost. This is not the case for the present context, as alternatives are virtually infinite, so it would be useful to define a method that allows a systematic consideration of alternatives. Also, the type of constraints arising in physician time allocation is more complex than in resource allocation problems generally found in the literature, in which constraints are mainly related to the limitation in resources and interactions between options. For such reasons, the MCDA framework provides a suitable method for the allocation of physicians’ working time, yet requiring further considerations in order to account for all the features conditioning the allocation of human resources.

4. Methodological Framework

The previous chapters provided insight on the current situation of the Neurology department of the WLHC, as well as on the principles of varied methodologies that are found in the literature addressing resource allocation problems, analysing the potential applicability to the case study. As none of these methodologies provided a method answering to the requirements of allocating neurologists' working time at the WLHC, a methodological framework is proposed for this purpose. Firstly, a conceptual overview of the methodology is presented, and the main stages are then elaborated.

4.1. Framework Overview

At the outset, it may be worth to bring up the key aspects that constitute the most relevant features that must be considered upon conceiving a model for physician allocation:

- The existence of multiple objectives of different nature to be attained by the department, so as to properly analyse the impacts of allocating physicians to the different activities;
- The diversity of health services claiming for resources;
- The particular characteristics of physicians, regarding their qualifications to perform different activities;
- The need to define a process for creating allocation alternatives relevant for the context.

Such aspects bring complexity to the task of distributing neurologists amongst activities. For that reason, a first approach to handle such complexity would be the decomposition of the overall problem into more simple parts, yet ensuring that these are coherent with, the global context. The first stage of the proposed methodology concerns the process of structuring the problem and collecting relevant information that will provide the basis for subsequent development of the model. With such information, the options are generated and the evaluation model is built. To evaluate these options, a multicriteria model is built. Finally, the generated alternatives are rated, leading to the analysis of the results and the selection of efficient alternatives. Although the framework is separated into its main constituting parts, these are closely interrelated. The development of the methodology does not obey a one-way sequence, being adaptive and iterative, introducing adjustments when necessary.

The developed methodology makes use of theoretical bases presented in the literature, yet it is differentiated from the existing techniques. The approach employed principles from different methods conjointly, and can be considered in the frontier between MCDA and operations management. The problem structuring process and the construction of the evaluation model are performed in the scope of MCDA, through a socio-technical approach. On the other hand, the technique for modelling of the characteristics of the context, namely the specification of activities and physicians and the construction of performance descriptors are based on the principles of operations management, which may also be considered related to the discretisation of working time for the generation of alternatives. At this point, it is important to outline the mathematical formulation of the methodology.

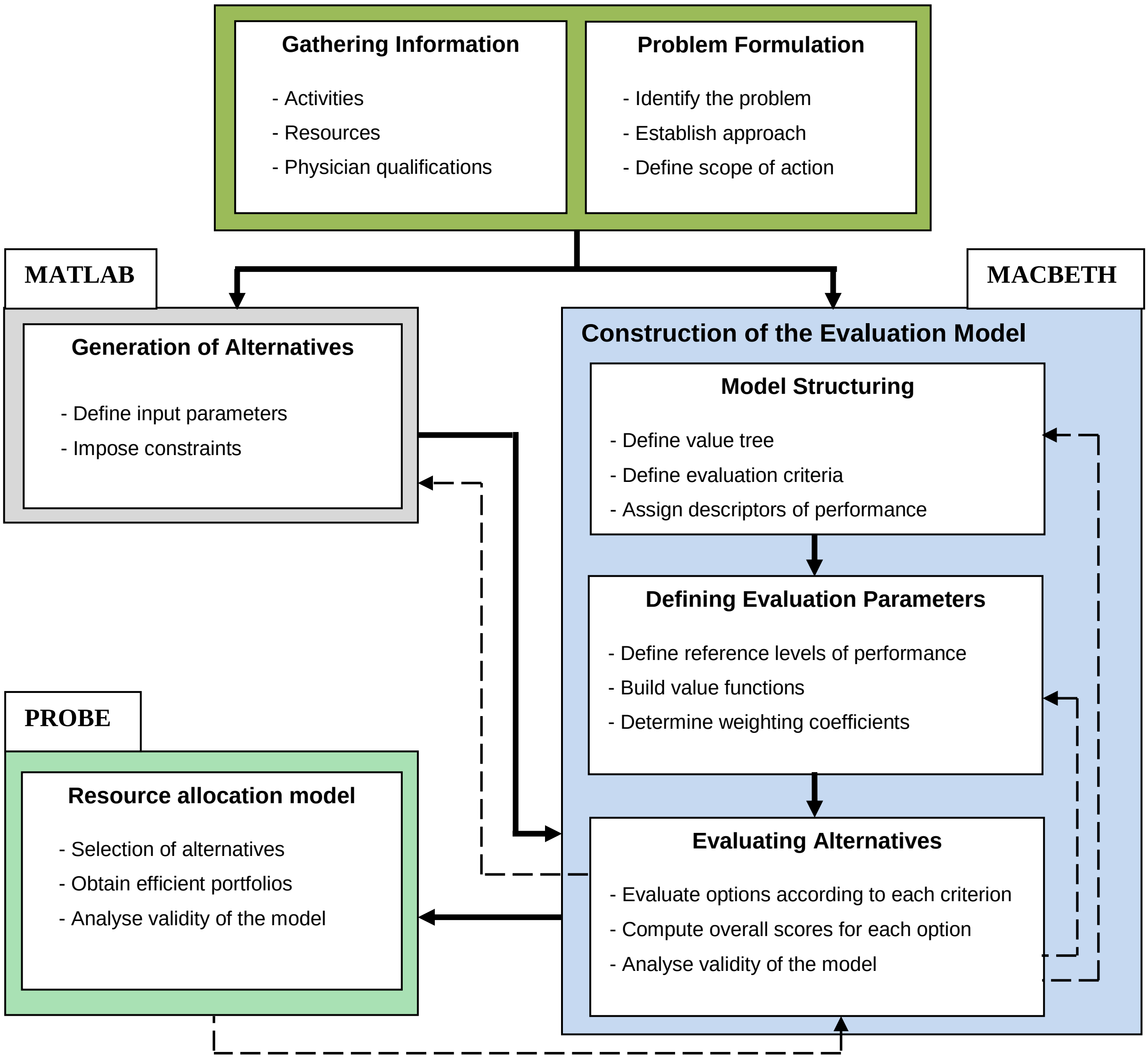


Figure 7. Conceptual Framework of the proposed methodology. Solid arrows represent a sequential relation. Dashed arrows correspond to iterative processes of model adaptation and improvement.

The central objective of allocating the available physicians to activities is to maximise the benefit outcome, which corresponds to maximising the benefit yielded by the set of alternatives selected, as only one alternative is selected for each physician. For each alternative, the benefit is given by the weighted sum of the score $v_{ij}(x_{ij})$ of alternative j in criterion i. Each criterion is, in turn, assigned a descriptor of performance X_i composed of levels of performance x_i, and the performance of an alternative j is associated with a level from X_i, designated as x_{ij}. The mathematical formulation consists in:

$$maximise \quad V_j = \sum_{i=1}^{n} w_i v_{ij}(x_{ij}) l_j \qquad (4)$$

$$subject\ to: \sum_{j=1}^{m} c_j l_j \leq B \qquad (5)$$

$$\sum_{i=1}^{n} w_i = 1 \qquad (6)$$

$$l_j \in \{0,1\} \qquad (7)$$

In the above formulation, w_i the weight of criterion i and l_j is a binary variable that assumes the value 1 if an alternative is selected and 0 otherwise. B represents the budget, which in this case corresponds to the total amount of monthly working hours of physicians. The maximisation of (4) represents the knapsack problem, regarding the optimisation of the overall portfolio benefit.

Having presented the general mathematical formulation of the model to be developed, the next sections will regard the construction of such model, from the structuring phase to the stage of portfolio analysis. In the socio-technical process of structuring and building the evaluation model, as well as upon evaluating alternatives and analysing results, the role of the facilitator will be developed by the thesis author. It is also necessary to identify the person responsible for taking those decisions, with whom the facilitator interacts through the aiding process. In this case, the decision maker is the Chief Director of the Neurology department, Dr Mário Veloso.

4.2. Problem Formulation

The complexity and the absence of consensual formulation demands that a proper structuring is achieved. The first issue concerns the definition of the concrete problem. Traditional approaches from operational research are mostly directed to problems whose structure allows the designation of measures and relations through which the alternatives produce outcomes. On the other hand, in ill-structured problems, an approach that can accommodate multiple perspectives, is interactive and iterative and fosters the ownership of the model would better suit decision makers [78]. There are several problem structuring methods found on the literature, with varied approaches and scopes of action, according to a review published by Mingers and Rosenhead [79].

In line with the taxonomy proposed by Phillips [65], one may analyse a given situation in terms of the uncertainty and the range of the objectives. The Neurology department is characterised by the existence of multiple objectives to be accounted for, which assume a much greater importance than the uncertainty underlying the problem. Such fact justifies the use of the MCDA framework, so as to properly accommodate these objectives in an integrated approach. In this sense, the proposed methodology makes use of a multicriteria model for the evaluation of allocation options.

At the problem definition stage, it is also important to attend to the nature of the alternatives that should be consistent with the present problem. In the present case study, the form of the alternatives to be considered is somehow more intuitive. As the central idea is the allocation of physicians to the different activities, it is instinctive to associate an alternative with a specific way of distributing physicians' time. Although at this stage there is no clear definition of how these alternatives are to be elaborated and represented, the decision maker starts off with a general idea of what to expect for the alternatives to be like.

Gathering Information

At this early stage, it is necessary to gather the relevant information that will allow a more specific characterisation of the context of the Neurology department and serve as a basis for the generation of alternatives and construction of descriptors of performance. Firstly, it is necessary to define the format according to which the activities that take place within the Neurology department will be considered. The main delivered services were presented in section 2.4.2, but these services themselves comprise more specific activities that require further consideration in order to enable an accurate modelling. On the other hand, it is also required to fully characterise the set of human resources available in the Neurology department, which consists on gathering information, for each physician, about the working hours and the respective qualification profile, that is, defining the activities to which a given physician may be allocated. Furthermore, it is necessary to assess the current distribution of physicians amongst the activities, as it will serve as the starting point for the creation of alternatives.

Once the referred information has been gathered, organised and structured, and having established the MCDA framework as the approach to drive the methodology, the decision aiding process then turns to the stage of building the evaluation model and generating the alternatives accordingly.

4.3. Generation of Alternatives

It is important to clarify the choice of presenting this process at this stage of the methodology. As outlined in Figure 7, both processes of generating alternatives and constructing the evaluation model follow the problem structuring stage, covered in the previous subchapter. In conceptual terms, there is no relation of precedence of which part of the process should be addressed first. That is, the generation of alternatives makes use of the gathered information, regarding the characterisation of physicians and activities, whilst the construction of the evaluation model is performed in line with the selected MCDA framework and established scope of action. Both processes should converge upon applying the constructed evaluation model to the generated alternatives. However, the appearance of the method for generating alternatives before the explanation of model construction may suggest that the first precedes the latter, which would be incorrect. As will be made clear in the proper section, the first stages of building the evaluation model are performed disregarding the generated alternatives, i.e., the definition of evaluation criteria is not based upon the generated alternatives, but instead in the department's values and strategic objectives [70]. The choice of presenting the creation of alternatives at this point derives from two reasons: (1) the decision maker is already acquainted with the type of alternatives that are to be generated and (2) the explanation of the process of building the evaluation model can thus be carried out in its logical sequence, integrating the generated alternatives in due time.

Approach to the generation of alternatives

Generating alternatives aims to create courses of action according to which the objectives can be achieved. As Keeney stated, "alternatives are relevant only because they are means to achieve values" [80]. In the scope of this methodology, the alternatives should represent a way of applying the available resources so as to, to some extent, contribute to the achievement of the department's objectives.

In concrete terms, each alternative is defined as a combination of amounts of time assigned to the different activities. The generation of alternatives is to be performed for each physician. The initial concept of alternative consisted of a combination of allocated times of one physician that did not consider the allocation of working time of the remaining neurologists. However, it was realised at a later stage (upon defining descriptors of performance) that it would not be possible to appraise such alternatives because of the fact that these descriptors required the information on the allocation profile of all physicians. In order to overcome this fact, the concept of alternative was modified in order to meet such requirements. Therefore, the settled concept of alternative consists of a combination of values of a physician's working time assigned to the possible activities, and this combination is in turn associated with the current allocation profile of all other physicians. The generation of alternatives starts off from the collective allocation profile of all physicians and manipulates only the time of the physician whose alternatives are being generated.

It is then necessary to establish the way of handling the resources upon generating alternatives. This deliberation was carried out jointly with the decision maker and was set that the distribution of working time in different alternatives should vary in finite quantities, i.e., considering discrete variations in the amount of time assigned to each activity. Through discretisation, the set of all possible alternatives becomes finite, which would not be the case if the resources were handled as a continuous measure. Also, creating a discrete set of alternatives allows the application of a resource allocation model based on PDA. In addition, the computational load required for analysing resources as a continuous variable would be likely to render the process infeasible.

Algorithm for generating alternatives

The generation of alternatives was enabled by means of an algorithm, requiring a set of input parameters. The central idea of the algorithm is to yield the possible combinations of amounts of time assigned to the activities, for each physician, while these amounts differ in finite quantities, from now on designated as blocks. However, if the options are created without constraints, the number of resulting combinations would be unmanageable, even with the discretisation of resources. In this sense, it is necessary to narrow the resulting alternatives to a more practical set. If the alternatives were to be generated without constraints, some of them would correspond to allocation profiles that would make no sense in the context of the Neurology department, as for instance, an option that would correspond to assign the total working time to a single activity. Such alternative would be pointless in reality, as acknowledged by the decision maker. In this sense, the creation of alternatives attempted to achieve a balance of widening the set of alternatives whilst defining boundaries to preserve their reasonableness and avoid excessive computational load.

The intuitive algorithmic approach to generate these alternatives would be the determination of all possible combinations of time-activity assignment and eliminate the ones that do not comply with the stated constraints. However, the number of unconstrained combinations resulting initially is too large to be supported by an average computer. For instance, if one considers a simple case with 10 possible amounts of time to assign to each activity, of a total of 10 possible activities, the number of unconstrained combinations would be equal to 10^{10} combinations. Hence, it was necessary to take a different algorithmic approach to generate alternatives.

In order to simplify this process, a different method was adopted. This method takes the current distribution of time as a starting point, and computes the desired variations of this distribution according to parameters defined by the user. These variations correspond to multiples of the dimension of the blocks in which resources are to be discretised, represented as Δ_t. Furthermore, the use of the current allocation as a starting point also reduces the appearance of obsolete options, which would occur in unconstrained combinations. The resulting alternatives could be interpreted as different modes of partially reallocating the current distribution of time. In order to clarify such method, a schematic representation is presented.

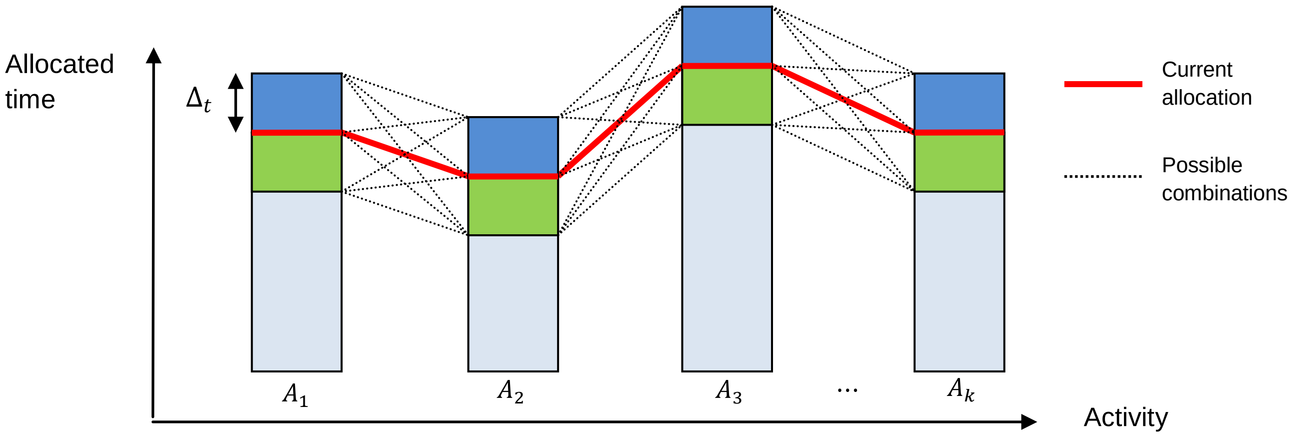


Figure 8. Schematic representation of the method for generating alternatives for one physician.

The algorithm starts off from the current allocation, i.e., the amount of time assigned to each activity at the beginning of the analysis. The user then specifies the range of variation of the time allocated to each activity, defining the number of blocks Δ_t of time that may be taken from or added to these amounts. Such specification defines the different quantities that are to be considered in each activity. Then, the generation of alternatives is performed, through the combination of the possible amounts of time in each activity, only considering the combinations whose total sum of time equals the total working time, since the objective is to determine alternatives for distributing the total physician's working time. This mechanism can be exemplified in Figure 8. The red lines represent the current time allocation, which represents the starting point, and the size of the vertical bars represent the time allocated to activity A_j. It was defined that, for each activity, three possible values of allocated time can be considered, corresponding to the current time (red line), the result of taking the green block, or the result of adding the blue block. The three possible levels correspond to defining the number of variations as one - one up and one down. The dashed lines represent the possible combinations of the different values of each bar, then selecting only those which preserve the total working time of the initial allocation profile.

The algorithm considers the same range of variation for all the activities (taking only non-negative values), mainly for the sake of simplicity. However, the decision maker may wish to introduce further constraints to narrow the range of variation of a specific activity. In this sense, the algorithm also allows the specification of minimum and maximum values assigned to the concerned activities, filtering the results of the initial combinatorial calculation and eliminating those which do not comply with the constraints. Hence, the algorithm is able to accommodate different types of specifications for generating alternatives, granting a considerable flexibility to the process. The algorithm obviously has limitations on the number of possible values for each activity, but the computational load of the proposed algorithm is, in fact, much lower than if all the possible combinations were to be generated, as it reduces the number of obsolete alternatives generated unnecessarily.

Implementation of the Algorithm

This algorithm was implemented in the MATLAB® environment, due to its capability for numerical computing and the possibility to interact with Microsoft Excel®. The generation of alternatives was integrated in a simple routine, in which the user inserts the set of input parameters by means of a dialog box. These parameters are as follows:

- Name of the Excel file in which to record the data;
- Current allocation profile;
- Block dimension (in hours) - $\Delta_{\mathbf{t}}$;
- Number of variations, $\boldsymbol{N_{vars}}$;
- Total number of activities under consideration - $\boldsymbol{M}$;
- Monthly working hours, $\boldsymbol{WT}$;
- Minimum services, $\boldsymbol{SMin}$;
- Maximum services, $\boldsymbol{SMax}$;

The algorithm first computes the possible combinations, based on the current allocation profile, the block dimension and the desired number of variations, and then filters these results according to the constraints specified by the minimum and maximum levels of services that the decision maker may find necessary to specify. If the decision maker does not wish to define constraints at this level, the fields may be left blank, yielding the alternatives resulting from the initial combinatorial mechanism.

The program output, the set of alternatives Θ for a given physician, is structured in a rectangular matrix, in which each line represents an alternative, and each column corresponds to a specific activity. Such representation is transposed to Microsoft Excel, preserving the layout.

$$\Theta = \begin{bmatrix} T_{1,1} & \cdots & T_{1,M} \\ \vdots & \ddots & \vdots \\ T_{K,1} & \cdots & T_{K,M} \end{bmatrix} \tag{8}$$

Each matrix entry $T_{r,s}$ indicates the time allocated to activity s in alternative r. The outline of this matrix was transposed to Microsoft Excel, in which the evaluation model was implemented. In matrix Θ, $T_{k,j}$ represents the time allocated to activity j in alternative k. It is important to refer that matrix Θ includes the columns of all the possible activities, including those that are not considered to that physician (resulting in columns filled with zeros). The point is to adopt a format for this matrix that enables the systematisation of the evaluation process, which will make use of the alternatives recorded in an Excel sheet.

4.4. Model structuring

The structuring of a decision aid model entails several procedures and consists of an interactive and learning process, through which the facilitator helps the decision maker, in line with the constructive approach presented in section 3.4. [81].

Identifying concerns through discussion

At this stage, evaluation criteria are defined. In order to carry out such task, a top-down approach is adopted, firstly identifying the key issues that directly arise in a discussion with the decision maker about how to evaluate the attractiveness of different alternatives (in this case, alternatives for resource allocation). These issues represent the decision maker’s concerns (cf. Bana e Costa and Beinat [81]), and may be related to strategic objectives or to specific characteristics that the decision maker finds important to analyse in each option.

Typically, the concerns that are primarily identified in a discussion often correspond to global aspects that do not represent evaluation criteria. In this sense, the progression aims at identifying and clarifying the issues that are encompassed in each of these global concerns, as described by Keeney and Raiffa [66]. Such process of identifying more specific objectives or concerns is characteristic of a top-down approach, which was primarily followed in the discussion, although not too strictly, since a mix of both top-down and bottom-up seems to be the most adequate. In fact, the decision maker’s concerns arising in discussion may be quite general and represent a global point of view, but may also be a specific characteristic of alternatives that reveals a hidden global concern.

Define evaluation criteria

The evaluation criteria, which are compatible with the notion of key concern from Bana e Costa and Beinat [81] and of fundamental objective [70] allow the decision maker to determine the impact of an alternative in respect to the concern expressed by that evaluation criterion. Keeney and Raiffa stated that a family of evaluation criteria if they possess five key characteristics: completeness, operationalisability, decomposability, non-redundancy and minimum size [66].

At this point, it is important to clarify the concept of *descriptor of performance*. According to Bana e Costa et al. (2002), a descriptor of performance consists of an ordered set of plausible impact levels that allow the decision maker to measure the extent to which a given alternative contributes to the achievement of the stated objectives [82]. These measures may be quantitative (continuous or discrete) or qualitative, depending on the nature of the evaluation criterion. The possibility to assign a descriptor of performance to each evaluation criterion comes from its operationalisability. Given the variety of evaluation criteria that may arise in the process of building an evaluation model, it is often necessary to recur to different types of descriptors of performance that best suit the evaluation criteria under consideration. Keeney considers three types of descriptors of performances: *natural*, *proxy* and *constructed* [70]. A natural descriptor makes use of an inherent feature of the evaluation criteria to represent the impact levels, while proxy descriptors, in turn, represent indirect measures that are directly related to the aspects concerned in the evaluation criterion, yet it is important to caveat that the interpretation of the impact levels of the proxy descriptor should be made in respect to the concern of that evaluation criterion. Lastly, in constructed descriptors, the decision maker defines plausible levels of performance in which the impact of the different alternatives may be accommodated.

The selection of the descriptor of performance to assign to an evaluation criterion should take into account the decision maker’s capability to interpret its different levels of impact. The process of defining descriptors of performance may also reveal the existence of redundant evaluation criteria, if alternative descriptors of the same concern arise. In such case, the decision maker should revise the structure of the model, hence the iterative nature of the structuring process.

Yet another issue related to the definition of evaluation criteria is the requirement that these present *ordinal* and *cardinal* preferential independence, which is closely related to the decomposability property from Keeney and Raiffa [66]. Ordinal dependence occurs when the ranking of options according to each evaluation criterion is made irrespective of the performance on the remaining evaluation criteria. Furthermore, evaluation criteria must also comply with the condition of cardinal preferential independence, so that each evaluation criterion represents an isolated evaluation axis, i.e., that the judgments on differences of attractiveness of alternatives can be elicited irrespective of the performance on other criteria. If positive or negative synergetic effects exist between candidates to evaluation criteria, the descriptors of performance may be clustered into a single evaluation criterion. Furthermore, the ordinal and cardinal independence of evaluation criteria will allow the adoption of an additive aggregation model, as will be further presented [81].

After defining a family of evaluation criteria possessing the required properties, it is possible to represent this set in the form of a *value tree*, in which criteria are grouped according to their area of concern. Structuring criteria in the form of a value tree should allow the decision maker to have a global view of the model structure achieved so far. It is important that the validity of this representation is checked, as well as of the defined performance descriptors. If the decision maker agrees with the structure developed so far, the decision aiding process then turns to the stage of building the additive evaluation model, in which the value functions and the weighting coefficients of each criterion are defined.

4.5. Scoring and Weighting

This stage is concerned with building the evaluation model, through the definition of the value functions of each criterion and of the weighting coefficients. Firstly, it is necessary to clarify the basic notions underlying the use of an additive evaluation model. Once such notions have been established, the procedure for building value functions and determine criteria weights is described.

4.5.1. The additive evaluation model

The central purpose of the additive model is to yield an overall rating of options that should traduce the decision maker's preferences elicited throughout the decision aiding process. Since the MCDA framework is based on breaking down the evaluation task into simpler, more comprehensible parts, it is necessary to then aggregate these parts in order to arrive to an overall result of the evaluation of alternatives. The explanation of the features of the additive evaluation model will make use of the symbols and terminology adopted by Bana e Costa et al. [83], although the terminology represented in (4) stands. The distinction was made because of the fact that construction of descriptors of performance and value functions is performed irrespective to the generated alternatives, and hence it would not make sense to include the index j present in (4).

The structuring phase resulted in the definition of the set of n evaluation criteria E_i, and the respective descriptors of performance X_i (an ordered set of levels of performance x_i), according to which the resource allocation alternatives are to be evaluated. In general terms, the additive model consists in assigning, for a given alternative, a value score in each of the evaluation criteria, which is in turn multiplied by the respective weighting coefficients, yielding an overall value score for that alternative, similarly to the mechanism expressed in equation (4). The overall score v of an alternative $\boldsymbol{x}$ can be expressed in terms the partial value scores v_i and the weighting coefficients w_i as follows:

$$v(\boldsymbol{x}) = \sum_{i=1}^{n} w_i v_i(x_i) \tag{9}$$

The weighting coefficients must be positive numbers and should be normalised, so that:

$$\sum_{i=1}^{n} w_i = 1, \qquad \forall_{w_i} > 0 \tag{10}$$

The additive aggregation model is a compensatory model, in the sense that the contribution of the score assigned to an alternative in a given criteria may be compensated, either positively or negatively, by the scores obtained in other criterion. The additive model is a rather simple mechanism of combining multiple criteria, and has the advantage to allow not only the ordering of the alternatives according to their overall score (attractiveness), but also the assessment of the extent to which an alternative is better than another. It is important to bring up the requirement of cardinal and ordinal independence of the evaluation criteria, in order to preserve the validity of the principles underlying the additive aggregation model [82].

4.5.2. Building value functions

The process of building a value function for each evaluation criterion consists on determining the function $v_i(x_i)$ that assigns a value score to each level of performance x_i contained in the descriptor of performance X_i. Such functions should traduce the decision maker's preferences and allow the assessment of the local impact of alternatives.

Value functions represent scales of value scores whose properties differ on the basis of the adopted type of scale, from the four types of scales proposed by Stevens in 1946 [84]. In the scope of an additive aggregation model, adopted in this case study, the model required the existence of cardinal (quantitative) information on the value scores assigned to level of performances, in order to enable the analysis of the attractiveness of the alternatives. As will be explained in the following subsection, the scale adopted to build the value function of each criterion consisted in an interval scale.

MACBETH method for building value functions

The numerical methods for the definition of value functions include the direct rating and bisection methods, which require the decision maker to elicit numerical judgments about the attractiveness of a given level of performance. However, as von Winterfeld and Edwards stated, the elicitation of numerical judgements may be much more difficult to the decision makers than eliciting judgments based on differences in attractiveness [85]. In this sense, the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach presents a methodology for creating quantitative value functions in which the decision maker is asked to elicit qualitative judgments about differences of attractiveness. The MACBETH method is based on the additive aggregation model, and consists of an interactive and learning process between the decision maker and the facilitator, so as to conduct a coherent construction of the evaluation model – comprising both the definition of value functions and also the determination of criteria weighting coefficients. The MACBETH approach to the construction value functions is hereby described, leaving the determination of weights to the next subchapter. Both explanations will be based on the working paper published by the method's authors, Bana e Costa et al. [86].

The MACBETH method is implemented in the M-MACBETH decision support system, in which the value tree and descriptors of performance are defined. The decision maker is firstly asked to state, for each criterion, two explicit references of intrinsic value that will represent the notions of a *good* and *neutral* performance level in that criterion. The explicitation of such references may contribute to the intelligibility of the evaluation criteria [82] and allow the further definition of weighting coefficients on a valid theoretical basis.

	N1	N2 = 'Good'	N3	N4 = 'Neutral'	N5
N1	no	moderate	strg-vstr	v. strong	vstrg-extr
N2 = 'Good'		no	↓ strg-vstr	↑ moderate	v. strong
N3			no	moderate	v. strong
N4 = 'Neutral'				no	v. strong
N5					no

Figure 9. Example of a judgment matrix of M-MACBETH. (Based on Bana e Costa et al. [83])

The construction of a judgment matrix requires the selection of levels of impact contained in a descriptor that will serve as reference points for judgment elicitation. In quantitative descriptors, it is necessary to split its range into finite intervals whose limits are taken as reference levels for comparative judgments. Taking, for instance, 5 performance levels, N1 to N5, in which N2 and N4 correspond to the 'Good' and 'Neutral' references, respectively, the MACBETH judgment matrix appears as follows:

The determination of a cardinal value function is performed by means of filling a judgment matrix for each evaluation criterion, similar to the one presented in Figure 9. Each entry of the matrix corresponds to a judgment about the difference of attractiveness between pairs of performance levels. If the decision maker finds that there is no difference of attractiveness between two levels of performance, the corresponding entry of the matrix is defined as *no*. If a difference of attractiveness is perceived, such judgment is based on the MACBETH qualitative scale, which comprises six semantic categories according to which the intensity of preference is expressed: *very weak*, *weak*, *moderate*, *strong*, *very strong*, *extreme*. Hesitations are allowed, i.e., the decision maker may choose to select a range of qualitative judgments, such as the '*strg-vstr*' judgments presented in Figure 9. However, such hesitations should be interpreted as 'strong or very strong' rather than 'strong to very strong'. The mechanism of eliciting judgments consists in asking the decision maker about the difference of attractiveness between a performance level of a row of the first column and a level of a column of the first row. In this sense, if the levels of performance are ordered according to the decision maker's preference, only the upper triangular matrix is filled in order to obtain the cardinal value scale. The maximum number of pairwise judgments for m performance levels under consideration is $m(m-1)/2$, although the M-MACBETH software uses an algorithm that is able to complete the matrix by transitivity, if a minimum of $m-1$ judgments have been elicited. It is important to refer that the M-MACBETH algorithm is designed to minimise the differences of attractiveness determined by transitivity, choosing the minimum judgment that ensures matrix consistency.

The M-MACBETH program tests the validity of the matrix and identifies existing inconsistencies, if any. In Figure 9, the program has detected an inconsistency, which arose because the difference between N2 and N4 should be greater than the difference between N2 and N3, in order to preserve the order of preference. The program presented two possible suggestions for correcting the inconsistency.

After having filled the judgment matrix, the M-MACBETH program is then able to compute a quantitative value function based on the qualitative judgments, corresponding to interval scales, which implies that the scores assigned to the different levels of performance may only be interpreted in terms of the magnitude of difference between options. Interval scales possess the necessary properties to permit their use in the additive aggregation model, which is the central aspect to be taken into account for developing this methodology.

4.5.3. Weighting evaluation criteria

The determination of weighting coefficients for evaluation criteria is a key task in the construction of the evaluation model, as these will allow the aggregation of the local scores of alternatives in an overall score. Such task may be subject to a lack of theoretical basis and thus lead to a misinterpretation of the obtained results. In order to prevent biased procedures, the MACBETH approach is then again employed to provide a guideline for the decision maker towards the determination of these weighting coefficients, although with a slight combination with the swing weighting procedure.

In general, there are three main techniques for determining weighting coefficients. These are swing weighting, trade-off procedure and the MACBETH method. For the purpose of this paper, the trade-off procedure was not employed, and thus will not be elaborated in this section.

Swing weighting procedure

The swing weighting procedure allows the determination of weighting coefficients through a three-stage method [87]. It is a simple and accessible method for weighting evaluation criteria, in which the decision maker is asked to express the attractiveness of the 'neutral'-'good' swings in each criterion. However, it involves the elicitation of quantitative judgments that may be difficult to obtain from the decision maker. In addition, the structure of the value tree and the number of evaluation criteria under consideration may render this process much more difficult. Hence, the proposed methodology did not adopt the swing weighting procedure as the central method for determining weighting coefficients. Instead, the MACBETH approach was combined with the principles of swing weighting, as described in the following paragraphs.

MACBETH approach to weighting evaluation criteria

M-MACBETH also allows the determination of weighting coefficients by means of eliciting qualitative judgments based on the same scale of six semantic categories used to fill a judgment matrix. However, the facilitation of such process presents some differences in respect to the task of building value functions [87].

In the MACBETH approach to weighting evaluation criteria, the facilitator asks the decision maker to consider fictitious alternatives whose performance in the different criteria is manipulated according to the judgment under consideration.

The process of filling the matrix is carried out by pairwise comparison. In each cell, the decision maker elicits a judgment about the intensity with which he prefers a fictitious alternative with a 'Good' level in a given criterion against another with 'Good' level in another criterion. In the last column of the matrix, the judgments are not elicited through comparison of two hypothetical alternatives, but instead are concerned with the evaluation of the attractiveness of a swing from the 'Neutral' to the 'Good' level on each criterion.

	E_1	E_2	E_3	[Neutral all over]
E_1	no	moderate	strong	v. strong
E_2		no	strong	v. strong
E_3			no	moderate
[Neutral all over]				no

Figure 10. Judgement matrix for weighting criteria

Weighting criteria in using the MACBETH matrix may become impracticable in the presence of a large number of evaluation criteria. In fact, this will be the case of the model developed in this work. In order to overcome the complexity of the problem, the weighting process has been adapted in order to render it more accessible for the decision maker. The adopted technique is similar to the approach followed by Thomaz [88].

In order to determine weighting coefficients for the evaluation criteria, when these are numerous, the elicitation of qualitative judgments may be centred on the evaluation of the attractiveness of the swings from 'Neutral' to 'Good' in each of the criteria, which correspond to the filling of the last column of the judgment matrix. Prior to such judgments, the facilitator should ask the decision maker to order his preference on these swings. If such ordering is not possible, the judgments may be elicited without the criteria ordered in the matrix. After judging qualitatively all swings in the last column, the M-MACBETH software performs the ordering of criteria by pressing the 'Build scale (MACBETH)' button. The software is able to complete, to the possible extent, the matrix entries by transitivity. However, if the number of criteria is large, there will be repeated intensities of preference along the last column, since there are only six semantic categories for expressing judgments, plus the possibility to declare indifference. With repetitions, the software needs further information in order to distinguish the swings that were evaluated with the same semantic preference. In this sense, the differentiation of criteria equally evaluated may be enabled by filling the entries of the matrix over the matrix diagonal, corresponding to the direct comparison between those criteria. When enough information has been entered, M-MACBETH is then able to produce a set of weighting coefficients compatible with the elicited judgments. The facilitator should then interact with the decision maker in order to validate the produced scale, introducing further judgments if the latter finds necessary. The described approach will be better exemplified in the application of the proposed methodology, presented in chapter 5. Nevertheless, it is already possible to observe the potential of such method to overcome the difficulties inherent to complex value trees with a large number of criteria, as well as the difficulty to elicit quantitative judgments, by means of performing a *qualitative swing weighting* procedure.

At this point, it is important to stress some important issues related to the process of defining weighting coefficients. As could be observed, all the judgments elicited for this purpose were anchored to the 'Neutral' and 'Good' references defined in each evaluation criterion. Such aspect is fundamental to guarantee the validity of the process. The influence of the impact ranges on the determination of weighting coefficients is documented in the literature [89], and Keeney refers to such misinterpretations as "the most common critical mistake" [70].

4.6. Implementation of the Evaluation Model

After developing the multicriteria evaluation model and selecting the alternatives to submit for evaluation, it was necessary to implement the evaluation model in a system that enabled a systematic evaluation of alternatives. Although the M-MACBETH software allows the introduction of alternatives and their evaluation, such method would not be suitable for such a very large number of alternatives, as visualisation and data processing would be unpractical. In order to overcome such limitation, the evaluation model was implemented in Excel, since the mathematical programming underlying the additive model is not complex. However, the complexity of the developed model, namely regarding the number of evaluation criteria demanded the model implementation to be properly organised. For the purpose of organisation and ease of interpretation, each component of the model was placed in an independent data sheet, schematically represented in Figure 11.

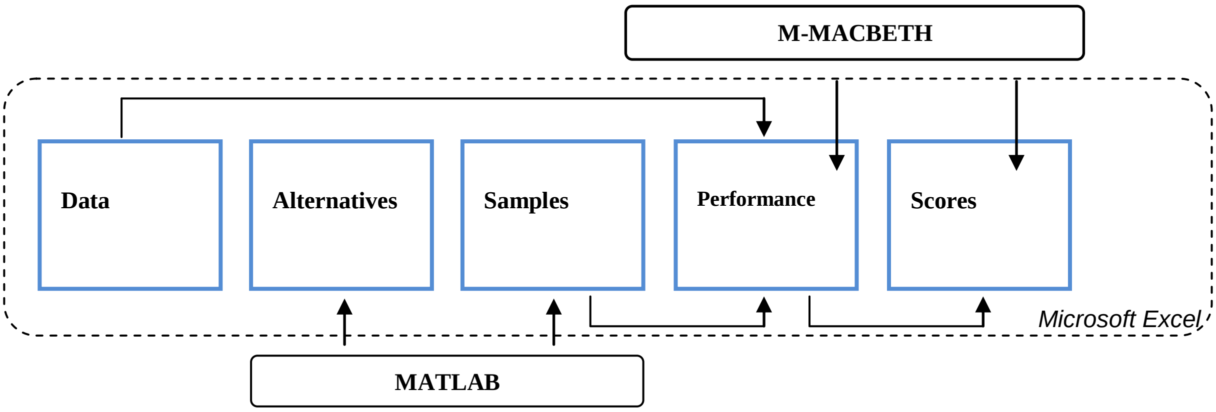


Figure 11. Schematic representation of the implementation of the evaluation model in Excel, integrating the alternatives generated in MATLAB and the value functions and weighting coefficients yielded by M-MACBETH.

The process of evaluating alternatives also involves a critical analysis on the validity of the model. Sensitivity analysis and robustness analysis provide a strong basis for assessing the impact of modifying the model's parameters in the resulting conclusions. The decision maker may identify aspects that need further adjustment when facing the overall ranking of alternatives, as well as their local impact in respect to each evaluation criterion. Such adjustments concern not only tuning the models parameters, but may also require the re-structuring of the model, so as to arrive at a point in which the decision maker accepts the model structure and feels that his preferences are coherently modelled, that is, until the model is requisite according to Phillips: "a requisite decision model is defined as a model whose form and content are sufficient to solve a particular problem" [90].

The analysis of the validity of the evaluation model assumes a great importance in the process since the results of the evaluation of alternatives will constitute the basis for the next stage of the proposed methodology, concerning the structuring of the resource allocation model in the framework of portfolio decision analysis. The fact that the proposed framework involves the adoption of multiple methodologies requires that the integration of the different stages guarantees coherence and validity of assumptions, hence the significance of ensuring the validity of the evaluation model.

4.7. Resource Allocation Model

The last stage of the proposed methodology involves the application of a resource allocation model that meets the concrete purpose of this thesis, since the scoring of alternatives yielded by the evaluation model may require further analysis in order to assess the extent to which the expected benefit of the alternatives may be collectively optimised. In this sense, the framework of this section is constructed on the basis of portfolio decision analysis, making use of its principles, such as the VfM principle, to approach this task.

Portfolio Decision Analysis in the allocation of human resources

In the scope of PDA, the central problem concerns the determination of the set of projects that maximises the benefit outcome without exceeding a limited budget of resources. This set has to be selected from the alternatives generated by the algorithm. Since the number of possible combinations is rather large, it is impossible for the decision maker to consider them all, therefore requiring the adoption of a method that allows a systematic analysis. In this sense, the scope of PDA is to determine efficient portfolios.

As presented by Lourenço and Bana e Costa, there are two approaches to portfolio resource allocation, i.e., to the selection of efficient portfolios [91]. The first approach, the prioritisation method, consists simply in ordering the alternatives according to their benefit-to-cost ratio (B/C), equivalent to the VfM, and selecting them in decreasing order. The result is an efficient frontier, Pareto-efficient or convex-efficient (as presented by Phillips and Bana e Costa [69]). The second method makes use of an optimisation algorithm to solve the knapsack problem through mathematical programming, maximising the overall benefit without exceeding the available resource budget. The optimisation approach finds both Pareto-efficient and non-convex efficient portfolios. The knapsack problem is represented in equation (4) of section 4.1.

Yet an important consideration on the use of PDA is the requirement to base the analysis on ratio scales of benefit scores, establishing a fixed zero in the value scale rather than an arbitrary value (which is the case of interval scales, as the one yielded by M-MACBETH). In order to comply with this requirement, portfolio analysis was based on incremental benefit scores, i.e., the benefit scores were calculated as the difference in respect to the *status quo*, corresponding to the initial allocation profile of physicians. In this sense, the validity of the choice of the baseline for multicriteria portfolio analysis is ensured [92].

The integration of PDA in the framework of the proposed methodology presents some differences in respect to its typical applications. The first specificity of the proposed methodology is the fact that all the alternatives, for each physician, have the same cost in terms of working time, in fact corresponding to the total amount of working time. Such aspect results that, for each physician, only one alternative can be selected, considering the form according to which the options were conceived in the method for generating alternatives proposed in section 4.3. Nevertheless, the objective of the decision maker is to maximise the collective benefit and consider the resource allocation process as a whole, as the actions of physicians must have some level of articulation.

The first issue is concerned with selecting the alternatives that the decision maker wishes to consider, from the whole set generated with the MATLAB algorithm. The selection may not necessarily be performed in decreasing order of overall scores, but instead the decision maker may define constraints on the alternatives that are worth considering in the allocation model. It would be impracticable to consider all the options from all physicians, as it would render the optimisation approach infeasible due to the associated computation load. Such task may be performed, for instance, by asking the decision maker if there are some activities that whose influence he would be especially interested in considering, thus searching for alternatives that could provide such information. Having selected the set of alternatives for analysis, these are then submitted to the resource allocation model. Secondly, the resource allocation model should accommodate the existence of several evaluation criteria defined in the evaluation model, in order to preserve coherence of methodologies. Given the complexity of the process, it was decided to recur to a decision support system that met these requirements, whilst being able to carry on a PDA approach. It was chosen to implement the resource allocation model in the PROBE software (developed by Lourenço e Bana e Costa [91]).

The PROBE system comprises two components: an MCDA and a PDA component. The MCDA component is based on the additive value model, which allows the definition of a value tree in which evaluation criteria are structured and the specification of the alternatives (previously selected) in terms of their local benefit scores. The software computes the overall scores according to the benefit scores and weighting coefficients. It is also necessary to specify the cost of each alternative, which in the present case will be constant, as each alternative corresponds to a distribution of a neurologist's working time. The MCDA module is then articulated with the PDA component, in which the program solves the knapsack problem in order to yield the efficient and Pareto-efficient portfolios of alternatives. It is possible to specify a given cost range of analysis, which in this case will be extremely narrow, as the amount of resources to be deployed is fixed and it is of interest these are fully utilised. In addition, the PROBE framework also allows the possibility to define constraints of different nature as well as synergies amongst the alternatives under consideration. In what concerns the constraints, these comprise the possibility to force in or out a given alternative, specify dependence, mutual inclusivity or mutual exclusivity between two options, and also define group constraints for a subset of alternatives. Such features may in effect be quite functional for type of alternatives under consideration, as for instance, the possibility to define that all the alternatives of a given physician are mutually exclusive, as it would not make sense to obtain portfolios containing two alternatives for the allocation of the working time of the same physician. The potential of such features will then be better explored in the following chapter, when presenting the results of application of the proposed methodology.

After finding the efficient portfolios, the decision maker and the facilitator should adopt a critical attitude about the results of the allocation model, concerning their concrete implications in terms of the decision making context and their soundness according to the decision maker's points of view. The validity of these results strongly depends on the coherence of the whole process of building the evaluation model (whose requisiteness should have been previously secured, to the possible extent) and on the specification of the alternatives that the decision makers wishes to submit to the scope of PDA. If the decision maker finds necessary to perform adjustments in the model, such adaptations should be introduced in order to meet the decision maker's convictions. It may happen that only at the final stage the decision maker detects incoherencies that may have been previously masked and are only manifested in the results obtained from the resource allocation model. Hence, the framework must allow the introduction of such adaptations in the results of earlier stages, either concerning the structuring of the evaluation model or the process of generating alternatives, with all the implications to the later stages that these modifications imply. The discussion of methods and results throughout the successive stages of the proposed methodology is strongly advised, as it may be fundamental to promptly identify potential faults that could lead to the loss of validity of the subsequent stages of the framework.

5. Application of the proposed methodology

The methodological framework proposed in chapter 4 was developed in the context of the Neurology department of the WLHC. The interactive process was performed with the Chief Director of the department in the role of the decision maker. This section aims to present the results of developing the proposed methodology in the WLHC case study, namely the decision-aiding model constructed throughout the structuring process and the algorithm created for the purpose of generating alternatives. The results of applying the constructed model in the context of the WLHC Neurology department are later presented in chapter 6.

5.1. Characterisation of Activities and Physicians

The problem formulation established the type of approach in which to base the proposed methodology. The scope of action and the key actors were previously identified, at the time of establishing the approach to be adopted, and hence this section will be more dedicated to the results of structuring activities and resources, which are the most relevant results of the methodology at the initial structuring stages.

Physician activities

The first discussion with the Chief Director aimed to elaborate a list of the activities that would be worth distinguishing in the allocation of physicians. The decision maker found that if such distinction was based simply on the different services delivered in the Neurology unit (such as consultations, ward and so on) the model would not be able to accommodate the required level of detail. Hence, it was necessary to further develop the list of activities, which was required found to be suitable for all the physicians. This task was not easy, mainly because it would be possible to specify a rather large number of elementary activities and it was necessary to preserve a certain level of simplification in the model. If too many specific activities were considered, limitations would arise at the time of generating activities, due to the associated computational load. In some cases, different activities were chosen to be clustered in a common designation. On the other hand, some activities, namely the CVA unit and the ED were chosen not to be considered. Whilst the CVA unit does not have a structured operation, the ED shifts offered no flexibility at all, and the decision maker chose not to consider these.

Table 8. List of Activities to be considered in the allocation of physicians.

List of Activities			
1	1st EC –General	11	Day Hospital
2	1st EC –Epilepsy	12	EEG exam
3	1st EC –Sleep	13	EMG exam
4	1st EC –Demyelinating	14	Group Meetings
5	1st EC – Movement	15	Clinical cases/video analysis
6	1st EC – Cognitive	16	Management Tasks
7	1st EC – Neuromuscular	17	Learning Techniques
8	Follow-up EC	18	Publications
9	Internal Consultation	19	Presentations
10	Ward (Inpatient Care)	20	Echo-doppler exam

It is important to refer that the list of activities developed in the initial structuring phase has later suffered modifications, since the decision maker acknowledged the necessity to do so throughout the later model stages. The final list of activities is presented in Table 8. Each activity was assigned a numerical code, for the purpose of algorithmic implementation.

Resources - Physicians

After having established the set of activities to be considered, it was then necessary to collect information for the characterisation of the human resources available in the Neurology department. Such information first regarded the current allocation of working time. For this purpose, it was provided, for each physician, the current distribution of working time with an estimate. This data was organised in a table and is presented in Table A1 of Appendix A.

The decision maker was then asked to specify, for each neurologist, the possible activities that can be considered in the generation of alternatives. Such task was necessary because the current allocation profile of a neurologist may not include all the possible activities, and it is of interest that the generated alternatives also consider activities that are not currently being performed. Furthermore, it was considered appropriate to also specify, at this time, the minimum and maximum services that the decision maker found necessary to specify for each physician. These parameters constitute additional constraints, besides the definition of the time block dimension and the number of desired variations (presented in section 4.3.). This data was grouped in Table A2, in Appendix A.

5.2. Generation of Alternatives

As presented in section 4.2, the approach for generating allocation alternatives has been implemented in MATLAB. The algorithm was integrated in a simple routine, which enables the introduction of the input parameters by means of a prompt dialog box. The possible values of time allocated for each activity (based on the block dimension and desired number of variations) are grouped in the form of vectors – elementary vectors, one for each possible activity. The computation of alternatives is made through the combinations of the entries of the elementary vectors, translating in computational language the mechanism schematically represented in Figure 8. In order to generate combinations, the implemented algorithm made use of the *allcomb.m* routine (available online[4]). After generating these combinations, the algorithm then filters the results according to the additional constraints, corresponding to the minimum and maximum services the decision maker has decided to impose. Finally, the program writes the resulting matrix of alternatives in the standardised form - specified in (5) - in the desired Excel file.

Upon generating alternatives, it was necessary to firstly define the time span to be considered. Initially, it was thought to model the allocation of working time for the period of one week. It was then realised that such period would require that the block dimension (Δ_t) to be set to a low value, otherwise a high value of Δ_t would imply abrupt variations of the time allocated to each activity. Furthermore, the decision maker observed that a longer

[4] Available for download at http://www.mathworks.com/matlabcentral/fileexchange/10064-allcomb

period of analysis would be more suitable to monitor activities whose performance could be subject to variability from one week to another. In this sense, the alternatives were generated for a time span of one month.

The block dimension and the number of variations were defined as being the same for all physicians, in order to enable an equivalent variation on the distribution of working time for all neurologists. These values were set to:

$$\Delta_t = 4 \text{ hours}$$
$$N_{vars} = 2 \qquad (11)$$

The value of 4 hours for the time block dimension approximately corresponds to half of a work day. The number of variations set to 2, which implies that, for each possible activity of a physician, the alternatives will include a maximum of 5 different values of time allocated to that activity. The implemented program was run for each neurologist, using the information in Table A1 Table A2, and the parameters specified in (11). It was necessary to derive the initial allocation profile from the data presented in Table A1, in order to match the list of activities to be considered. Namely, it was required to compute the number of first and follow-up consultations from the total amount of time placed upon general and differentiated EC. Such calculation was made using the percentage of 1st consultations from the previous year (23,1%), presented in Table 4. The next table presents the results of the process of generating alternatives.

Table 9. Results of the process of generating alternatives.

Physician	Number of generated alternatives	Elapsed time (seconds)	Physician	Number of generated alternatives	Elapsed time (seconds)
MV	73986	1461.57	**LA**	59289	589.44
IC	97077	1698.98	**RP**	66932	1160.41
JV	3439	25.02	**EM**	5070	6.30
MVB	20855	191.03	**DP**	3755	2.61
NC	18391	1560.64	**JM**	35619	142.15
SC	116243	1464.30	**GM**	10345	11.09
PB	73708	598.77	**TL**	1936	1.60
PA	2249	4.19	**HD**	55	1.20

At the end of the stage of generating alternatives, 16 Excel files were created, each one containing the alternatives generated for each neurologist. The number of generated alternatives was rather large, which gave rise to concerns on the possibility to submit all the resulting alternatives to the multicriteria evaluation model, due to computational limitations. Such limitation was confirmed upon implementing the model in Excel, thus it was decided to perform a sampling selection of the generated alternatives.

The sampling process was also implemented in MATLAB, by means of a simple routine. It was decided to select the samples according to a given order, rather than randomly, as the *allcomb.m* algorithm yields the alternatives ordered with a certain pattern, which derived from the mode of computing the alternatives in the MATLAB routine. In this sense, a fixed number of samples has been collected for all physicians, equally spaced in terms of position in the matrix of alternatives (Θ). For each physician, 10000 samples were collected, except in the case in that the number of alternatives was lower. Finally, the samples were recorded in Excel files, for integration in the multicriteria evaluation model.

5.3. Model structure and Value Tree

At this point, the methodological framework had been structured. The following stage of the methodology concerned the process of structuring the multicriteria evaluation model, namely the definition of the evaluation criteria and the associated descriptors of performance.

5.3.1. Definition of Evaluation Criteria

The initial task for the construction of the multicriteria evaluation model was the definition of the evaluation criteria. Such task was performed by means of discussions with the decision maker, in order to identify the main areas of concern. The discussion started with questions such as "*what kind of aspects is it necessary to account for upon distributing physicians amongst the activities?*". As the discussion went on, it became clear that a top-down approach to structuring the value tree would be more suitable, instead of selecting an approach such as cognitive mapping. In fact, as the decision maker was responsible for the management of the Neurology department, and being familiarised with the decisions for allocation of available human resources, the process of structuring the value tree started without major difficulties. At the beginning of discussion, the decision maker identified three main areas of concern:

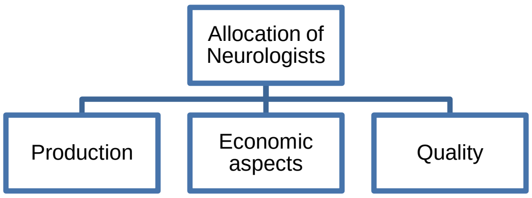


Figure 12. Main areas of concern identified in the beginning of the decision conference.

As was immediately recognised, such areas of concern encompassed multiple aspects and thus needed to be further explored and detailed. Starting by the first branch, '*Production*', the decision maker explained that this global concern was mostly related to the department's performance in relation to the proposed goals and contracted services, mainly based on indicators of performance. The decision maker then enumerated the parameters according to which the department's operation is monitored, and which will be included in evaluation. In brief terms these parameters included the number of EC and IC, the waiting time for EC and IC, percentage of 1^{st} EC, and day hospital, ward and laboratory productions. A total of 17 evaluation criteria were identified in this branch.

As for the '*Economic aspects*' branch, the evaluation criteria concerned the income and the costs of the department. The income arises from different sources, and is mostly based on the contracted services, namely the EC, the ward (payment according to DRG) and the performed complementary exams in the laboratory. Although the income comes from different sources, it was decided to aggregate it in a single evaluation criterion, since it would be pointless to evaluate different incomes in separate criteria, as these are all expressed in the same (monetary) unit and the decision maker did not wish to valuate differently the income from each source. Other than the income, the decision maker found important to consider the costs of operation. The decision maker identified that the expenditure would concern pharmaceutical products, staff, exams prescribed to external entities, clinical consumables, and so on. However, at this point it was necessary to discuss the relevance of these

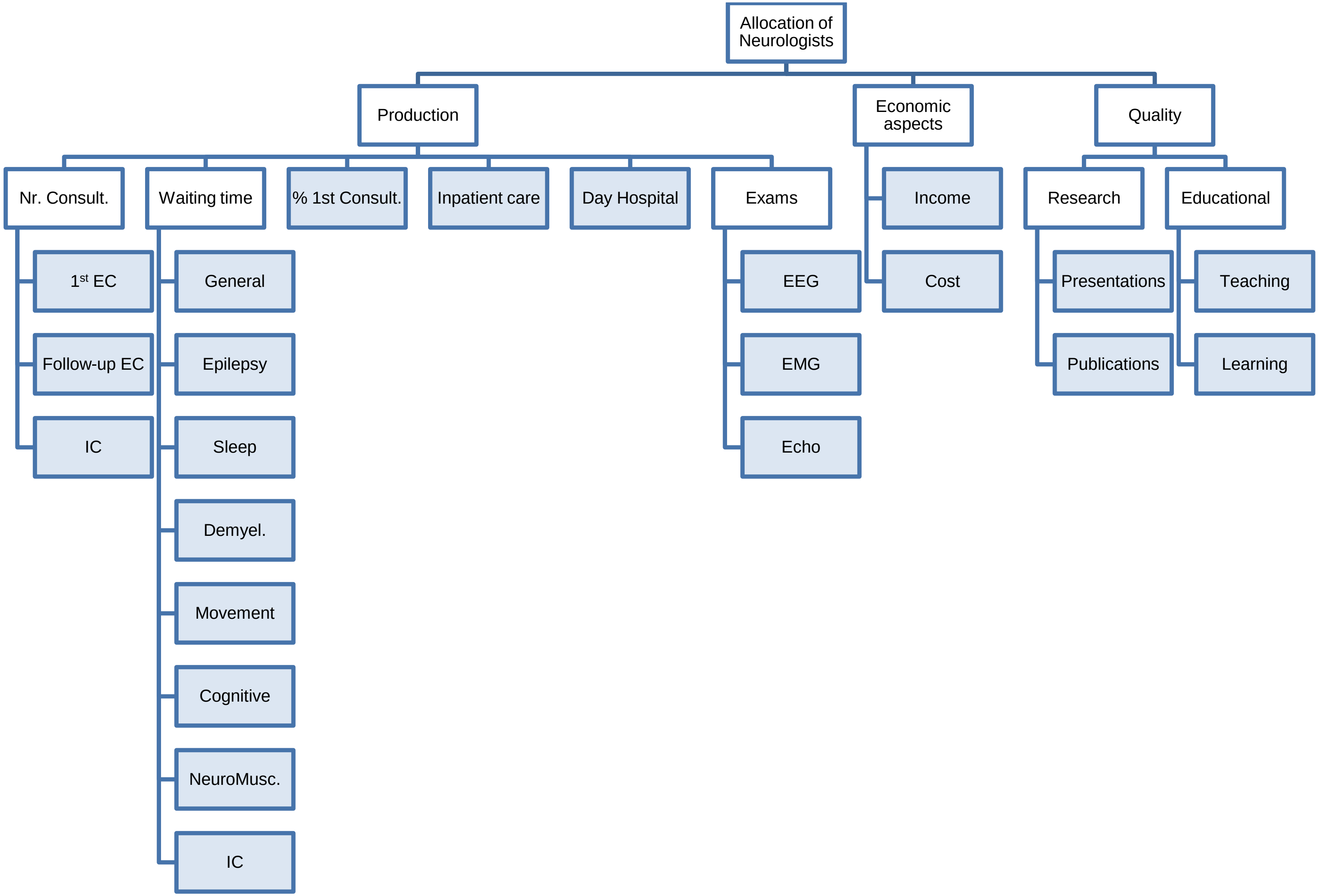


Figure 13. Value Tree. The blue-shadowed nodes represent evaluation criteria

cost sources. There seemed to be a tendency to think of the criteria for allocating physicians with the criteria to evaluate the Neurology department's condition, and it was important to clear such distinction in the process of structuring the value tree. The aspects related to the cost are an example of such a situation. Although such differentiation of costs is fundamental to monitor the department's operation, the decision maker was asked if these criteria, for instance, costs with staff, would influence the decision of assigning a physician to a given activity. As the answer was negative, it was decided to remove such costs, except the cost with exams (those which the Neurology department has resources to perform) requested to external entities. The reason for considering such costs comes from the fact these are, in fact, directly dependent on the allocation of physicians, since the more exams are performed within the department, the less exams are likely to be requested to private laboratories.

5.3.2. Descriptors of Performance

One of the requirements of evaluation criteria is the definition of a descriptor of performance that will allow determining the extent to which an alternative contributes to the achievement of that objective. In this sense, it was necessary to establish, for all the 23 evaluation criteria, a performance descriptor that enables such measure. Prior to the definition of these descriptors, an important issue must be addressed. In the context of the Neurology department, the alternatives consist of time distribution, and the aspect that allows their distinction is their unique combination of time values allocated to different activities. The alternatives are, therefore, characterised in quantitative terms. On the other hand, most of the evaluation criteria (namely in the branch of '*Production*' and '*Economic aspects*') immediately suggest the adoption of quantitative performance descriptors. For these evaluation criteria, the decision maker agreed on such type of descriptors. As for the '*Quality*' branch, the evaluation criteria needed further considerations in the selection of a descriptor of performance. The following tables present the performance descriptors for the evaluation criteria in the '*Production*' and '*Economic aspects*' branches. Some global variables have been defined to represent the descriptors in the corresponding mathematical expressions:

Table 10. List of variables used in the definition of performance descriptors.

Symbol	Parameter
$\boldsymbol{T_j}$	time allocated to activity *j*;
$\boldsymbol{N_j}$	production of activity *j*
$\boldsymbol{u_j}$	estimated duration of one event of activity *j*
$\boldsymbol{WT_j}$	waiting time for activity *j*
$\boldsymbol{D_j}$	estimated demand for activity *j*
$\boldsymbol{r_{1C}}$	percentage of 1st Consultations
$\boldsymbol{I}$	global income
$\boldsymbol{C}$	costs with EMG exams for third party entities
$\boldsymbol{i_j}$	income from activity *j*
$\boldsymbol{\alpha_{EEG}}$	percentage of EEG exams
$\boldsymbol{c_{EMG}}$	cost of an EMG exam in a third-party laboratory

The index j represents the numerical code assigned to each activity in Table 8. For ease of interpretations, the specification of performance descriptors has replaced the numerical indexes for simple codes such as 1C (1^{st} EC), FUC (follow-up), and so on.

Table 11. Performance descriptors for the Number of Consultations.

Evaluation Criterion	Mathematical expression
Nr. of 1^{st} Consultations	$N_{1C} = \frac{T_{1C}}{u_{1C}}$
Nr. of Follow-up Consultations	$N_{FUC} = \frac{T_{FUC}}{u_{FUC}}$
Nr. of IC	$N_{IC} = \frac{T_{IC}}{u_{IC}}$

Table 12. Performance descriptors for the calculation of waiting time for 1^{st} Consultation.

Evaluation Criterion	Mathematical expression
Waiting time - 1^{st} General	$WT_{Gen} = \frac{D_{Gen}}{T_{1Gen}}$
Waiting time - 1^{st} Epilepsy	$WT_{Epil} = \frac{D_{Epil}}{T_{Epil}}$
Waiting time - 1^{st} Sleep	$WT_{Sleep} = \frac{D_{Sleep}}{T_{Sleep}}$
Waiting time - 1^{st} Demyelinating	$WT_{DM} = \frac{D_{DM}}{T_{DM}}$
Waiting time - 1^{st} Movement	$WT_{Mov} = \frac{D_{Mov}}{T_{Mov}}$
Waiting time - 1^{st} Cognitive	$WT_{Cogn} = \frac{D_{Cogn}}{T_{Cogn}}$
Waiting time - 1^{st} Neuromuscular	$WT_{NMusc} = \frac{D_{NMusc}}{T_{NMusc}}$
Waiting time - 1^{st} IC	$WT_{IC} = \frac{D_{IC}}{T_{IC}}$

Table 13. Performance descriptors for the percentage of 1^{st} EC, number of discharged patients and number of day hospital sessions.

Evaluation Criterion	Mathematical expression
Percentage 1^{st} Consult.	$r_{1C} = \frac{T_{1C}}{T_{1C} + T_{FUC}}$
Ward (Nr. discharged patients)	$N_{DisP} = \frac{T_{ward}}{u_{ward}}$
Nr. D. Hosp. Sessions	$N_{DH} = \frac{T_{DH}}{u_{DH}}$

Table 14. Performance descriptors for the laboratory production.

Evaluation Criterion	Mathematical expression
Income	$I = i_{1C}N_{1C} + i_{FUC}N_{FUC} + i_{ward}N_{DisP} + i_{EEG}N_{EEG}\alpha_{EEG}$
Cost	$C = (D_{EMG} - N_{EMG})c_{EMG}$

All the descriptors of performance presented in the previous tables are quantitative direct descriptors, making use of parameters obtained through data collection. Whilst some of these parameters, such as the duration of EC, are established in the department as having a fixed duration, other parameters represent estimations, as the time of inpatient care required to discharge an inpatient.

As for the evaluation criteria integrated in the '*Quality*' branch, the construction of performance descriptors has revealed to be more complex. The decision maker found that it would be necessary to consider not only the time specifically dedicated to scientific and educational activities, but also the contribution of other activities to such criteria. In this sense, it was decided to construct a table in which the contribution of each activity to '*Presentations*', '*Publications*', '*Teaching*' and '*Learning*' (vide Figure 13) is estimated. Such estimation consisted in defining, for each activity, a percentage of the time allocated to that activity that contributes to scientific and educational activities. These estimations were organised in an equivalence table constructed by the decision maker, which is presented in Appendix D. For each alternative, the contribution $L_{j,p}$ of an activity j to a scientific or educational activity p can be expressed in terms of the estimated contribution $E_{j,p}$ (entry of the equivalence table) and the time allocated to activity j in that alternative.

$$L_{j,p} = E_{j,p} T_j \tag{12}$$

After having established the contribution of each activity to research and education, the descriptors of performance for the 4 evaluation criteria in the '*Quality*' branch were defined. It was chosen to define quantitative descriptors for all these evaluation criteria, mostly due to the nature of the alternatives, as these are described quantitatively. The decision maker found that the definition of a qualitative descriptor would not allow proper distinction of the alternatives in terms of performance in these evaluation criteria. For the evaluation criteria related to scientific activities, the descriptors of performance were defined by the number of presentations and publications, estimating the time required to their elaboration.

Table 15. Performance descriptors for the number of presentations and publications.

Evaluation Criterion	Mathematical expression
Nr. of Presentations	$N_{Pres} = \frac{1}{u_{Pres}} \sum_{j=1}^{M} L_{j,Pres},$
Nr. of Publications	$N_{Publ} = \frac{1}{u_{Publ}} \sum_{j=1}^{M} L_{j,Publ}$

As for the educational activities, it was decided to define the performance descriptors as the number of hours spent in '*Learning*' and '*Teaching*', based on the contributions of other activities expressed in the equivalence table.

Table 16. Performance descriptors for '*Teaching*' and '*Learning*' evaluation criteria.

Evaluation Criterion	Mathematical expression
Teaching	$Teach = \sum_{j=1}^{M} L_{j,Teach}$
Learning	$Learn = \sum_{j=1}^{M} L_{j,Learn}$

Having defined all the descriptors of performance, these were implemented in Excel, where the alternatives generated by the MATLAB algorithm were previously recorded. Such implementation allowed the computation of the level of performance of all the alternatives in each one of the evaluation criteria.

5.4. Value Functions

The value functions were obtained by means of the MACBETH methodology, in which the value tree was introduced. For the construction of value functions, it was necessary to specify the reference performance levels according to which the qualitative judgments were made. As all the descriptors were quantitative and assumed as continuous, the 'Good' and 'Neutral' references for each evaluation criterion were firstly defined. Most of the 'Good' references corresponded to the contracted goals in production criteria (scaled to the time span of one month). It was then decided to split the 'Good-'Neutral' interval in 3 equal parts, thus defining 2 equally spaced intermediate levels of performance. In addition, 2 more reference levels were defined, over and under the 'Good' and 'Neutral' references, respectively. This procedure was adopted for all evaluation criteria, resulting in a MACBETH judgment matrix as follows:

	237	230	224	217	211	204	Current scale
237	I	very weak	v. strong	v. strong	extreme	extreme	106
230		I	v. strong	v. strong	extreme	extreme	100
224			I	strong	strong	extreme	47
217				I	weak	v. strong	18
211					I	strong	0
204						I	-47

extreme / v. strong / strong / moderate / weak / very weak / no

Consistent judgements

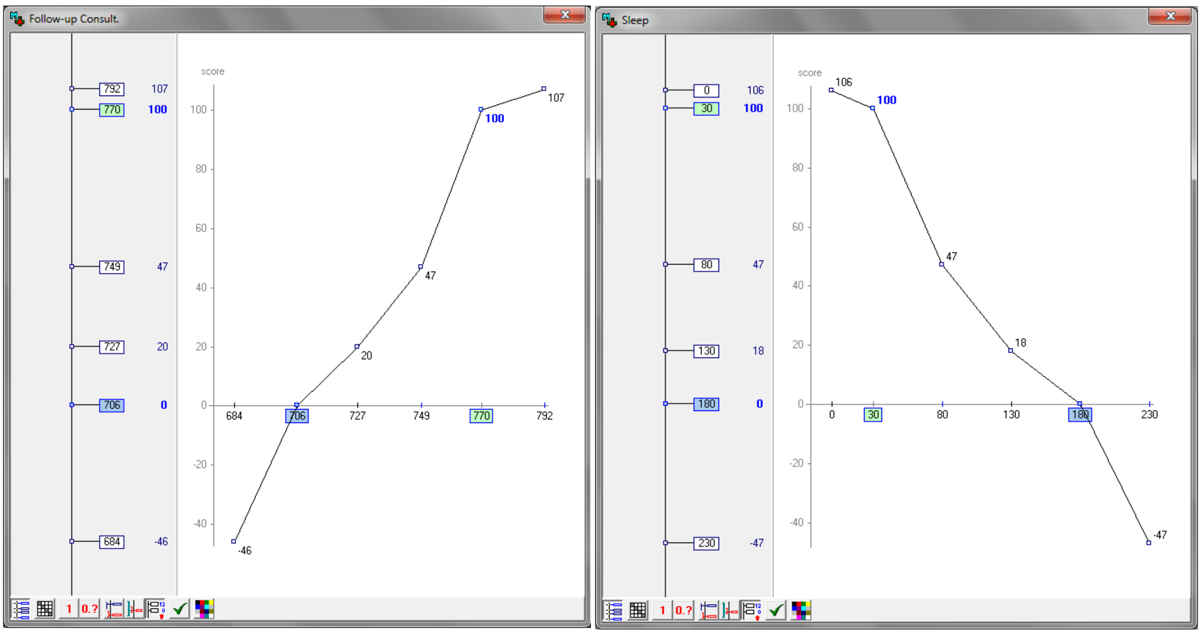
Figure 14. Judgment matrix for the criterion 'Number of 1st Consultations'.

Figure 14 shows the MACBETH judgment matrix. The green and blue cells represent the 'Good' and 'Neutral' levels, respectively. After ensuring the consistency of the elicited judgments based on the differences of attractiveness, the software built a piecewise linear value function, whose references are represented in the column entitled '*Current Scale*'. The validation of the value functions was ensured at this point.

The process of building value functions is typically performed for each evaluation criterion. However, in the present case study, the decision maker decided to adopt an equivalent value function to all the evaluation criteria, establishing equally spaced intermediate references and assigning the scores to those references of performance. In most of the criteria, the value functions are increasing functions (higher values of performance yield higher score). On the other hand, the criteria comprised in the '*Waiting Time*' branch were assigned a decreasing value function, since a higher value of waiting time is less preferred, thus assigned a lower score.

The shape of the value function results identical in all criteria, either increasing or decreasing, depending on the case. Although the construction of value functions was generalised, that is, the judgment matrix was not filled for every criterion, the value functions were validated. For such validation, the graphical representation of the value function was used, identical to the ones represented in Figure 15.

The obtained value functions were implemented in Excel, making use of the previously defined performance descriptors. In the Excel file, for each physician, the local scores were organised in the form of a table (or matrix), in which each entry $v_{k,l}$, represents the local score of alternative k in the evaluation criteria l. The outline is similar to the one presented by M-MACBETH, in which rows represent alternative and columns correspond to each evaluation criterion.



(a) (b)

Figure 15. Graphical representations of the value functions for (a) Number of follow-up consultations and (b) waiting time for a 1st Sleep consultation.

5.5. Weighting Coefficients

The definition of weighting coefficients was based solely on the 'Good' and 'Neutral' references defined for the evaluation criteria. This procedure was rather complex in the context of the Neurology department due to the large number of criteria to be considered. Furthermore, the hierarchical structure of the value tree is quite complex, with evaluation criteria placed at different hierarchical levels of the value tree. Hence, it was decided to adopt the procedure presented in the section 4.5.3, considering a judgment matrix for weight calculation that includes all the evaluation criteria.

Firstly, the decision maker was asked to order the swings from 'Neutral' to 'Good' in order of preference, achieving a first ordering. It is important to refer that this procedure was performed with visual support of the value tree and the explicitation of 'Good' and 'Neutral' references, consulted whenever necessary. After reaching a first ordering of the criteria, the last column of the judgment matrix began to be filled, starting from the first row – each judgment corresponding to the intensity of preference of each swing. As more cells were filled going down the last column, it was noticed that the first ordering had to be rearranged. Having filled the last column, the software rearranged the order of the criteria, yielding an order of preference and completing the matrix by transitivity. The next step was to refine the judgments, mainly to differentiate criteria whose swing has been assigned the same semantic category. For the criteria related to the waiting time of first differentiated EC, the decision maker expressed that the respective swings were all indifferent, also because of the fact that the 'Good' and 'Neutral' references were set to be equal in these criteria. Further adjustments were made, analysing of the resulting histogram and interpretation of the resulting weights. At the end of the process, the set of weighting coefficients was validated, and is presented in the next figure.

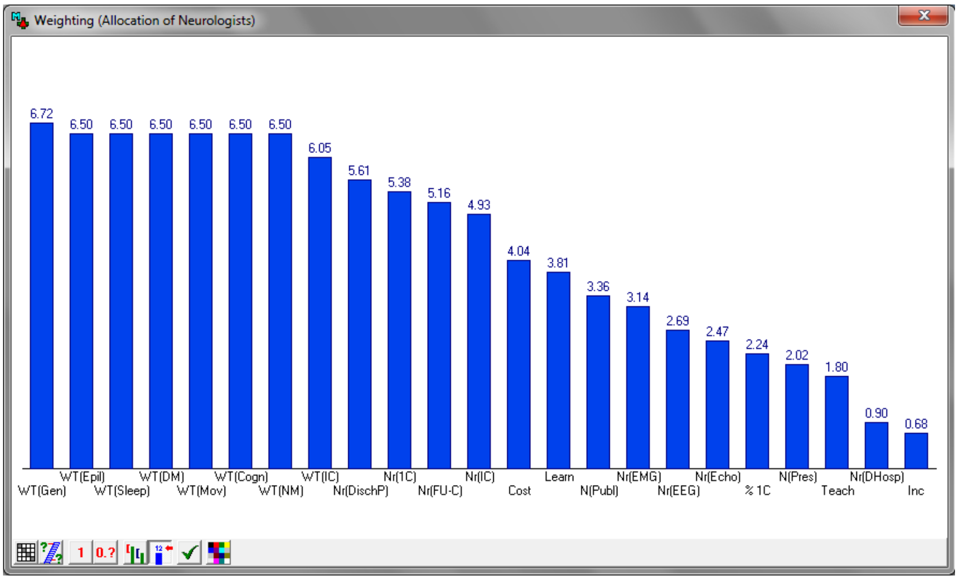


Figure 16. Histogram representing the weighting coefficients obtained in M-MACBETH.

The definition of weighting coefficients ends the stage of building the value model. The developed evaluation model was then implemented in Excel, following the scheme presented in Figure 11. Each Excel file contained the data of one physician, for the computation of the global scores according to the constructed value functions and weighting coefficients defined.

6. Model Results

This chapter presents the results obtained from the application of the developed multicriteria model in the evaluation of allocation alternatives generated in MATLAB. This procedure corresponds, in practical term, to the appraisal of the benefit obtained from each mode of distributing a physician's working time amongst the different service activities. In order to demonstrate the possibilities of application of the model, 3 different scenarios are considered. Such scenarios present plausible situations for the decision maker , which might indicate constraints regarding the collective allocation of physicians, instead of focusing solely on the specific allocation profile of each physician. Each scenario is, thus, characterised by a set of constraints. The following scenarios are considered:

- Scenario **S1** – No constraints: the collective allocation is based on the individual optimal alternatives;
- Scenario **S2** – Constraints imposed on scientific activity, limiting the number of physicians performing scientific activities;
- Scenario **S3** – Promote physician meetings, imposing a minimum number of hours for this activity.

The scenario analysis was performed using the PROBE decision support system, with the relevant constraints being defined for each scenario. Prior to the introduction of alternatives in the software, it a set of alternatives that are relevant to perform the desired analyses were selected. I.e., for each physician, the following alternatives (corresponding to alternative allocations of the physician to activities) were selected:

1 – Alternative with the highest score;

2 – Best alternative without scientific activity (neither '*presentations*' nor '*publications*');

3 – Best alternative with scientific activity;

4 – Best alternative with at least 8 monthly hours of meetings;

These criteria aimed to create a set of alternatives to be introduced in the software. This set should allow, for each scenario, the selection of an alternative for each physician. The alternatives selected according to each condition yielded in some cases overlapping results, as for instance the best alternative selected in condition 1 will appear either in 2 or 3, since the best alternative either comprises scientific activities, or it does not. Therefore, 2 different alternatives arise from condition 1, 2 and 3, and a third alternative arises in the case best alternative does not meet condition 4. As a result, the number of alternatives selected for each physician was not the same, depending on the overlapping of conditions 1 and 4.

Having introduced the alternatives in PROBE, their respective costs (working hours) and incremental benefits in relation to the *status quo* were also introduced. The choice of considering such incremental benefits instead of the scores obtained directly in the evaluation model aimed to ensure that the benefit scales used for portfolio analysis were ratio scales, with a fixed zero value corresponding to the baseline, as presented in section 4.8. In this sense, an alternative (project) with zero benefit adds no value to the portfolio, i.e., that alternative yields the same benefit as the *status quo*, whose benefit was computed according to the parameters of the evaluation model, making use of the current allocation profiles derived from Table A1. Also, it was necessary to define at that point the set of constraints common to all analyses. Such constraints regard the mutual exclusivity of alternatives of the same physician, since in any situation it would not make sense to select two alternatives from the same neurologist.

6.1. Scenario S1 – No constraints

The first analysis concerned a scenario in which the decision maker did not impose any constraints on the portfolio (i.e. on the allocation of physicians to activities that maximises benefits), besides those of mutual exclusivity of projects of the same physician. Such situation can be useful to analyse, for instance, the possible incremental benefit obtained for each physician if the optimisation of the working time is performed individually. The analysis performed in PROBE consisted in determining the convex and non-convex efficient portfolios of projects, in which such projects correspond to alternatives, and portfolios designate combinations of alternatives, one of each physician. The efficient portfolios are represented graphically in Figure 17.

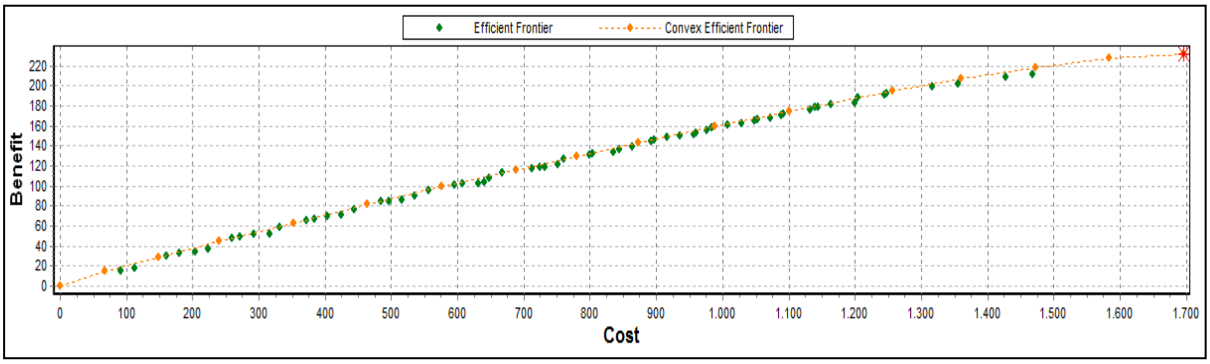


Figure 17. Efficient frontier obtained for scenario S1 in PROBE software.

The portfolio on the upper right corner of Figure 17 represents the efficient portfolio for the available resources, which correspond to a total of 1696 monthly working hours. This portfolio is in the convex-efficient frontier, which indicates that no other portfolio dominates it, i.e., there is no other portfolio yielding the same benefit with a lower cost or with a higher benefit for the same cost. Furthermore, as the selected portfolio is convex-efficient, this implies that it does not include any project with a lower B/C than a non-selected project (cf. Lourenço [91]). The portfolio selection may also be interpreted in terms of the B/C of alternatives. In PROBE software, it is possible to visualise projects by order of priority. Starting from the empty portfolio and going leftward on the convex frontier, it is possible to observe that projects are incorporated in the portfolio in decreasing order of the list of decreasing B/C, skipping the alternatives of physicians that already had an alternative selected, in order to comply with the constraints of mutual exclusivity. This method is in line with the prioritisation approach of Phillips and Bana e Costa [69] with the additional constraints of mutual exclusivity constraints. Such optimisation thus yields the highest benefit for the available budget of working hours. In light of the present context, the optimisation of the portfolio with the constraints of mutual exclusivity, and since the alternatives of each physician have the same cost, the performed selection is equivalent to the best alternative of each physician, since these are the ones that yield a higher value for resources (for a fixed cost, total working hours, the alternative yielding the higher benefit for each physician is, consequently, the most efficient).

In order to ease the interpretation of results, these were represented in the form of variations in the distribution of working time in respect to the *status quo*, as it would be impractical to interpret each physician's best distribution and its variations from the original allocation profile, given the number of physicians and activities involved. The results from the scenario S1 are presented in Table 17, where the green positive numbers indicate the increase in the number of hours assigned to an activity, whilst the red negative numbers indicate decrease. The rows represent different physicians, and each column corresponds to an activity, following the numerical code defined in Table 8. The last column represents the (incremental) B/C.

Table 17. Portfolio obtained for scenario S1 (physicians in rows; activities in columns).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	$^{Ben}/_{Cost}$
MV	-8	0	0	0	0	0	0	-8	4	8	-4	0	0	0	0	-8	0	8	8	0	0,126
IC	-4	0	0	0	0	8	0	-8	8	-8	-4	0	0	-8	0	0	0	8	8	0	0,170
JV	0	0	0	0	0	0	0	-8	4	-8	-4	0	0	-4	0	4	0	8	8	0	0,144
MVB	-8	0	0	0	0	0	0	-8	0	0	8	0	0	4	0	8	0	0	4	-8	0,180
NC	0	0	0	0	0	0	0	-8	4	0	4	0	0	-8	-8	4	0	4	8	0	0,123
SC	-4	0	0	0	0	0	0	-8	8	4	-4	0	0	-8	0	0	4	8	8	-8	0,164
PB	-8	0	0	0	8	0	0	-8	-4	4	-4	0	0	-4	0	0	0	8	8	0	0,141
PA	0	0	0	0	0	0	0	-8	4	-8	-4	0	0	0	0	0	0	8	8	0	0,147
LA	-8	0	0	0	0	0	0	-8	8	4	-4	0	0	-8	0	0	0	8	8	0	0,164
RP	-4	0	0	0	0	0	0	-8	4	-4	0	0	0	-4	-8	4	4	8	8	0	0,129
EM	0	0	0	0	0	0	-8	-8	0	0	0	0	0	4	0	0	0	8	4	0	0,214
DP	0	-4	0	0	0	0	0	-8	0	0	0	-8	0	4	0	0	0	8	8	0	0,163
JM	4	0	0	0	0	0	-4	-8	8	0	0	0	0	-8	0	0	4	4	0	0	0,150
GM	-4	0	0	0	0	0	0	-8	4	4	0	0	0	-8	0	0	-4	8	8	0	0,135
TL	-4	0	0	0	0	0	0	-8	0	4	0	0	0	-8	0	0	0	8	8	0	0,084
HD	0	0	0	0	0	0	0	0	0	4	0	0	0	-8	0	0	0	0	4	0	0,037

The fact that B/C ratios are all positive suggests that, in light of the developed evaluation model, it is possible to redistribute physicians working time and obtaining higher benefits. The increments in benefit are obtained, in almost all alternatives, through a decrease in the amount of time allocated to follow-up consultations, and several of them show a reduction on the time destined for 1st general EC, as well as for the day hospital. On the other hand, the alternatives in the portfolio indicate an increase in scientific activity, either presentations, publications or both. Such tendency probably arises from the situation in that, initially, there are no physicians spending time in scientific activities, following the specification of the initial allocation profiles specified in Table A1. These results can be observed in light of the compensatory nature of the model, as the loss of benefit from the reduction of 8 hours of 1st general EC and follow-up EC is lower than the benefit gained from deploying the these hours in developing scientific activities. Furthermore, the evaluation model establishes that research activities contribute very significantly to the education of physicians, which reinforces the tendency to the selection of alternatives that promote such activities. The same observation stands for physician meetings, which also show a tendency for reduction in order to promote research activities. It is important to remind that the specification of the contribution of each activity to the education of physicians was higher in the case of presentations and publications than in meetings, although the latter are considered of great importance from the decision maker's perspective.

Several results promote the allocation of working hours to IC (activity 10), assisting inpatients of other departments. The decision maker acknowledged that this service had been becoming unattended due to the scarcity of human resources, and thus was expected that the best alternatives would privilege this service in order to reduce the waiting time for IC. In addition, this criterion has been assigned a significant weight, and since the performance of the initial physician distribution in this criterion is rather below the 'good' level of 3 days, the model outputs suggest compensation on this criterion at the cost of other activities, mainly EC.

As for complementary exams, results indicate reduction in the time dedicated to EEG and echo-doppler exams (activities 12 and 20, respectively). However, in the decision maker's perspective, a reduction in the laboratories' production is not desirable, since these services have been where the impact of scarcity in human resource has been manifested more significantly, mostly EEG exams. In this sense, the valuation of scientific activities might have surpassed that of laboratory activities, which may have deviated results from the decision maker's preferences.

It is also worth observing the variations in the time allocated to 1st differentiated consultations, namely for the specialty of neuromuscular diseases. Although this type of consultations presents initially the highest waiting time (approximately 120 days), this value remains above the 'neutral' reference of 180 days contracted with the RHA. This level of 120 days is located in the vicinity of the neutral level, where the slope of the value function is lower (as shown in Figure 15-b), and thus yields lower benefit for increments in performance than if an equivalent amount of time was assigned to other activities that produce higher benefit, such as scientific activities. Nonetheless, results are in accordance with the defined references of 'good' and 'neutral', despite the great waiting time for neuromuscular consultations.

Upon analysing the results yielded by the model, it is rather important to keep in mind the nature of the alternatives. As stated before, each alternative corresponds to a given distribution of time amongst the considered activities, and the evaluation in each criterion is performed considering the remaining physicians at their current allocation profile. Hence, the results presented above should not be interpreted as the best combination of alternatives of the different physicians, but instead as the best alternative provided that other physicians' distribution of time remains unchanged. In fact, it is intuitive to verify that the decision maker would not consider adequate to have all physicians dedicating time to scientific activities, as the cumulative effect of reducing the number of hours of consultation and other services would greatly decrease production and move the Neurology department away from the contracted target goals. In this sense, it would be useful to consider situations in which additional constraints are imposed on the global distribution of physicians, so as to avoid redundancy of allocation profiles. Hence, different scenarios are considered in the following sections, regarding the definition of constraints at the portfolio level.

6.2. Scenario S2 – Constraints on Scientific Activities

As the best alternatives resulting from an unconstrained analysis were mostly characterised by an increase in the amount of time allocated to scientific activities, the S2 scenario aimed to perform an analysis in which the number of physicians dedicating time to scientific activities was limited (thus limiting the total time allocated to this activity). Furthermore, it was considered useful to differentiate graduate physicians and interns in these constraints, since the latter typically dedicate more time to research in the scope of their internship. In this sense, the S2 scenario consists of a situation in which it is established that all interns allocate time to scientific activities and 2 graduate neurologists should also dedicate time to these activities.

In the PROBE decision support system, the modelling of this scenario was enabled by the possibility to define project areas. For this purpose, a project area was created, on which the alternatives of each physician without scientific activities (resulting from condition 2) were incorporated. PROBE allows the definition of constraints on project areas, designated as group constraints. Since it was desired to have 2 graduate physicians dedicated to scientific activities, this was equivalent to impose that the remaining 10 physicians do not assign time to these activities. Hence, the group constraint consisted in imposing the selection of exactly 10 out of the 12 projects integrated in the created area. Since it was also necessary to impose that interns should perform scientific activities, the '*Force in*' feature was used to ensure the integration of each intern's best alternative with scientific activities (from condition 3) in the resulting portfolios.

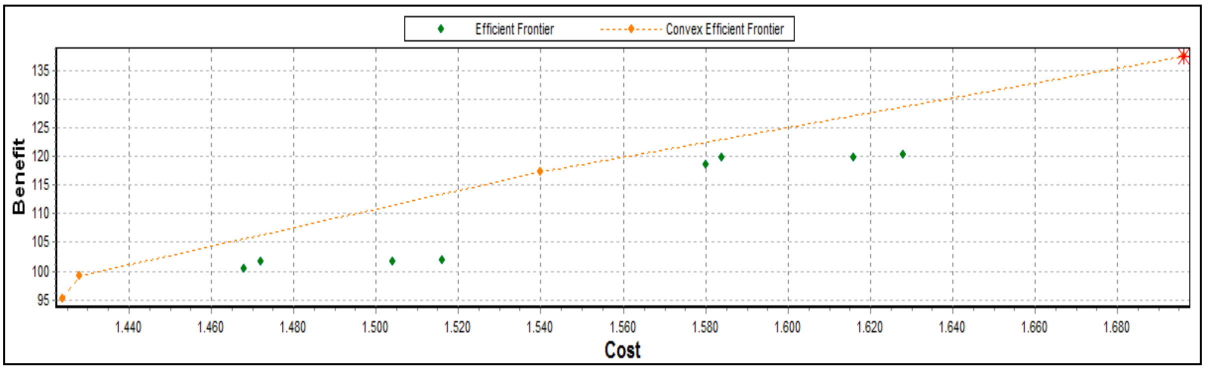


Figure 18. Efficient frontier obtained for scenario S2 in PROBE software.

Unlike the first scenario, the efficient frontier of scenario S2 does not start in the empty portfolio, as a consequence of the imposed constraint of selecting exactly 10 alternatives from the defined project area. In addition, as the constraints have been imposed, the number of efficient portfolios is considerably lower, being 12 in this case. Another significant difference from scenario S1 is the total portfolio benefit of approximately 137 points, which shows a considerable decrease. As was verified in Table 17, the best alternatives for each physician suggested an increase in scientific activity, and thus it would be expectable that restraining these activities would decrease the cumulative benefit. Yet another difference to be noticed is that the efficient and convex-efficient frontiers are quite more distant than in Figure 17, which is most likely related to the fact that constraints impose the selection of a fixed number of projects whose B/C is considerably lower than that of the alternatives with scientific activities, hence the discrepancy of the two efficient frontiers.

With respect to the B/C obtained for the unconstrained analysis in scenario S1, the values in Table 18 are quite lower for physicians not performing scientific activities. The decrease in these B/C ratios was also expectable given the decrease in the benefit of the portfolio. Since there was a tendency to increase the time assigned to these activities in S1, it is expected that these activities yield more benefit according to the parameters of the evaluation model. Thus, by restraining the possibility to select these alternatives, the benefit has decreased significantly in the case of physicians left out of these activities, as can be seen in the respective B/C in the last column of . The obtained portfolio shows, once more, the tendency to reduce the number of hours allocated to follow-up consultations. As for first consultations, the reduction is not as marked as in the first scenario, which indicates that the benefit lost in reducing follow-up consultations is lower than first consultations are reduced. This observation is in line with the model structure, since first consultations contribute to several groups of criteria – increase the number of consultations and decrease waiting times, whereas follow-up consultations contribute only for the respective number of consultations. In addition, payment for first consultations is higher, hence the preferential decrease in follow-up EC.

Table 18. Portfolio obtained for scenario S2 (physicians in rows; activities in columns).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	$^{Ben}/_{Cost}$
MV	-4	0	0	4	0	0	0	-8	4	8	0	0	0	4	0	-8	0	0	0	0	0,047
IC	0	0	0	0	0	4	0	-8	4	4	-4	0	0	-8	0	0	8	0	0	0	0,061
JV	4	0	0	0	0	0	0	-8	4	4	-4	0	0	-4	0	4	0	0	0	0	0,054
MVB	-8	0	0	0	0	0	0	-8	4	8	0	0	0	0	0	4	8	0	0	-8	0,058
NC	4	0	0	0	0	0	0	-8	4	8	0	0	0	-8	-4	4	0	0	0	0	0,047
SC	-4	0	0	0	0	0	0	-8	8	4	-4	0	0	-8	0	0	4	8	8	-8	0,164
PB	-4	0	0	0	0	0	0	-8	8	8	-4	0	0	0	0	0	0	0	0	0	0,051
PA	0	0	0	0	0	0	0	-8	4	8	-4	0	0	0	0	0	0	0	0	0	0,072
LA	0	0	0	0	0	8	0	-8	4	4	-4	0	0	-4	0	0	0	0	0	0	0,058
RP	8	4	0	0	0	0	0	-8	4	8	0	0	0	-8	-8	0	0	0	0	0	0,042
EM	0	0	0	0	0	0	-8	-4	0	8	0	0	4	0	0	0	0	0	0	0	0,064
DP	0	-4	0	0	0	0	0	-8	0	0	0	-8	0	4	0	0	0	8	8	0	0.163
JM	4	0	0	0	0	0	-4	-8	8	0	0	0	0	-8	0	0	4	4	0	0	0,150
GM	-4	0	0	0	0	0	0	-8	4	4	0	0	0	-8	0	0	-4	8	8	0	0,135
TL	-4	0	0	0	0	0	0	-8	0	4	0	0	0	-8	0	0	0	8	8	0	0,084
HD	0	0	0	0	0	0	0	0	0	4	0	0	0	-8	0	0	0	0	4	0	0,037

The alternatives also indicate reductions in the number of day hospital sessions and in physician meetings, promoting the allocation of time to IC (activity 9) and especially to inpatient care (activity 10). In fact, the latter presents significant differences in respect to the results of scenario S1, in which some alternatives showed reduction in the time spent on inpatient care. For that reason, it might be considered that results suggest that physicians that do not carry out scientific activities would obtain higher benefit in attending inpatients of the Neurology department's ward and also of other services of the hospital centre (i.e., internal consultations). The benefit of these activities arises both in the improvement of production on these services and in the educational contribution of these activities. Some alternatives also show an increase in the time allocated to learning techniques (activity 17). Such increase may derive from their contribution to the educational objectives.

The results showed how it is possible to impose constraints at the portfolio level, which is also simple in terms of implementation in PROBE. Hence, as the scenario has changed, it was possible to observe the adaptation of the model results to the imposed constraints.

6.3. Scenario S3 – Promote physician meetings

The decision maker showed significant interest in promoting physician meetings, as these were considered to be of great importance to the education of physicians and sharing of medical knowledge. Such meetings regard both the discussion of clinical cases and of discharge notes. On the one hand, the evaluation of these notes contributes to a higher control of quality of care. On the other hand, discussion of clinical cases is likely to improve the efficacy of diagnosis, due to the coexistence of specialised knowledge in multiple fields of Neurology. Moreover, the elaboration of diagnoses by means of meetings reduces the need to prescribe costly complementary exams that could be substituted by the collective experience and knowledge of neurologists. The decision maker explicitly stated that this aspect was of great importance in the context of the Neurology department, especially when the objectives comprise reducing the expenditure and training skilled professionals.

In this sense, this scenario was modelled by imposing the constraint of a minimum of 8 hours of monthly meetings, selected according to condition 4 (best alternative with at least 8 hours of monthly meetings). In PROBE, the procedure consisted in specifying 'Force out' constraints for the alternatives of each physician that did not comply with the requirement of the minimum 8 hours of meetings. Having specified such conditions, PROBE computed the efficient portfolios (*vide* Figure 19).

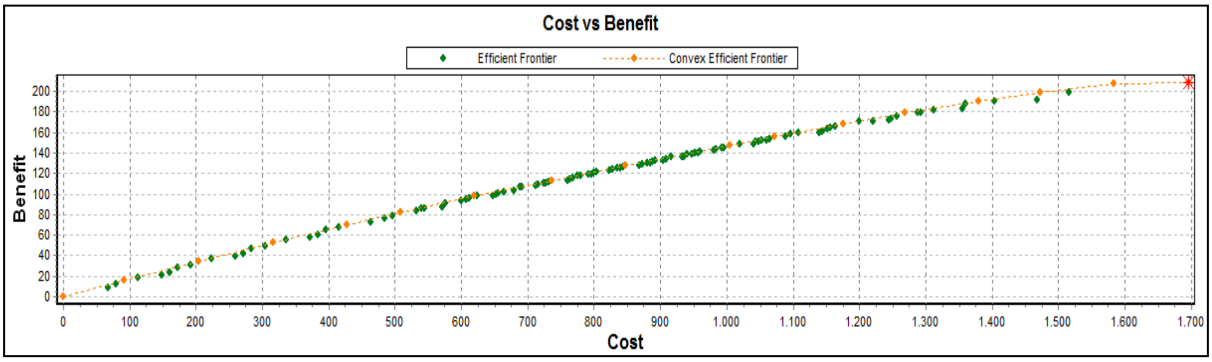


Figure 19. Efficient frontier obtained for scenario S3 in PROBE software.

The efficient frontier is similar to that of the first scenario, which was expectable given that most of the best alternatives of each physician complied with the requirement of at least 8 hours of meetings, and consequently the resulting efficient portfolios have these alternatives in common with the efficient portfolios of Figure 17. However, as some projects differ (and these have less benefits, as they are not individual optimal alternatives), the total benefit outcome of about 208 points is lower than in the first scenario.

Table 19. Portfolio obtained for scenario S3 (physicians in rows; activities in columns).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	$^{Ben}/_{Cost}$
MV	-8	0	0	0	0	0	0	-8	4	8	-4	0	0	0	0	-8	0	8	8	0	0,126
IC	-4	0	0	0	0	8	0	-8	8	-8	-4	0	0	-8	0	0	0	8	8	0	0,170
JV	0	0	0	0	0	0	0	-8	4	-8	-4	0	0	4	0	4	0	4	4	0	0,116
MVB	-8	0	0	0	0	0	0	-8	4	4	0	0	0	4	0	4	0	0	8	-8	0,154
NC	0	0	0	0	0	0	0	-8	4	-8	0	0	0	-4	-8	8	0	8	8	0	0,120
SC	-4	0	0	0	0	0	0	-8	8	4	-4	0	0	-8	0	0	4	8	8	-8	0,164
PB	-4	0	0	0	4	0	0	-8	-4	0	-4	0	0	0	0	0	0	8	8	0	0,133
PA	0	0	0	0	0	0	0	-8	0	-8	-4	0	0	8	0	0	0	4	8	0	0,097
LA	-8	0	0	0	0	0	0	-8	8	4	-4	0	0	-8	0	0	0	8	8	0	0,164
RP	-4	0	0	0	0	0	0	-8	4	-4	0	0	0	-4	-8	4	4	8	8	0	0,129
EM	0	0	0	0	0	0	-8	-8	0	4	0	0	0	8	0	0	0	4	0	0	0,122
DP	0	-4	0	0	0	0	0	-8	0	0	0	-8	0	4	0	0	0	8	8	0	0,163
JM	-4	0	0	0	0	0	-4	-8	0	4	4	0	0	0	0	0	-8	8	8	0	0,135
GM	-4	0	0	0	0	0	0	-4	4	4	0	0	0	-4	0	0	-8	8	4	0	0,128
TL	-4	0	0	0	0	0	0	-8	0	4	0	0	0	0	0	0	0	0	8	0	0,075
HD	0	0	0	0	0	0	0	0	0	-4	0	0	0	0	0	0	0	0	4	0	0,013

The efficient portfolio represented in Table 19 maintains the observations stated earlier, regarding the reduction of time for first and follow-up consultations, as well as of day hospital. The tendency to increase the time spent on internal consultations (activity 9) is also verified. In fact, since some of the alternatives are common to the portfolio represented in Table 17, and therefore most of the observations presented in scenario S1 stand for the present scenario. However, it is possible to observe that the resulting portfolio shows fewer reductions in physician meetings, as a result of the imposed constraints.

As for B/C ratios, the variations from scenario S1 are not significant, also in the alternatives that differ. Such facts suggest that physician meetings also represent a contribution to the incremental benefit of the portfolios, as otherwise the imposition of physician meetings would decrease the benefit outcome of the selected alternatives.

In effect, the portfolio presented in scenario S1 indicates reduction in meetings for almost all alternatives, whereas in the portfolio for the present scenario, only some alternatives show decrease in this activity. In this sense, an increase in the time dedicated to meetings, although decreasing in other activities, does not reduce significantly the benefit outcome.

6.4. Comparison of results

The creation of scenarios and their analysis in the PROBE decision support system illustrated the use of the developed model in situations where constraints regarding the global allocation of physicians might exist. It was possible to observe variations in the model's outputs, depending on the constraints of each scenario.

Table 20. Summary of the results obtained for the three scenarios.

Scenario	Incremental Benefit	Nr. of efficient portfolios
S1	231,762	52
S2	137,462	12
S3	208,831	120

For each scenario, the results concerning the total incremental benefit and the number of efficient portfolios differs, as would be expectable. Firstly, the fact the differences in benefit outcome are mostly related to the existence of constraints. Although constraints exist both on scenarios S2 and S3, the establishment of 10 physicians without scientific activities has represented the main source of benefit reduction. The constraints imposed on scenario S3 are compatible with the existence of scientific activities, which is probably the reason for the resemblance of the incremental benefit of scenarios S1 and S3, since the alternatives considered in scenario S3 may comply with minimum of 8 hours, yet preserving scientific activities. In this sense, it is possible to observe the effect of imposing constraints at the portfolio level. Furthermore, the effect of the constraints highly depends on their type and on the concerned activities.

The results of each scenario also differed in the number of efficient portfolios. The most noticeable difference arises in scenario S2, in which the number of efficient portfolios is considerably lower. In effect, the imposition of a fixed number of projects to select from an area is expected to narrow the range of candidates to efficient portfolios, since the number of possible combinations of alternatives entering the portfolio is reduced. Nonetheless, it is not adequate to assume that the imposition of constraints on portfolios implies a reduction in the number of efficient portfolios. For instance, in scenario S3, despite the existence of constraints, the number of efficient portfolios is significantly higher.

Some other applications might have included selecting one physician for initiating the learning of EEG/EMG techniques or analysing of the consequences of limiting the number of physicians working in the day hospital. Moreover, such analyses may also be conceived as combining multiple constraints regarding different services and physicians. The examples of application of the developed model showed possible situations in which the model can be suitable. The possibilities of application are enabled by means of variation in several parameters for analysis, mainly in the portfolio constraints, which are in turn in close relation with alternatives selected for analysis. The results obtained in the different scenarios traduced the effects of the imposed constraints, illustrating the capability of the model to accommodate different situations.

7. Discussion

The application of the developed methodology has resulted in the construction of a multicriteria evaluation model, applied to the allocation alternatives generated by means of the implemented algorithm. The model results were illustrated in the previous chapter, exemplifying possible applications. After developing and applying the proposed methodology, the purpose of this chapter is to perform a critical analysis on the most important issues, identifying the most significant contributes to address the allocation of human resources, as well as the potential weaknesses of the model.

7.1. Problem structuring approach

At the beginning of the analysis, it was necessary to establish the type of approach on which to base the development of the methodology. The start-off point consisted of a situation of scarcity in the available human resources, and the central objective consisted in optimising the usage of resources. In such case, two directions could have been assumed – either the methodology addressed the efficiency, balancing production against time expenditure, or instead aimed to inform the Chief Director on how to distribute the working time of physicians. The current situation of the Neurology department and the decision maker's perspective advocated for the adoption of a procedure for the management of human resources amongst the existing activities. Such approach demonstrated to be suitable for the problem, given the complexity involved in the allocation of human resources regarding the multiple objectives of the department influencing the distribution of physicians with specific characteristics amongst varied activities. However, it might be considered that addressing the problem without questioning the efficiency of resource utilisation does not promote cost containment and reduction of expenditure, which presently also constitutes a major problem within the Neurology department. The developed methodology was based on fixed parameters of time expenditure, not considering if these adequately use the required time. The usage of resources can thus be looked upon in two levels – the first considering the usage of time in performing each specific activity, and a second level regarding the mode of deploying the available human resources. This thesis focused in the latter, and it may be worth considering the two levels of resource utilisation as complementary issues that aim to improve the benefit obtained from the available human resources.

The implementation of the methodology involved the specification of activities performed by physicians, which required a certain degree of simplification in order to preserve the amount of information at a manageable level. In this sense, it was decided not to consider the activities related to some services, the most evident being the emergency department (ED), which is of great importance in the context of the Neurology department. Although ED shifts are scheduled and might be considered isolated from other activities, given the lack of performance indicators and the location outside the HEM facilities, the decision to leave this service out of the analysis does not allow the consideration of the potential additional benefits. Namely, physicians' work in ED shifts may contribute to the operation of the CVA unit and improve the provision of care to inpatients in the ward of departments located in the HSFX. Not taking into account such potential benefits may have suggested deploying physicians to certain activities that might have been assigned lower priority in face of ED shifts. Hence, the set of activities considered for analysis are a central issue for the developed model and greatly influence the results, thus presenting a potential source of issues related to the validity of results.

7.2. Generation of Alternatives

The proposed methodology proposed a method for the generation of allocation alternatives, based on the discretisation of working time and the specification of ranges of variation. It is possible to identify the main advantages of such approach:

- The discretisation of working time, which has revealed adequate in the scope of the activities under consideration, since it allowed the computational implementation, with acceptable efficiency, of an algorithm which systematised the process;
- The possibility to specify the activities to be incorporated in the options, conferring flexibility to the process and allowing adaptation to different contexts, by constraining or widening the range of alternatives for each physician, being also able to consider variations in the available human resources;
- The approach to the computation of alternatives, taking the initial allocation profile as starting point and considering variations of this distribution with the specified range of variation in each activity simplifies the process and increases efficiency by eliminating the generation of obsolete alternatives;
- The possibility to introduce additional constraints on the alternatives by specification of upper and lower bounds of time allocated to each activity, enabling the differentiation of the ranges of variation between activities of the same physician;
- The standardised layout of the outputs in a matrix Θ, as specified in (5), allows a systematised evaluation and comparison of the set of alternatives generated for each physician.

Despite the usefulness of the implemented approach, there still exist some drawbacks. Although the conceptual framework of the methodology is adequate, the computational load of the process has demanded that, firstly, the alternatives are generated for each physician, instead of considering the joint allocation of working time of all physicians, since activities are often in close articulation and either synergies or constraints might have not been accounted for. Additionally, it was necessary to specify a relatively high value for the dimension of time blocks (Δ_t, as represented in Figure 8), resulting in relatively abrupt variations of time assigned to each activity, and thus optimal allocations may be skipped in the generation of alternatives.

In such approach, the ideal method for generating alternatives would be considering all the possible combinations between alternatives of the different physicians, which in turn would be generated through the combinations of amounts of time assigned to each activity. These variations in the amount of time would be desirably as small as possible, in order to avoid the non-appearance of potentially optimal solutions.

7.3. Process of building the evaluation model

The process of building the multicriteria evaluation model presented a major challenge in the whole process, given the internal complexity of the Neurology department. It is therefore important to highlight some aspects related to this stage of the methodology.

Identification of Evaluation Criteria and Structuring of Value Tree

Given the nature of the alternatives under consideration and, especially, considering their number, it was verified that a top-down approach to the process of structuring the multicriteria model, using the principles of value-focused thinking proposed by Keeney [70], has revealed adequate to address the problem. Starting off the discussion between the facilitator and the decision maker from the department's objectives and main areas of concern has significantly eased the process of identifying evaluation criteria and of structuring these in a value tree, since the criteria have mostly arisen by successively specifying the areas of concern.

The main issue regarding the structure of the value tree was the high number of evaluation criteria, which is much higher than in most of applications of multicriteria models, and Bana e Costa [93] considered the evaluation criteria should not be more than a dozen. Moreover, although the organisation of criteria in the value tree improves their interpretation, the existence of criteria at multiple levels of the value tree also introduces complexity to the subsequent process of defining the parameters of the evaluation model, as it involves expressing preferences between different branches and levels of the value tree. In this sense, the amount of information contained in the value tree may have influenced the process of modelling preferences. Nevertheless, the complexity of the value tree is mostly a result of the intricacy of the Neurology department, and therefore it would also be unadvisable to leave important criteria unattended, as this could have introduced significant biases in the results. Hence, the construction of the value tree has tried to manage the balance in the consideration of all important aspects, whilst aiming to preserve the amount of information at a manageable level.

Definition of performance descriptors

Each evaluation criteria was operationalised by the association a descriptor of performance. This stage has represented significant obstacles, as it was extremely difficult to establish the necessary cause-effect relationship between the time allocated to a given activity and the resulting performance in evaluation criteria. While this task was simple for external consultations, it was necessary to estimate durations of other activities, as inpatient care and the time required to elaborate scientific activities. Such estimations may have constituted faults of the model, as one may question the legitimacy of assigning a fixed amount of time required to discharge an inpatient, given the variability of clinical conditions of inpatients, both in the ward of the Neurology department and in wards of other medical specialties (internal consultations). In what concerns scientific activities, the estimations may have also introduced imprecision in the model, especially for the reason that it is rather difficult to specify not only the time required to develop, for instance, a presentation, but also the portion of this time that is distributed amongst working and non-working hours. In this sense, these estimations probably constitute one of the most significant vulnerabilities of the developed model.

As for the specification of the contributions of each activity to scientific and educational activities, although its conception stands on valid principles and models concrete relationships, the estimation of these contributions was also subjectively performed. The implicit variations introduced by these estimations and the reliability of its values are difficult to assess. Hence, these issues may require a more precise specification in order to properly traduce such relationships within the Neurology department.

The definition of performance descriptors presented an additional limitation, which concerns the fact that, as it was not possible to evaluate most of the criteria in the '*Production*' branch based on the alternatives of each physician, it was established that these performances were to be calculated using the information contained on the initial allocation profiles of other physicians. Furthermore, this information did not provide full detail on the required parameters, as for instance, the number of first and follow-up consultations was derived from the amount of time allocated to consultations (not distinguishing the first and the follow-up). Although these assumptions are based on data of the Neurology department, they may introduce generalisations that bias the obtained results and presents, in effect, a limitation of the developed model.

Construction of value functions

Prior to the definition of value functions, the 'good' and 'neutral' levels of performance were defined for each criterion. While in criteria related to the production and economic aspects this specification definition relatively direct, in the criteria from the '*Quality*' branch it has revealed to be more problematic, mainly in the case of teaching and learning, since it involved considering not only the time dedicated specifically to education, but also time of teaching and learning embedded in other activities. Therefore, the specification of such reference levels might not have fully traduced the decision maker's preferences. Another aspect that is worth referring is the generalisation of the reference levels of educational activities to both interns and graduate physicians. This approximation represents a conceptual limitation of the evaluation model, in the sense that this was desired to be applicable for all the generated alternatives. A modification in the reference levels of these criteria would also imply the modification of the weighting coefficients (since these are determined in relation to the 'good' and 'neutral' levels), and thus would result in two different models.

As for the definition of value scales for the appraisal of alternatives in each evaluation criterion, the MACBETH methodology has revealed to be suitable for the construction of value functions, also because of the small number of used reference levels, which resulted in a simple judgment matrix. The MACBETH capability to derive quantitative value functions from qualitative judgments was verified, as these functions were validated by the decision maker.

The main drawback concerning value functions was the generalisation of a generic value function to all the evaluation criteria, with the required adaptations in respect to the order of preference of performance levels. Although the value function was validated, the MCDA framework recommends that each criterion should be subject to the definition of a specific value functions. In this sense, such generalisation may have caused the model to deviate from the decision maker's preferences, even if the value function seems adequate for all the evaluation criteria, as the validation is not as legitimate as if each criterion had been assigned a specific value function. A proper definition of specific value functions for each criterion would probably contribute significantly to the robustness of the methodology.

Determination of weighting coefficients

The number of evaluation criteria in consideration rendered the calculation of weighting coefficients quite difficult, because of the size of the judgment matrix and the existence of criteria at different hierarchical levels of the value tree. The qualitative swing weighting procedure adopted to perform such task has been helpful in overcoming the complexity of the process, since it firstly addressed the judgment of the attractiveness of 'neutral'-'good' swings, then refining the preferences by differentiating the swings which had been attributed the same intensity of preference. The achieved scale was validated, and used for implementation of the evaluation model.

However, the number of evaluation criteria caused the values of weighting coefficients to be relatively similar than if fewer criteria existed. The analysis of resulting weights required the interpretation of non integer values and the comparison of multiple values, which made the validation process limited. Also, only a portion of the judgment matrix was filled, though further refinements would not introduce relevant changes at a perceptible level. Despite these difficulties, it is considered that the methodology was able to handle the process of weighting criteria.

7.4. Model results and possibilities of application

After some remarks have been made on the conception and application of the proposed methodology, it is important to focus on obtained results and identify the possibilities of application.

Utility and limitations of results

The creation of scenarios showed the possibility to adapt the developed model to specific situations, by imposing constraints at the portfolio level that aim to specify the global allocation of physician. Hence, the whole methodology enables the possibility to constrain the scope of analysis both at the physician level, at the time of generating alternatives, and also at the department level, specifying constraints on the number of physicians performing each activity. Though, while the restraining of alternatives is performed systematically in the algorithm, the specification of constraints at the portfolio level requires a previous selection of alternatives, in order to ensure that each physician is able to have an alternative integrated in efficient portfolios. The alternatives integrating efficient portfolios provide information on a possible redistribution of the working time of a given physician in order to increase the benefit outcome.

The interpretation of results presents significant limitations, which must be bore in mind at the time of analysis. Firstly, the obtained portfolios cannot be interpreted as the optimal collective allocation if no constraints are imposed, since the evaluation of a physician's alternatives assumes other physicians at their initial allocation profile, and thus the total incremental benefit is not calculated on the collective allocation expressed in the portfolio. Such facts have consequences on the portfolio yielded in the efficient frontier, resulting, for instance, in a general tendency to promote scientific activities. Obviously, it would not be adequate to consider such a shift towards these activities, and the results make sense if one considers that each alternative yields the benefit of preserving other physicians at their initial allocation profiles, instead of calculating the benefit according to the other alternatives present in the same portfolio. In accordance, the conception of portfolio constraints aims to help avoiding the redundancy of the alternatives in efficient portfolios.

The definition of constraints at the portfolio level may be considered an advantage of the methodology, since it helps overcoming the difficulty to appraise the alternatives individually for each physician. Depending on the type of constraints, it is necessary to perform a selection of the alternatives, which consists in finding the one with the highest benefit from those that comply with the constraints, though this process is not systematised.

Possibilities of Application

Some possible applications of the resource allocation model were illustrated by means of scenario S1, S2 and S3. It was shown that the PROBE decision support system enables the definition of multiple types of constraints, which are able to accommodate different types of constraints. Namely, these constraints may be, for instance, imposing the number of physicians performing each activity or simply defining mutual exclusivity of alternatives of different physicians that the decision maker does find worth considering jointly. Additionally, such constraints can be combined in the same analysis, as long as there are alternatives complying with all the defined constraints, which also require a proper specification upon selecting the alternatives for analysis. Hence, the possibilities of application of this method are considerably wide, demonstrating adaptability to different situations.

8. Conclusions and future work

The work performed along this thesis has aimed to develop a methodological framework to inform the allocation of physicians in the context of the Neurology department of the Western Lisbon Hospital Centre. As the department had been experiencing a situation of progressive reduction of human resources, these have revealed to be insufficient to ensure all the necessary activities. In such scarcity of human resources, it is crucial that resources are deployed in put to the best use, in order to maximise the benefit outcome. However, the Neurology department entails a complex structure of physicians and activities on which resource allocation decisions have to be taken. Furthermore, these decisions have to account for multiple objectives, which may even be in conflict. In this sense, the developed framework had the purpose to aid the decision maker handling the complexity of deploying human resources.

The initial phase of this work, presented in chapter 2, concerned the characterisation of the context of the Neurology department, regarding the different activities integrated in the department's operation and the working physicians, in terms of their qualifications and relationships with the structured activities. In order to identify existing methodologies to address the allocation of human resources, a bibliographical review was conducted, presenting the most relevant approaches in the third chapter, which fall mostly in the range of economic techniques and optimisation and scheduling methods. None of the existing methods provided a suitable solution for handling the allocation of physicians in the Neurology department, and hence, a methodological framework was developed. In chapter 4, this framework was conceived, integrating the stage of generating allocation alternatives (through the combination of values of time assigned to the different activities) for each physician and the construction of a multicriteria evaluation model to enable the appraisal of the benefit of the generated alternatives. The application of such methodology was carried out by means of a socio-technical process of interaction between the decision maker and the facilitator, from which resulted the set of alternatives for each physician and the defined evaluation model, comprising the value tree, performance descriptors, value functions and weighting coefficients. The outputs of evaluation of the generated alternatives according to the multicriteria model have been selected for analysis in the PROBE decision support system, in which portfolio optimisation has been performed. The applications consisted in defining illustrative scenarios, each one characterised by a set of constraints on the collective allocation of physicians, so as to present examples of possible applications of the resource allocation model.

The obtained results showed that, in spite of the existence of limitations in the developed model, the framework has been able to handle the complexity inherent to the decisions of allocating physicians to the department activities, suggesting rearrangements in the distribution of time that might increase the benefit outcome. In effect, the central capabilities of the developed framework rely in the possibility to adapt the analysis to different contexts, by means of imposing constraints on the global allocation of physicians, as for instance, specifying the number of physicians that perform each activity, or imposing that the considered alternatives comprise a minimum amount of time assigned to particular activities. Furthermore, these constraints may be combined, extending the range of application in different situations. Although the considerations of these constraints requires the selection of alternatives from all the evaluated samples, the approach has, in fact, proved to be viable and showed the applicability of the methodology to the allocation of physicians within the hospital department.

The developed methodology is differentiated from other approaches documented in the literature and it can be considered to be in the frontier of operations management and multicriteria decision analysis. This methodology combines both paradigms in a framework that is able to accommodate multiple objectives and attributes. It preserves flexibility in the type of activities and the physicians considered, as it allows the modification of input parameters according to the context. Scheduling methods and operations management have characteristic scopes of analysis, addressing the allocation of resources but also specifying the chronologic sequence of such allocations. Conversely, the developed methodology aims to provide a different type of information, which consists essentially in specifying the amount of working time that each physician should dedicate to each activity, without considering the sequence in which activities are performed. Hence, the main contribution of this thesis to the literature consists in providing a methodology that yields such information in scenarios that entail complex objectives and attributes, particularly when it is useful to specify the distribution of human resources disregarding the sequence of events.

The development and application of the methodological framework constituted a first approach to a complex problem of allocating human resources within a particular hospital department. The obtained results have showed the potential utility of such method in addressing such situations and the problem formulation created the groundwork for the development of this generic approach. A critical analysis of the process identifies possible setbacks that, at this point, are worth mentioning as constructive directions for future work, towards the improvement of this approach.

Firstly, the most outstanding issue concerns the mode of assessing performance of alternatives in evaluation criteria, especially in those related to production. For each physician, these performances were determined considering the remaining physicians at their initial time distribution. In this sense, it would be of utmost importance to adapt the methodology in order to allow the calculation of performance levels in respect to the generated alternatives, instead of the initial allocations. A possible approach to circumvent this problem would be the consideration of allocation alternatives as combinations of individual alternatives, thus allowing a proper assessment of performances. However, since the generation of individual alternatives has already presented a considerable computational load, the combination of individual alternatives would involve even more calculations, and thus demand for a proper and efficient implementation.

The amount of information rendered available at the time of collecting data did not present the level of detail required for the specification of initial allocation profiles in terms of the considered activities. Hence, estimations had to be made, and may have presented a fragility of the model. Examples of lacking data regard not only the initial allocation of physicians, but also the patient demand for first consultations and a more precise assessment of the duration of activities. The collection of more precise data, especially concerning the initial allocation of physicians to the different activities, will most certainly contribute to the reliability of results.

As a first approach, the created model had to adopt certain simplifications that may be worth reconsidering upon improving the methodology. Namely, it might be worth including important activities such as the emergency department, and additionally the integration of the Epilepsy Surgery Program and the CVA unit. Although the model has preserved the flexibility to accommodate additional activities in the generation of alternatives, the inclusion of new activities may also require restructuring the value tree and the descriptors of performance, in order to properly account for the benefit of such new activities.

The final suggestion for further developments concerns the systematisation of the process of selecting alternatives for performing portfolio analysis on PROBE. This selection was relatively straightforward in the case of simple constraints. However, if more complex constraints were to be combined, the selection of alternatives for analysis may become quite unpractical. Hence, a scheme for selecting alternatives based on the specified constraints may be of use in such application and thus improve the utilisation of efficient portfolios for scenario analysis.

In the development of a novel approach, the arousal of setbacks is inevitable and often tends to hinder the progress. As expected, this was also the case of this thesis. Nevertheless, it was possible to carry on the conception of the resource allocation model and apply the method to the case study. The outcomes advocate for the potential utility of the developed approach in addressing the allocation of human resources in a context with multiple objectives and complex internal relationships. Although the methodology may be subject of further improvement, it is legitimate to consider that the objectives of this thesis have been attained.

9. References

1. Ministério da Saúde. *História do SNS*. 2010 [cited 2010 21.06.2010]; Available from: http://www.min-saude.pt/portal/conteudos/a+saude+em+portugal/servico+nacional+de+saude/historia+do+sns/historiadosns.htm.
2. Barros, P. and J. Simões, *Portugal: Health system review.* Health Systems in Transition, 2007. **9**(5).
3. INSA, *Inquérito Nacional de Saúde 2005/2006*. 2009: Lisbon.
4. Direcção Geral de Saúde, *Rede de Referenciação Hospitalar de Neurologia*. 2001.
5. Tribunal de Contas, *Auditoria de Acesso aos Cuidados de Saúde do SNS*. 2007.
6. *Law nr. 101/2006*. 6 June 2006. p. 3856-3865.
7. Unidade de Missão para os Cuidados Continuados Integrados, *Relatório de monitorização do desenvolvimento e da actividade da Rede Nacional de Cuidados Continuados Integrados (RNCCI)*. 2010.
8. OECD, *OECD Health Data 2010 - Frequently Requested Data*, OECDHealthData_FrequentlyRequestedData.xls, Editor. 2010.
9. Gerdtham, U. and B. Jönsson, *International comparisons of health expenditure: theory, data and econometric analysis.* Handbook of health economics, 2000. **1**: p. 11-53.
10. Pinto, C. and F. Aragão, *Health care rationing in Portugal: a retrospective analyses.* 2003.
11. Pereira, J., et al., *Health care reform and cost containment in Portugal.* Health Care and Cost Containment in the European Union. E. Mossialos and J. Le Grand. Aldershot, Aldgate, 1999.
12. *Law nr. 27/2002*. 8 Novermber 2002. p. 7150-7154.
13. Hospitais SA, *Relatório de Actividade do Ano 2003*. 2003.
14. Hospitais EPE, *Presentation for the International Monetary Fund - Health Systems Reform in Portugal*. 2003.
15. Ribeiro, J.M., *Reforma do sector público hospitalar: programa de empresarialização de 34 hospitais portugueses.* Revista Portuguesa de Saúde Pública, 2004. **Temático 4**: p. 65-77.
16. Urbano, J. and M. Bentes, *Definição da produção do hospital: os Grupos de Diagnósticos Homogéneos.* Revista Portuguesa de Saúde Pública, 1990. **8**(1): p. 49-60.
17. Fetter, R., et al., *Case mix definition by diagnosis-related groups.* Medical Care, 1980.
18. IGIF, *Cálculo dos doentes equivalentes e do Índice de Case-Mix*. 2007.
19. CAHSA, *Resultados de Avaliação dos Hospitais SA - Síntese dos Resultados*. 2006.
20. *Law nr. 93/2005*. 7 June 2005. p. 3636-3637.
21. Tribunal de Contas, *O Modelo de Financiamento e a Situação Económico-Financeira Global dos Hospitais do SEE*. 2006.
22. Devers, K., et al., *Implementing organized delivery systems: an integration scorecard.* Health Care Management Review, 1994. **19**(3): p. 7.
23. Santana, R. and C. Costa, *A integração vertical de cuidados de saúde: aspectos conceptuais e organizacionais.* Revista Portuguesa de Saúde Pública, 2008. **Temático 7**: p. 29-56.
24. CHLO EPE. *Organograma*. [cited 2010 6 May 2010].
25. CHLO EPE, *Relatório de Gestão e Contas*. 2008: Lisboa.
26. *Decree-Law nr. 233/2005*. 29 December 2005. p. 7323-7333.
27. *Portaria nº 146/98*. 1998. p. 920-924.

28. Victor, M. and A. Ropper, *Adams and Victor's Principles of Neurology*. 8th ed. 2001: McGraw-Hill New York.
29. Murray, C., A. Lopez, and B. Mundial, *The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020*. 1996: Harvard University Press Cambridge, MA.
30. Sartorius, N., *Rehabilitation and quality of life.* Hospital & community psychiatry, 1992. **43**(12): p. 1180.
31. Gwatkin, D., M. Guillot, and P. Heuveline, *The burden of disease among the global poor.* The Lancet, 1999. **354**(9178): p. 586-589.
32. Ministério da Saúde, *Plano Nacional de Saúde 2004-2010: mais saúde para todos*. 2004: Lisboa. p. 70.
33. Aarli, J.A., et al., *Neurological Disorders - Public Health Challenges*. 2006, World Health Organisation: Geneva.
34. Fauci, A., et al., *Harrison's Principles of Internal Medicine*. 17th ed. 2008: McGraw-Hill Medical.
35. Evangelista, P., *Ressonância Magnética no Centro Hospitalar de Lisboa Ocidental*, in *Jornal do Centro*. 2010, CHLO: Lisbon. p. 4-5.
36. Martin, J., *The integration of neurology, psychiatry, and neuroscience in the 21st century.* American Journal of Psychiatry, 2002. **159**(5): p. 695-704.
37. Serviço de Neurologia, *Relatório de Actividades 2009 e Plano de Actividades 2010*. Nov. 2009, Hospital de Egas Moniz: Lisbon.
38. Serviço de Neurologia, *Resumo do Plano de Acção 2010.* 2010: p. 1.
39. Serviço de Neurologia, *Plano de Actividades, Triénio 2009-2011*. 2008, CHLO EPE,: Lisbon.
40. INFARMED, *Estatística do Medicamento 2008*. 2008.
41. Cabral, P., *Cirurgia de Epilepsia no Centro Hospitalar de Lisboa Ocidental*, in *Jornal do Centro*. 2010, CHLO: Lisbon. p. 8-9.
42. Ham, C., *Priority setting in health care: learning from international experience.* Health Policy, 1997. **42**(1): p. 49-66.
43. Kleinmuntz, D.N., *Resource Allocation Decisions*, in *Advances in decision analysis: from foundations to applications*. 2007, Cambridge University Press: Cambridge, UK.
44. Drummond, M., et al., *Methods for the economic evaluation of health care programmes*. 3rd ed. 2005: Oxford University Press, USA.
45. Weinstein, M. and W. Stason, *Foundations of cost-effectiveness analysis for health and medical practices.* New England Journal of Medicine, 1977. **296**(13): p. 716.
46. Briggs, A., M. Schulper, and M. Buxton, *A critical review of the use of sensitivity analysis in the economic evaluation of health care programmnes.*, Health Economists' Study Group and F.o.P.H. Medicine, Editors. 1993: York.
47. Robinson, R., *Cost-utility analysis.* British Medical Journal, 1993. **307**(6908): p. 859.
48. Torrance, G., M. Boyle, and P. Horwood, *Application of multi-attribute utility theory to measure social preferences for health states.* Operations Research, 1982. **30**(6): p. 1043-1069.
49. Gold, M., D. Stevenson, and D. Fryback, *HALYs and QALYs and DALY S, Oh My: Similarities and Differences in Summary Measures of Population Health.* Annual Review of Public Health, 2002. **23**(1): p. 115-134.

50. Mitton, C. and C. Donaldson, *Twenty-five years of programme budgeting and marginal analysis in the health sector, 1974-1999.* Journal of Health Services Research & Policy, 2001. **6**(4): p. 239.
51. Mitton, C. and C. Donaldson, *Setting priorities in Canadian regional health authorities: a survey of key decision makers.* Health Policy, 2002. **60**(1): p. 39-58.
52. Wordsworth, S., C. Donaldson, and A. Scott, *Can we afford the NHS?* 1996.
53. Mitton, C., et al., *Priority setting in health authorities: a novel approach to a historical activity.* Social Science & Medicine, 2003. **57**(9): p. 1653-1663.
54. Mitton, C. and C. Donaldson, *Health care priority setting: principles, practice and challenges.* Cost effectiveness and resource allocation, 2004. **2**(1): p. 3.
55. Baltussen, R. and L. Niessen, *Priority setting of health interventions: the need for multi-criteria decision analysis.* Cost effectiveness and resource allocation, 2006. **4**(1): p. 14.
56. Boyd, S. and L. Vandenberghe, *Convex optimization*. 2004: Cambridge Univ Pr.
57. Ozcan, Y., *Quantitative methods in health care management: techniques and applications*. 2009: Jossey-Bass.
58. Ehrgott, M., *Multicriteria optimization*. 2005: Springer Verlag.
59. Tamiz, M., D. Jones, and C. Romero, *Goal programming for decision making: An overview of the current state-of-the-art.* European Journal of Operational Research, 1998. **111**(3): p. 569-581.
60. Kwak, N. and C. Lee, *A linear goal programming model for human resource allocation in a health-care organization.* Journal of Medical Systems, 1997. **21**(3): p. 129-140.
61. Blake, J. and M. Carter, *A goal programming approach to strategic resource allocation in acute care hospitals.* European Journal of Operational Research, 2002. **140**(3): p. 541-561.
62. Pinedo, M., *Scheduling: theory, algorithms, and systems*. 2008: Springer Verlag.
63. Tkindt, V. and J. Billaut, *Multicriteria scheduling: theory, models and algorithms*. 2006: Springer Verlag.
64. Vermeulen, I., et al., *Adaptive resource allocation for efficient patient scheduling.* Arificial Intelligence in Medicine, 2009. **46**(1): p. 67-80.
65. Phillips, L., *Decision Analysis in 2005.* OR47 Keynotes/Tutorials, 2005.
66. Keeney, R. and H. Raiffa, *Decisions with multiple objectives: preferences and value tradeoffs. 1976.* New York: Wesley, 1976.
67. Phillips, L., *Gaining corporate commitment to change.* 1992.
68. Bana e Costa, C., *The use of multi-criteria decision analysis to support the search for less conflicting policy options in a multi-actor context: case study.* Journal of Multi-Criteria Decision Analysis, 2001. **10**(2): p. 111-125.
69. Phillips, L. and C. Bana e Costa, *Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing.* Annals of Operations Research, 2007. **154**(1): p. 51-68.
70. Keeney, R., *Value-focused thinking: A path to creative decisionmaking*. 1992: Harvard Univ Pr.
71. Von Winterfeldt, D. and G. Fischer, *Multi-Attribute Utility Theory: Models and Assessment Procedures.* 1975: p. 47.
72. Belton, V. and T. Stewart, *Multiple criteria decision analysis: an integrated approach. 2002*, Kluwer, Boston.

73. Keefer, D., C. Kirkwood, and J. Corner, *Perspective on decision analysis applications, 1990–2001*. Decision analysis, 2004. **1**(1): p. 4-22.
74. Lourenco, J., B. e Costa, and A. Morton. *Software packages for multi-criteria resource allocation*. 2008.
75. Kleinmuntz, C. and D. Kleinmuntz, *A strategic approach to allocating capital in healthcare organizations.* Healthcare financial management: journal of the Healthcare Financial Management Association, 1999. **53**(4): p. 52.
76. Jehu-Appiah, C., et al., *Balancing equity and efficiency in health priorities in Ghana: the use of multicriteria decision analysis.* Value in Health, 2008. **11**(7): p. 1081-1087.
77. Bots, P. and J. Hulshof, *Designing multi-criteria decision analysis processes for priority setting in health policy.* Journal of Multi-Criteria Decision Analysis, 2000. **9**(1-3): p. 56-75.
78. Rosenhead, J., *What's the problem? An introduction to problem structuring methods.* Interfaces, 1996. **26**(6): p. 117-131.
79. Mingers, J. and J. Rosenhead, *Problem structuring methods in action.* European Journal of Operational Research, 2004. **152**(3): p. 530-554.
80. Keeney, R., *Value-focused thinking: Identifying decision opportunities and creating alternatives.* European Journal of Operational Research, 1996. **92**(3): p. 537-549.
81. Bana e Costa, C. and E. Beinat, *Model-structuring in public decision-aiding.* 2005.
82. Bana e Costa, C., *Facilitating bid evaluation in public call for tenders: a socio-technical approach.* Omega, 2002. **30**(3): p. 227-242.
83. Bana e Costa, C., et al., *Development of reusable bid evaluation models for the Portugese Electric Transmission Company.* Decision Analysis, 2008. **5**(1): p. 22-42.
84. Stevens, S., *On the theory of scales of measurement.* Science, 1946. **103**(2684): p. 677-680.
85. Von Winterfeldt, D. and W. Edwards, *Decision analysis and behavioral research*. 1986: Cambridge University Press Cambridge.
86. Bana e Costa, C., J.-M. Vansnick, and J.-C. Corte, *MACBETH, Working Paper LSE OR 03.56.* London School of Economics and Political Science, 2003.
87. Lourenco, J., *Modelo aditivo hierárquico: exemplos de métodos de ponderação e problemas associados, Working Paper 12/2002.* Centro de Estudos de Gestão - Instituto Superior Técnico, 2002.
88. Thomaz, J., *O apoio à tomada de decisão na avaliação do desempenho de pessoas: contributos para o processo de decisão militar em tempo de paz*. 2005, Instituto Superior Técnico: Lisbon.
89. Von Nitzsch, R. and M. Weber, *The effect of attribute ranges on weights in multiattribute utility measurements.* Management Science, 1993. **39**(8): p. 937-943.
90. Phillips, L., *A theory of requisite decision models.* Acta psychologica, 1984. **56**(1-3): p. 29-48.
91. Lourenço, J. and C. Bana e Costa, *PROBE–A multicriteria decision support system for portfolio robustness evaluation.* London School of Economics and Political Science, Working Paper LSE OR 09.108, 2009.
92. Clemen, R. and J. Smith, *On the choice of baselines in multiattribute portfolio analysis: A cautionary note.* Decision Analysis, 2009. **6**(4): p. 256.
93. Bana e Costa, C., *Readings in multiple criteria decision aid*. 1990: Springer-Verlag.

Appendix A

Data for generating of alternatives

	External Consultation							Ward	IC	Day Hosp.	ED	ECHO	EEG	EMG	Video Analysis	Meetings	Management	Learn Tech.	Total (week)
	General	Cognitive	Movement	Demyel	Epilepsy	Sleep	NMusc												
MV	11			3				8		1						3	13		39
IC	7	4,5						2	4,5	1	12					4			35
JV	4		4	4				8,5		1	12					1,5			35
MVB	10							5,5			15	3,5				1			35
NC	2				4			5			12				12	3			38
SC	9,5							7		1	12	6,5				4			40
PB	12,5		4			4,5			5	1	12					2			41
PA	4		4					13,5		1	12					0,5			35
LA	15	4,5							3,5	1	12					4			40
RP	7,5				4			8,5			12				6	2			40
EM							10							7					17
DP					6								20			2			28
JM	6						6	8			12					2		6	40
GM	8							12			12					3		5	40
TL	8							18			12					2			40
HD								26			12					2			40
Total	***104,5***	***9***	***12***	***7***	***14***	***4,5***	***16***	***122***	***13***	***7***	***159***	***10***	***20***	***7***	***18***	***36***	***13***	***11***	

Table A1. Distribution of weekly working time of neurologists. Cells filled in blue correspond to graduate physicians and grey-filled cells represent interns.

Table A2. Specification of possible activities, minimum and maximum services, for each neurologist. The values of monthly working hours have already been subtracted the time spent on ED shifts.

	Working Hours	Possible activities	Minimum Services	Maximum Services
MV	156	1, 4, 8, 9, 10, 11, 14, 16, 18, 19	(16, 24)	(16, 48), (17, 12)
IC	92	1, 6, 8, 9, 10, 11, 14, 16, 17, 18, 19		(16,4) (17, 12)
JV	92	1, 4, 5, 8, 9, 10, 11, 14, 16, 17, 18, 19	(16, 4)	(16, 12) (17, 12)
MVB	80	1, 8, 9, 10, 11, 14, 16, 17, 18, 19, 20	(16, 4)	(16, 8) (17, 12)
NC	104	1, 2, 8, 9, 10, 11, 14, 15, 16, 18, 19	(16, 4)	(16, 12) (17, 16)
SC	112	1, 8, 9, 10, 11, 14, 16, 17, 18, 19, 20		(16 , 8) (17, 12)
PB	116	1, 3, 5, 8, 9, 10, 11, 14, 16, 17, 18, 19		(16, 12) (17, 8)
PA	92	1, 5, 8, 9, 10, 11, 14, 16, 17, 18, 19		(16, 4) (17, 12)
LA	112	1, 6, 8, 9, 10, 11, 14, 16, 17, 18, 19		(16, 4) (17, 12)
RP	112	1, 2, 8, 9, 10, 11, 14, 16, 17, 15, 18, 19		(16, 4) (17, 12)
EM	68	1, 7, 8, 10, 11, 13, 14, 16, 17, 18, 19		(16, 4) (17, 12)
DP	112	2, 8, 11, 12, 14, 16, 17, 18, 19		(16, 8) (17, 12)
JM	112	1, 7, 8, 9, 10, 11, 14, 16, 17, 18, 19		(16, 4) (17, 12)
GM	112	1, 8, 9, 10, 11, 14, 16, 17, 18, 19		(16, 4) (17, 12)
TL	112	1, 8, 10, 11, 14, 16, 17, 18, 19		(16, 4) (17, 12)
HD	112	10, 14, 16, 17, 18, 19		(17, 12)

Appendix B

MATLAB algorithm for the generation of alternatives

Algorithm generate options (WT, init, S, delta, M, SMin, SMax)

```
% WT - monthly working hours
% init - initial allocation profile
% S - block dimension
% Q - possible activities
% M - total nr. of possible activities
% SMin - minimum services
% SMax - maximum services

%Generate elementary vectors for combination
count = 1;
vecs = cell(size(init,1),1);
for a = 1:size(init,1)
    aux1 = [];
    for b = -delta:1:delta
        if init(a,2) + b*S >= 0
            aux1 = [aux1 init(a,2)+b*S];
        end
    end
    vecs{count} = aux1;
    count = count+1;
end

% Generate combinations of the entries in elementary vectors
aux_comb = allcomb(vecs{1:end,:});

% build standardised vector of options
options = zeros(size(aux_comb,1),M);

for c = 1:size(init,1)
    options(:,init(c,1)) = aux_comb(:,c);
end

% Select options
optionsf = [];

for d = 1:size(options,1)
if sum(options(d,:),2) <= WT+1 && sum(options(d,:),2) >= WT-1
optionsf = [optionsf; options(d,:)];
end
end

% Discard options based on constraints (sm & sM)

for k = 1:size(SMin,1)
    aux2 = find(optionsf(:,SMin(k,1)) < (SMin(k,2)));
    if ~isempty(aux2)
        optionsf(aux2,: ) = [];
    end
end

for l = 1:size(SMax,1)
    aux3 = find(optionsf(:,SMax(l,1))> (SMax(l,2)));
    if ~isempty(aux3)
        optionsf(aux3,:) = [];
    end
end
```