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. Lastly, the analysis of efficient allocation profiles was performed in PROBE.

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 the context of analysis.

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

I. INTRODUCTION

Health care provision in developed countries has been experiencing an increasing demand, which associated with the pressures for cost containment, has given rise to scarcity of financial and human resources. This scarcity imposes the need for making decisions on how to deploy the available resources in order to maximise the benefit outcome. Physicians working within a clinical department of a certain medical specialty have to divide their time by the different activities. This allocation is often made by periodic scheduling procedures and requires the manager to make decisions about the service levels for different activities. Such distribution of working time is often characterised by multiple objectives, and these may not be properly considered at the time of taking decisions. Furthermore, when the number of physicians is insufficient to cover all the existing demand for the different services of the department, some type of prioritisation must occur, so as to establish which activities are to be carried out at the cost of others.

Despite the recurrence of scarcity of human resources, there seems to be a lack of available methodologies to inform decision makers (DM) on how to deploy human resources in a context that demands accounting for multiple objectives. The allocation of human resources has been approached in the scope of operations management. However, a systematic, progressively constructed method for assisting the allocation of human resources may, in fact, be of use.

The aim of this thesis is to develop a methodology to help allocating the working time of physicians working in the Neurology department of the WLHC, so as to highlight the activities that may represent a greater contribution to the benefit outcome and potentially improve the utilisation of human resources.

II. CONTEXT AND CASE STUDY

A. The NHS and the recent reforms

The Neurology department operates within the WLHC, a public hospital centre integrated in the National Health Service. Patients come from primary care centres or attend the emergency department (ED), and then flow to and from external consultations and inpatient care. The activities integrating the operation of a clinical department entail complex relationships, mainly related to the multiplicity of tasks that are carried out within the hospital and also within each medical specialty. In a situation of insufficient resources to perform all the desired activities, the complexity of the context of analysis becomes a major obstacle in the process of prioritising activities.

The Portuguese NHS has undergone significant restructuring, with special emphasis on recent reforms. Most of these have had implications in the WLHC, regarding modifications in the management model. The increase in health expenditure [1] has raised questions regarding the under-utilisation of resources, as the issue does not lie in the level of expenditure, but in the general waste of resources [2]. This issue has lead to these recent reforms, from which the most relevant for the present case study are presented in Table 1.

Table 1. Policy measures most relevant to the hospital centre [3].

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

The transformation of hospitals into public limited companies (PLC), in 2002 [4], and later into public entrepreneurial entities (EPE) [5] constituted the first approach to implement a corporative management model in the public hospitals of the NHS. The new financing model is a central feature of the new hospital statute and implements a formal division between purchaser (Government) and provider (hospital), establishing individual labour contracts that define the allocation of funds. These contracts define specific objectives that constitute targets to be achieved by the department's operation, in order for the hospitals to receive funds. The financing model establishes incentive policies and penalises the providers in case the targets are not achieved [6].

The reforms also involved the creation of hospital centres, with merger of management teams. Such measure made use of the geographical proximity and high level of specialisation of hospitals, eliminating supply redundancy and taking advantage of the complementarity of specialised clinical departments present in the different hospitals [7].

B. The Neurology Department at the WLHC

The WLHC integrates three hospitals, with most of the facilities of the Neurology department being located in *Hospital de Egas Moniz* (HEM), except for the ED located in *Hospital de São Francisco Xavier* (HSFX). These facilities comprise the ward, consultation rooms, EEG and EMG laboratories and a day hospital division.

The multiple strategic objectives stated by the department are a central issue, and are mainly related to the provision of quality care services, achievement of the contracted services and promotion of scientific and educational activities [8]. It is important to observe that the achievement of these objectives is difficult to assess, and, furthermore, the objectives may also be conflicting, since, for instance, fostering an increase in production may compromise the quality of services.

The development of this work considered 16 neurologists working in the department, of which 4 were interns. In recent years, the number of physicians has been suffering a progressive reduction, which has obviously had implications on the department's operation. It is also necessary to account for the specificities of each physician. Although these physicians work in the same medical specialty, it is important to emphasise the fact that, as in many 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 qualifications of each physician, raising restrictions in the assignment of physicians to activities. The areas in which physician specialisation has most influence in the allocation of resources regard mostly the differentiated consultations and the performance of EEG, EMG and echo-doppler exams. Therefore, physician resources are heterogeneous and care provision makes use of complementarity and specificity of medical knowledge amongst physicians.

C. Care Services in the Neurology department

Provision of care to patients in the Neurology department is organised in different activities or functional units, as described in the Annual Report of Activities [9]. Firstly, inpatient care occurs in the ward, integrating also the training of interns. The operational indicators of this service regard, for instance, the number of discharged patients. The main problem resides on the lack of time for providing adequate education to interns, which is not possible to assess in the operational indicators.

External consultations (EC) also present a significant volume of services and are organised in a system of differentiated consultations (DC), each one referring to a specific group of pathologies. The types of consultations are *General*, *Epilepsy*, *Sleep*, *Demyelinating*, *Movement*, *Cognitive and Neuromuscular*. First and follow-up EC are distinguished for administrative purpose, as their production is considered separately and the percentage of first EC is also established in labour contracts, integrating the incentive policy.

Neurologists are also requested to provide care to inpatients of other medical specialties of the hospital centre, whose wards may be located outside the HEM. Although this service is not encompassed in labour contracts, it is an essential factor of the quality of care provided to patients of the whole hospital centre. If possible, internal consultations (IC) are performed in HSFX while physicians are working in ED shifts. However, the remaining hospitals (*Santa Cruz*), IC require physicians to attend inpatients in their wards, which may become rather time-consuming. As for ED shifts, these consist in 12 weekly hours, and may also include assistance to patients with cerebrovascular attacks (CVA) in the CVA unit.

The laboratories perform EEG and EMG exams, whose production is monitored. The latter have been undergoing a very significant scarcity of human resources, leading to a decrease in production and a consequent inability to respond to the existing demand.

Scientific activities are a common practice in Neurology department and are developed either by interns or attendants. These activities are integrated and articulated with other services. As for medical education, most of the performed activities somehow contribute to these learning processes, with scientific meetings presenting a significant contribution. In the case of interns, inpatient care is perhaps the most relevant to their training.

D. The Decision Problem

The Neurology department has stated multiple and varied objectives, which constitute the guidelines for the department's operation. Although there are specific operational targets to achieve, it is desired for care to be provided with quality. Moreover, scientific and educational activities demand for close articulation with other services. On the other hand, the multiplicity of care services adds complexity to the assignment of physicians to activities, whilst accounting for all the department's objectives. Additionally, physicians have specific qualifications that introduce constraints in their distribution, and are not in sufficient number to ensure all the required activities. Hence, the decisions of assigning neurologists to activities constitute resource allocation problems in a context of high internal complexity of both the delivered services and specific qualifications of physicians.

III. LITERATURE REVIEW

A bibliographic review was conducted in order to identify methods for addressing resource allocation problems in health care. For this purpose, online databases were consulted using queries as "*resource allocation in hospitals*" and "*physician scheduling*". The relevant methods are presented, whereas some methods have been excluded, such as non-economic methodologies of allocation based on history and cost of illness.

A. Methods based on economic principles

Economic evaluation is defined as "*the comparative analysis of alternative courses of action in terms of both their costs and consequences*" [10]. The costs refer to the resources and the consequences regard the outcomes resulting from a given action. Different types of economic evaluation include, for instance, cost-effectiveness analysis and cost-utility analysis. These techniques vary in the mode of appraising both the costs and the outcomes of allocation alternatives, and aim to minimise cost while maximising benefit [11]. However, methods based on economic evaluation lack features required to properly address the present resource allocation problem and, thus, do not provide an adequate solution for the Neurology department.

Alternatively, program budgeting and marginal analysis (PBMA) considers the concepts of opportunity cost and the margin [12]. In brief terms, the process involves the definition of criteria according to which allocation options will be evaluated by and advisory panel. The options are then rated according to each criterion and the scores are multiplied by the respective criteria weights. These scores are analysed and recommendations are elaborated regarding the prioritisation of allocation options. Although some features of PBMA may be of use for the allocation of neurologists, namely the contemplation of multiple criteria, the method does not provide guidelines on the elicitation of criteria, scoring of options and determination of weights, which may introduce biases in the model. Hence, despite the valid key principles, PBMA does not respond to the allocation of physicians.

B. Optimisation Methods

In the field of optimisation, the complexity of resource allocation problems is 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 computational capacities to process the required amount of information [13]. The principle consists in minimising or maximising an objective function, subject to a set of constraints defined in the scope of analysis. In health care resource allocation, objective functions are often expressed as a linear combination of the decision variables, and the optimal solution may be determined by means of linear programming [14]. In multicriteria optimisation (MCO), the objective function may be expressed as a linear combination of such functions deriving from conflicting objectives, using weighting coefficients as scaling factors [15]. The notion of maximising the global objective function may be considered adequate to handle the multiple objectives of the Neurology department, although the pure mathematical formulation may not be viable in this context. Goal programming, on the other hand, presents a method in the field of multicriteria optimisation whose principles lie in the definition of objective functions by means of goals to be achieved. The objective functions are modelled in such a way that the deviations from the respective target values penalise the overall objective function [16].

The MCO methodology might be suitable for the present case study in some of its basic principles, as it is able to accommodate multiple objectives of different nature, since the objective functions are scalarised into a single function. However, the procedures for defining objective functions and scaling coefficients require proper consideration, given the intangible nature of some criteria such as those related to scientific activities, whose mathematical formulation may be infeasible. Hence, despite the validity of the central principles of MCO, it presents an analytic approach that would be more adequate in contexts in which mathematical modelling is able capture all the relevant features influencing the resource allocation process.

C. Scheduling Methods

Briefly, scheduling regards the 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. These methods have been used in different contexts, such as manufacturing and services [17]. Scheduling also requires modelling the context in mathematical terms, though in a perspective different from that of optimisation. The mathematical framework derives from operations management, requiring parameters such as the duration of activities and also the start and finishing times. These methods yield the sequence of processes that optimise an objective function.

Although the scheduling approach is recurrently used in addressing resource allocation problems, including in health care contexts, these determine both the distribution of resources amongst different areas and the sequence in which this distribution occurs, which falls off the scope of the case study. The activities that are carried out within the Neurology department require a certain level of flexibility in terms of their sequence, and thus it would not be worth relying on scheduling methods.

D. Multicriteria Decision Analysis

The methods in the scope of multicriteria decision analysis (MCDA) address problems characterised by multiple objectives, aiming to identify evaluation criteria that enable the assessment of the contribution of an allocation alternative to the organisation's objectives [18]. Each alternative thus consists of a possible decision to be taken by the DM. Furthermore, the DM is typically not able to attain full understanding of all the details of all alternatives, as their perception capability has natural limitations [19]. In this sense, MCDA comprises a methodology for the evaluation of alternatives, assigning utility values to the alternatives in the evaluation criteria. The purpose of creating such value measures is to express attributes of criteria of different nature in a common unit that allows comparison and considering trade-offs [20].

MCDA provides a useful approach for aiding the DM allocating physicians' working time in the Neurology department, since it allows the consideration of multiple objectives in a constructive process, even if these are conflicting and of different nature. Furthermore, it provides procedures for building value functions and determining criteria weights. Nevertheless, the allocation of neurologists still requires a methodology to be developed, especially concerning the creation of allocation alternatives according to the context of analysis and the characteristics of the human resources.

IV. METHODOLOGICAL FRAMEWORK

Since the methods available in the literature did not meet all the requirements to address the allocation of physicians, a methodology was developed in order to fill such gap. The approach employed different methods conjointly. While based on sound theoretical foundations, the methodology may be considered in the frontier of MCDA and operations management, as it makes use of the structuring and evaluation methods from MCDA, by means of a socio-technical approach, while considering discrete events (such as consultations) in structuring physicians and activities, and also discretising resources for the purpose of generating alternatives.

Firstly, it was necessary to characterise the context and identify the scope of action, gathering information on the available human resources and structuring a list of activities to be considered in the analysis. It was established that alternatives consist, for each physician, in combinations of time assigned to the different activities. These alternatives are generated by means of an algorithm and evaluated according to the multicriteria evaluation model constructed for the purpose.

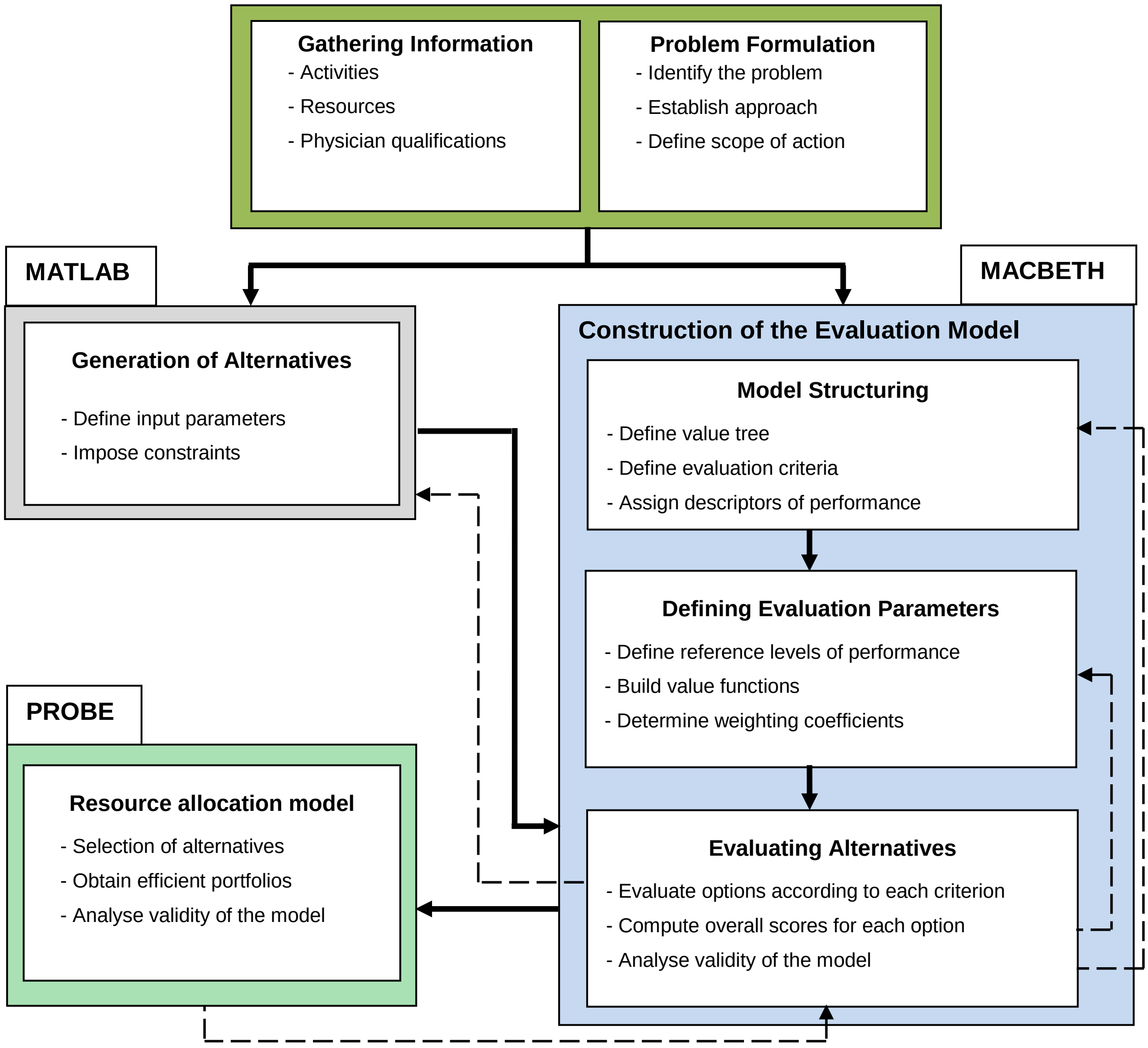

Figure 1. Conceptual Framework of the proposed methodology.

A. Mathematical Formulation of the Model

The central objective of the methodology is to maximise the benefit outcome, which corresponds to maximising the benefit yielded by the set of alternatives selected, selecting only one alternative 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 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:

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

$$\textit{subject to}: \qquad \sum_{j=1}^{m} c_j l_j \leq B \qquad (2)$$

$$\sum_{i=1}^{n} w_i = 1 \qquad (3)$$

$$l_j \in \{0,1\} \qquad (4)$$

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 correspond to the total amount of working hours of physicians. The maximisation of (1) represents the knapsack problem.

B. Generation of Alternatives

As it would not be possible to appraise the alternatives based solely on the allocation of a particular physician, it was settled that of alternative consist of a combination of values of a physician's working time assigned to the possible activities. Alternatives are generated by means of an algorithm implemented in MATLAB, which starts off from the initial allocation profile and manipulates the time assigned to each activity. The combinations are obtained by discrete variations of the amount of time assigned to each activity, specifying both the increment of variation and the number of incremental variations. The program inputs require the definition of the possible activities for the physician. Additionally, it is possible to specify further constraints on the generated alternatives, regarding minimum and maximum values of time allocated to specific activities. The output is of the form:

$$\Theta = \begin{bmatrix} T_{1,1} & \cdots & T_{1,M} \\ \vdots & \ddots & \vdots \\ T_{K,1} & \cdots & T_{K,M} \end{bmatrix} \tag{5}$$

The 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.

C. Model structuring

The structuring of the multicriteria model consisted of an interactive learning process between the DM and the facilitator (the author), in which a top-down approach was mostly followed. Firstly, it is necessary to focus on the department's objectives [21], aiming to identify the main areas of concern and then explore these areas in order to define specific evaluation criteria. A mix of top-down and bottom-up approaches is more likely to ease the process of defining evaluation criteria[22]. In order to provide a conceptual structure of the set of evaluation criteria, these are grouped in a value tree.

One of the requirements of evaluation criteria is the possibility to assign a descriptor of performance (DOP), which 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 [23]. These measures may be quantitative (continuous or discrete) or qualitative, depending on the nature of the evaluation criterion. Furthermore, evaluation criteria must respect *ordinal* and *cardinal* preferential independence.

D. Construction of 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 DOP X_i. Such functions should traduce the DM's preferences and allow the assessment of the local impact of alternatives, which will then be aggregated in the additive model, so as to reach an overall score. Firstly, two reference levels of intrinsic value are defined, designated as 'good' and 'neutral' levels, which are assigned 100 and 0 points, respectively.

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 [24]. Implemented in the M-MACBETH software, this method avoids the difficulties of some decision makers to elicit quantitative judgments. The determination of a cardinal value function is performed by filling a judgment matrix for each evaluation criterion. Each entry of the matrix corresponds to a judgment about the difference of attractiveness between pairs of performance levels, elicited according to a semantic scale whose levels express intensity of preference. If inconsistent judgments are detected, the software suggests required modifications.

After filling the judgment matrix, the software computes a quantitative value function from the qualitative judgments. The DM must validate the resulting value functions, suggesting modifications if necessary.

E. Weighting Evaluation Criteria

The weighting coefficients represent the scaling constants that will allow the aggregation of the local scores of alternatives in the additive model. The MACBETH methodology for determining criteria weights also involves filling a judgment matrix regarding differences of attractiveness of fictitious alternatives, each one being neutral in all criteria except one (in which has good performance). The judgments use the same qualitative scale of the procedure for building value functions.

The filling of the judgment matrix becomes a complex task in the presence of numerous criteria. In this sense, it was decided to adapt the procedure for this work. This adaptation consisted in eliciting judgments on the attractiveness of the 'neutral'-'good' swings in all criteria, then differentiating equivalent judgments. This procedure can be considered as a qualitative swing weighting. At the end of the procedure, M-MACBETH yields a scale of weights that also has to be interpreted, adjusted in case of need and validated.

F. Evaluation of Alternatives using PDA

After having constructed the evaluation model, it was necessary to perform its implementation in a system that enabled a systematised evaluation of the high number of generated alternatives. For this purpose, the model was implemented in Excel, where the generated alternatives are also recorded. Portfolio Decision Analysis (PDA) allows the analysis of combinations of alternatives for determining efficient solutions, that should be subject of a critical analysis with the DM. In this methodology, analysis of portfolios comprised the selection of relevant alternatives and the definition of constraints on the collective allocation of physicians, in order to obtain efficient combinations of alternatives, identifying potential benefit improvements.

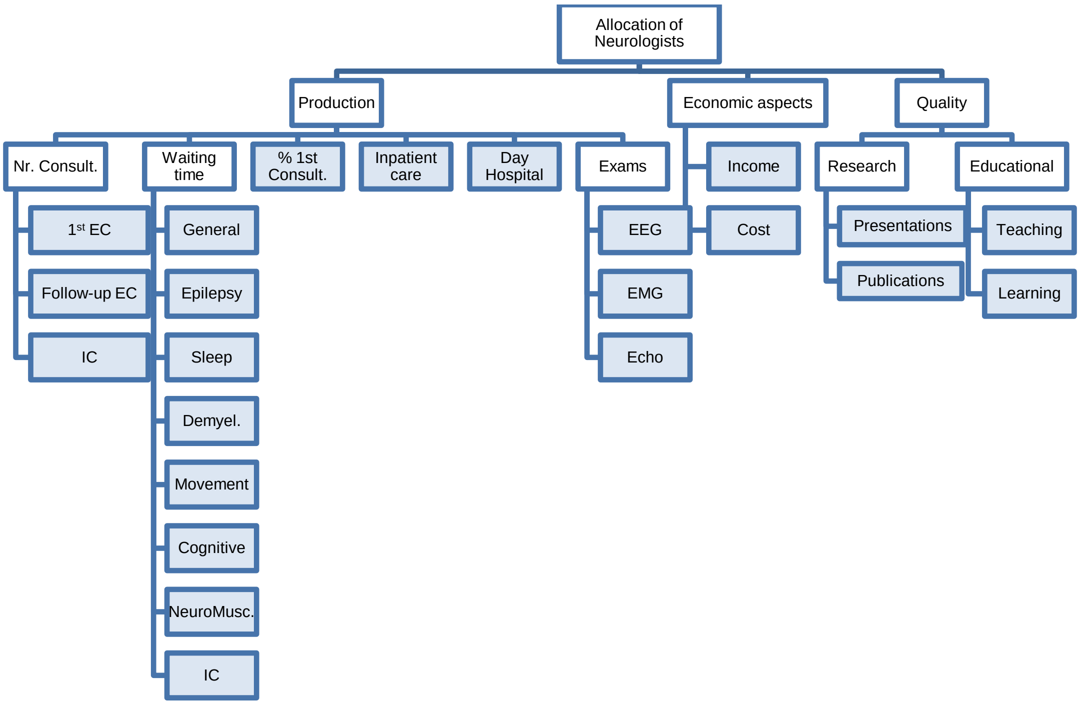

Figure 2. Representation of the value Tree. The blue-shadowed nodes represent evaluation criteria.

In order to perform such analysis, the methodology made use of the PROBE decision support system, for the computation of efficient frontiers and portfolio analysis [25].

V. APPLICATION OF THE METHODOLOGY

In the context of the Neurology department, the initial structuring phase established 20 activities to be considered in the allocation of physicians. The alternatives were generated for each physician, with variations of 4 hours in the time allocated to each activity and a maximum of 2 variations, thus considering maximum variations of 8 hours. The time span of alternatives was set to 1 month.

Table 2. List of considered activities.

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

The initial phase of structuring the evaluation criteria showed the existence of three main areas of concern: *Production*, *Economic Aspects* and *Quality*, which were further explored. However, the development of the value tree was not an easy task, given the complexity of the department and the relationships between activities. It was necessary to differentiate first and follow-up EC, as well as to specify the waiting time for each type of EC. The economic aspects regarded the income from the payment methods and the costs with exams requested to external entities, as the DM decided to leave out other costs that did not influence the allocation of physicians to the different activities. Lastly, the *Quality* branch concerned scientific and educational activities. The full structure of the value tree is represented in Figure 2.

After defining the value tree, it was necessary to define the DOP. Given the nature of the elicited criteria, all of the DOP were quantitative, as it was necessary to establish a relation of cause-effect between the time allocated to an activity and the resulting performance in related evaluation criteria. Some of the DOP required the estimation of parameters, such as the patient demand for EC and the duration of laboratory exams. On the other hand, the definition of DOP in the third branch required considering the contribution of all activities to scientific and educational purposes. It was estimated, for each activity, the contribution to each criterion of the *Quality* branch.

The construction of value functions was performed by means of the MACBETH judgments matrix. Given the high number of activities, the DM decided to adopt an equivalent value function to all the evaluation criteria, establishing equally spaced levels of performance and assigning the respective scores to those references of performance. Despite the generalisation, the value functions were validated. As for the process of weighting criteria, the qualitative swing weighting procedure yielded the scaling constants that were validated and used for model implementation in Excel.

VI. MODEL RESULTS

The appraisal of alternatives was performed according to the developed model, whose application was made by means of 3 hypothetical scenarios. Each scenario presented a plausible situation for the DM and was characterised by a set of constraints regarding the collective allocation of physicians. The following scenarios were 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.

For each scenario, the necessary constraints were defined. Before performing the portfolio analysis in PROBE, a set of alternatives to perform the desired analyses were selected. This set should enable, for each scenario, the selection of an alternative for each physician. Four alternatives were selected: best alternative; best alternative without scientific activities; best alternative with scientific activities; best alternative with at least 8 hours of meetings.

The selected alternatives were introduced in PROBE, with their respective costs and scores. Given the requirement to operate on ratio scales in portfolio analysis, the scores of alternatives were considered as the incremental benefits in respect to the *status quo* [26].

For each scenario, the efficient frontier was computed, and the alternatives contained in the resulting efficient portfolios were analysed in terms of the variations in time distribution amongst the activities.

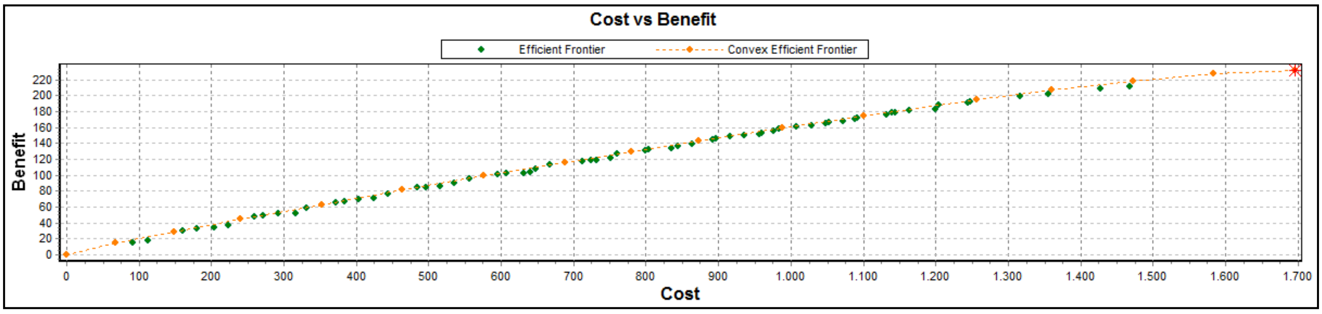

Figure 3. Efficient frontier obtained in PROBE for scenario S1.

	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

Table 3. Portfolio obtained for scenario S2 (physicians in rows, activities in columns). Red and green numbers indicate decrease or increase in the time allocated for an activity, respectively.

A. Scenario S1

The first analysis consisted of 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 benefit). For all physicians, the efficient portfolio indicated a positive incremental benefit, which suggested that redistributing physician working time may yield more benefit. The resulting portfolio showed an increase in the number of hours dedicated to scientific activities, and a reduction in the time allocated to consultations, especially those for follow-up. Results also indicated reductions in physician meetings. Several alternatives suggested the allocation of working hours to IC.

These tendencies observed in the results suggest that scientific activities may have contributed significantly to increase the incremental benefit of alternatives. However, the analysis of results must keep in mind that the benefits were calculated, for each physician, considering other physicians at their initial allocation profiles. In this sense, imposing additional constraints on the global distribution of physicians may avoid redundancy of allocation profiles.

B. Scenario S2

In scenario S2, scientific activity was restricted to 4 interns and 2 graduate neurologists. The objective was, thus, to find the most efficient combination of alternatives under these constraints. In PROBE, the modelling of this scenario was enabled by the possibility to define project areas and impose constraints on these areas.

Both the number of efficient portfolios and the incremental benefit of alternatives have decreased with the constraints. The obtained portfolio showed, once more, the tendency to reduce the number of hours allocated to follow-up consultations. The alternatives also indicate reductions in the number of day hospital sessions and in physician meetings, promoting the allocation of time to IC and especially to inpatient care. It was possible to observe the adaptation of the model results to the imposed constraints.

C. Scenario S3

As the DM had shown great interest in promoting meetings, given their contribution to the learning process of physicians, the third scenario imposed a minimum of 8 hours of meetings. Some of the best alternatives obtained for physicians in S1 were preserved in this scenario, since these already included the 8 required hours of meetings, whilst other were modified. As a result, the benefit outcome of alternatives did not decrease as much as in the previous scenario. In fact, the portfolio is not much different than that of S1, which may indicate that most of the best alternatives already comprised physician meetings.

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 performed as combining multiple constraints regarding different services and physicians.

VII. 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 of such method. A critical analysis on the results may provide insight on the potentialities of such methodology, as well as on existing flaws and possible improvements.

The possibility to accommodate multiple and conflicting objectives in a single model constitutes one of the main advantages. The structuring process is decomposed into simpler parts that helped the DM handling and overcoming the great complexity of the decision problem. The procedures for building value functions and determining weights provided the required theoretical basis and enabled a constructive and interactive approach. PDA, in turn, allowed a further exploration of the results besides the simple ranking of allocation alternatives by decreasing order. In effect, the possibility to specify constraints at the portfolio level, limiting the number of physicians dedicated to an activity or imposing minimum hours dedicated to activities extends the scope of analysis and confers adaptability to the model.

The method developed for generating alternatives presents an original approach. Firstly, the systematisation of such process eases the creation of alternatives, which in this case would be difficult to conceive. Secondly, the conception of the algorithm's inputs allows the manipulation of multiple parameters and, more importantly, makes possible to accommodate additional activities that have not been considered in the applications. For instance, in case the CVA unit gains momentum, it would be useful to also integrate this activity in the generated alternatives.

Nevertheless, the developed methodology has fragilities that may constitute sources of imprecision and bias. The decision to leave out some activities, the most important being ED, may have caused the model to neglect potential benefits of such activities. It would be useful, thus, to extend the scope of analysis to more activities of the department, at least covering the essential services.

As for the definition of DOP, these have required estimates of the duration of activities and also of patient demand, which were probably subject to uncertainty and thus introduced imprecision in the model, Additionally, there was a lack of information on the initial allocation of physicians' working time, in order to determine the *status quo*. In this sense, the collection of more accurate data, regarding the duration of activities and the distribution of working time may present a significant improvement in the methodology.

The construction of the evaluation model may raise questions on the validity of the value functions, as these have been generalised from a standard function obtained with M-MACBETH. On the other hand, filling the judgment matrix for determining weights may have yielded incomplete information. Further exploring the validity of the evaluation model may also contribute positively to the improvement of the methodology.

VIII. CONCLUSIONS

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 flexibility of the model, the systematisation of alternative generation and evaluation, and the adaptability of the resource allocation model to the scope of analysis indicate that such a method may have the potential to inform decisions on the allocation of medical professionals. In this sense, the objectives of this thesis can be considered achieved.

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