Evaluation of the quality and access to health care in the Portuguese public hospitals: A multicriteria approach

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Abstract

The Portuguese healthcare sector is characterized by having a National Health Service (NHS) that ensures access to health care to the population. The healthcare policy reforms that have occurred in Portugal during recent years, particularly those made during the financial crisis, which led to the intervention of foreign aid (2011-2015), have had a significant impact on the efficiency of health care provided by the NHS. The disinvestment in infrastructures and the reduction of human resources compromised the objectives of improving the system's efficiency and its quality. Since then, some measures have been taken to improve the quality and access to health care providers, which enhances the importance of evaluating these dimensions in those care providers. The hospitals' quality and access assessment should be made considering all criteria involved in the situation, but also only specific subsets of them. To make this evaluation, the ELECTRE TRI-nC method with Multiple Criteria Hierarchy Process (MCHP) is implemented in *phyton* and applied to a data set. ELECTRE TRI-nC is a multicriteria sorting method that assigns each action (in this case, a Portuguese public hospital) to pre-defined and ordered categories (representing levels of quality and accessibility). The hospitals are evaluated according to several criteria organized in a hierarchical structure, enabling the use of MCHP to access each hospitals' evaluation considering specific criteria or the comprehensive level. This study intends to highlight the potential of using the proposed method in the healthcare sector as a tool for increasing the NHS' efficiency and ensuring a sustainable system.

Keywords: Multiple Criteria Decision Aiding, ELECTRE TRI-nC, Multiple Criteria Hierarchy Process, Quality assessment, Hospitals, National Health Service

1. Introduction

In Portugal, the healthcare system is characterized by having a National Health Service (NHS), financed by the state budget, that grants universal coverage for all health needs, to the entire Portuguese population (Nunes, 2018b). Portugal has passed through some health reforms in recent years due to political changes and more recently due to the financial crisis from which Portugal is still recovering. One of the consequential measures implemented was to improve the healthcare system's efficiency. However, it is important to note that in terms of health, improving efficiency should not compromise the level of quality and access to said system, but rather improve it, if possible.

Although there are some positive indicators the main goal has not yet been completely achieved, which is reflected in the unsustainable growth of the NHS expenses in percentage of the nominal Gross Domestic Product (GDP). For instance, the growth in 2018, 2019 and 2020, has been 6.2%, 5.2% and 6.8%, respectively, which in comparison to 2015 and 2016, were considerably higher (1.7% in 2015, 2.4% in 2016) (Portuguese Public Finance Council, Budgetary Evolution of the NHS, Nº 06/2021). The prevalence of the structural debt imposes challenges to the financial sustainability, factor that must be considered in the context of the future definition of health policies and reforms. To establish future measures, it is important to firstly assess the actual level of important parameters regarding public health. The public hospitals are the main providers of differentiated care to the Portuguese citizen, which highlights the importance of evaluating the quality and access to them through a multicriteria hierarchy approach.

The ELECTRE TRI-nC method with MCHP was selected to assess the hospitals' level of quality and access. The possibility of assessing hospitals' level of quality and access by considering only specific criteria in the hierarchical tree is utmost useful in a situation as presented above, hence the reason to select this new approach.

2. Problem Context

2.1 Portuguese healthcare sector

The importance of the health care sector, and its social and financial repercussions, is almost incommensurable. The linkages between this sector and the reduction of poverty, accompanied by economic growth, is more powerful than it is generally recognized (Weil, 2014). In Portugal, as in many other countries, there are approved laws that grant several rights regarding the health area. The Portuguese constitution, which has been in effect since 1976, despite some modifications during the years, states in article n.º 64 that "everyone has the right to health protection and the duty of defending and promoting it", and that this right is accomplished through "a universal and general national health service", that is usually free of charge. To ensure that right, the Portuguese government must grant several conditions, from which, considering the theme of this research, it is essential to highlight three:

- "Guarantee the access of all citizens to the preventive, curative and rehabilitation medicine care";
- "Guarantee a national and efficient coverage of the entire country in human resources and health units";
- "Discipline and supervise business and private forms of medicine, and their articulating with the national health service, in order to ensure, in public and private health institutions, adequate standards of efficiency and quality".

The Portuguese health care sector is characterized by NHS that was created in 1979 (Nunes, 2018b), with the intention of ensuring the conditions defined in the Portuguese constitution of 1976. The system is based on the Beveridge model, and it is mainly sustained by the public taxes imposed to the Portuguese population. The Portuguese government is responsible for managing the NHS, and consequently the health care providers that are part of it (Decree-Law Nº 124/2011 of 29th December from Ministry of Health, 2011).

2.2 Problem characteristics

The main objective of the NHS is to provide an equitable and tendentiously free of charge access to quality health care providers to the entire Portuguese population. However, particularly in recent years, this level of quality and access has been decreasing, mainly due to the repercussions of the financial crisis that began in the year 2009 and drove Portugal to resort to external intervention. The Memorandum of Understanding (MoU) that was signed between Portugal and multiple entities, led to implementing multiple government reforms focused on reducing the cost and improving the efficiency of the public services, which had a great impact on the public health sector (Nunes, 2018b; Simões et al., 2017). Those austerity measures have reduced the secondary care expenditures and worsened the quality and access to healthcare providers, especially because of the disinvestment in equipment and infrastructures in the Portuguese public hospitals (Nunes, 2019).

Following the external intervention period (2011-2015), the new elected government introduced in its program a new strategy to revitalize the NHS (Nunes, 2018a). Different tools were implemented, as the benchmarking process from the *Central Administration of the health system* (ACSS), which evaluates the performances of several indicators of specific dimensions, as quality and access, within the Portuguese public hospitals.

Despite some good indicators, as the increase in Portugal's ranking position in the Euro Health Consumer Index (EHCI) from 20th to 13th place during the period 2015-2018, there are still major concerns with the actual state of the NHS, namely its financial sustainability. Between 2014 and 2020, the accumulated budgetary execution of the NHS presented a negative balance of 2865 million of euros (M€), 2018, and 2019, where the years with the highest negative deviations, respectively, 732 M€ and 628 M€ (Portuguese Public Finance Council, Budgetary Evolution of the NHS, Nº06/2021). These data reveal the inability to keep pace with the continuous growth of the public health expenses, which goes against the idea of having a sustainable NHS.

Considering all these aspects, it is crucial to continue improving the efficiency of the NHS without compromising the quality and the access to its health care providers, namely the public hospitals, hence the importance of studying the actual level of both these dimensions in them.

The assessment of the quality in the Portuguese public hospitals through the application of the ELECTRE TRI-nC method was already suggested by Rocha et al. (2021). However, and although the criteria of the model used are structured in a hierarchical way, a hierarchical process was not applied. Instead, another ELECTRE method (ELECTRE TRI-C) was used to determine the scales of criteria at the higher levels based on the scales of criteria at the lower levels.

The new approach proposed in this research work is also based in the same model defined by Rocha et al. (2021), however, the applied method uses a MCHP to deal with the hierarchical structure of criteria. Thus enabling, the possibility of assessing the hospital's level of quality and access by considering specific criterion located in different levels of the hierarchical tree.

3. Methodology

This section defines the method used in this research and its procedure. In last, it is described the computational program developed to apply this method.

3.1 Methods

The method selected to assess the level of quality and access to the Portuguese public hospitals was the ELECTRE TRI-nC with MCHP.

ELECTRE TRI-nC is an outranking method that was created to aid the decision maker (DM) in MCDA problems where his/her objective is to sort the objects of a decision (actions) to a set of pre-ordered categories, taking into consideration their evaluation in multiple criteria (Almeida-Dias et al., 2012). Each category is characterized by one or more reference actions, which the DM considers to be the most representative ones of that category. The preference relations established between the potential actions and the reference actions enable the possibility of applying an assignment procedure to make the intended sorting. Nevertheless, these preference relations can only be computed by considering all criteria defined.

Corrente et al. (2012) presented a new process to be applied within the MCDA problematic, the MCHP. It has the capacity to formulate a hierarchical structure of criteria to represent a problem with multiple criteria. Instead of a flat structure, this process leads to a hierarchy tree of criteria, with multiple nodes dividing themself into other nodes, until decomposing all the complex criteria into simple ones, resulting in multiple levels in the hierarchy tree. The main idea of MCHP is to consider preference relations at each node of the hierarchy tree. This new process was proposed to be applied in the ELECTRE TRI-nC method by Corrente et al. (2016). The several features that result from the incorporation of the MCHP in the ELECTRE TRI-nC method are most useful in many real-word problems. Especially when the problem is particularly hard to define, and there is the need to sort the actions to categories by considering specific criteria.

The evaluation of the quality and access to the Portuguese public hospitals is one of the problems that benefits from this new methodology, hence the reason to select the ELECTRE TRI-nC method with MCHP to make this study.

3.2 Method's data and notation

The ELECTRE TRI-nC method with MCHP is based in a co-construction interactive process between an analyst and a DM, which is the person that defines the model and benefits, or represent those who benefit, from decision aiding in the defined problem (Almeida-Dias et al., 2010).

The DM must define a set of potential actions, $A = \{a_1, a_2, \ldots, a_i, \ldots\}$ that will be evaluated in a set of criteria Ğ and assigned to a set of pre-ordered categories $C = \{C_1, \ldots, C_h, \ldots., C_q\}$. Each category is characterized by a set of reference actions $B = \{B_0, B_1, \ldots, B_h, \ldots, B_{q+1}\}$ which in turn is composed by one or more reference actions, $B_h = \{b_h^r, r = 1, \ldots, m_h\}$, that the DM considers to be the most representative ones of that category.

3.2.1 Criteria

The evaluation criteria are structured in a hierarchical way, thus leading to the existence of several levels in the hierarchy. G_r denotes a criterion from any level in the hierarchy. $G_{r,s}$, with $s = 1, \ldots, n(r)$, denotes all subcriteria that directly descend from G_r in the subsequent level. The criteria in the last level of the hierarchy are the elementary ones (EL), g_j, and they descend from the criteria in the last but one level (LBO), which in turn descend from others in higher levels of the hierarchy, if any (Corrente et al., 2016). The root criterion, G_0, represents the comprehensive level.

All criteria in the model must have an intrinsic weight associated with them. In the ELECTRE family of methos, weights are interpreted as the relative importance of a certain criterion in the overall analysis of an action (Figueira et al., 2010). To estimate the value of the intrinsic weights it was used the SRF weighing procedure, developed in Figueira & Roy, 2002, and adapted in Corrente et al., 2016, to be applied in a hierarchical structure of criteria. The SRF method uses a co-construction interactive process between the analyst and the DM, based on a procedure that uses a set of cards to create intervals between criteria, which are interpreted in a way that allows to estimate their weights (Figueira & Roy, 2002).

Each non-elementary criteria must be associated with a cutting level value, λ_r, that defines the minimum value consistent with the outranking relation between two actions.

The elementary criteria, g_j, have an indifference threshold, q_j, and preference threshold, p_j, associated with them, that were defined to consider the imperfect character of the data regarding the computation of the performances in all actions (Almeida-Dias et al., 2012). It is also possible to associate a veto threshold, v_j, with each elementary criterion to reject the possibility of an outranking relation between two actions when the differences in performances between both in one criterion is large enough (Roy & Bouyssou, 1993). The elementary criteria are the only ones in which it is necessary to define a performance value for each action. Those performances allow to compare each potential action, a_i, with each reference action, b_h^r, thus enabling the definition of outranking relations between both actions, if any.

3.2.2 Outranking relations

The most common definition of an outranking relation is "action a outranks action b if a is at least as good as b", which is equal to "a not being worse than b" (Roy, 1990). This is a binary relation designated by aSb, which happens when there are sufficient arguments to conclude that a is at least as good as b, and there is no arguments sufficiently strong to refute that conclusion. This outranking relation is also established by considering the performances of both actions in a single elementary criterion, aS_jb, or a single non-elementary criterion, aS_rb.

To verify the outranking relation between two actions, a and b, in each non-elementary criterion, G_r, it is required to compute the value of the partial concordance index, $C_r(a,b)$, and the partial credibility index, $\sigma_r(a,b)$. However, these partial indexes must consider the arguments in concordance and discordance with the outranking relation between a and b, in all elementary criteria descending from G_r. The elementary concordance index, $\phi_t(a,b)$, and the elementary discordance index, $d_t(a,b)$, were defined to, respectively, measure the degree of concordance and discordance of the premise, a outranks b in criterion g_j. The value of the partial indexes, $C_r(a,b)$ and $\sigma_r(a,b)$, are then compared with the cutting level value, λ_r, to make conclusions regarding the three following outranking relations:

(O1) $aS_r'b \Leftrightarrow C_r(a,b) \geq \lambda_r$;

(O2) $aS_r''b \Leftrightarrow C_r(a,b) \geq \lambda_r \wedge g_t(b) - g_t(a) < v_t$, for all $t \in E(G_r)$;

(O3) $aS_r''b \Leftrightarrow \sigma_r(a,b) \geq \lambda_r$.

Any of these outranking relations can be used to define the three possible binary relations for each non-elementary criterion G_r:

- $a \succsim_r b$ (a is preferred to b on criterion G_r) iff aS_rb and $not(bS_ra)$;

- $a \sim_r b$ (a is indifferent to b on criterion G_r) iff aS_rb and bS_ra;

- $a \, ?_r \, b$ (a is comparable with b on criterion G_r) iff $not(bS_ra)$ and $not(aS_rb)$.

3.2.3 Assignment procedure

The assignment procedure of this method is based in two rules that are used conjointly, the ascending rule and the descending rule. Those rules compare the values of the partial credibility indexes, $\sigma_r(a,B_h)$ and $\sigma_r(B_h,a)$, for all $h = 1,\dots,p$, with the cutting level value, λ_r, defined in each non-elementary criterion. Each credibility indexes $\sigma_r(a,B_h)$ and $\sigma_r(B_h,a)$ represent, respectively, the maximum and minimum credibility index obtained by comparing a with each reference action b_h^k, with $k = 1,\dots,m_h$, and vice-versa. Both rules select a category in which action a should be assigned to. When the two categories are equal, action a is assigned to a unique category, when they are different, action a is assigned to a range of categories (Almeida-Dias et al., 2012).

Another variable is also used to investigate, in each rule, the possibility of assigning a to the adjacent category of the one pre-selected. This variable, $\rho_r(a, B_h)$, is equal to the minimum value resultant by comparing $\sigma_r(a, B_h)$ and $\sigma_r(B_h, a)$.

3.2.4 Natural requirements

The input data implemented in the method must

fulfil certain natural requirements to validate the model. There are four structural requirements that must be verified (*Conformity, Homogeneity, Monotonicity, and Stability*), two coherence properties (C1 and C2) and three separability conditions (*weak*, *strict,* and *hyper-strict*) (Corrente et al., 2016).

3.3 Computational program

During this research, in order to apply the ELECTRE TRI-nC method with MCHP in any real-word problem modelled to have the input data required by this method, a computational program (*CP*) was developed.

The *CP* program is based on a programming code written in *python* which accesses a formatted *Excel* file. The programming code is a modular one, allowing to execute specific components of the method whenever it is commanded. The interface between the *CP* and the *Excel* file is very efficient in this type of method because it allows to access the information inserted by the *CP* in the file in different moments of the model's implementation. The capacity of the *CP* to apply the method without requiring any modifications for it to be adjusted to the model used, and the visual format of the *Excel* file, resulted in the development of a flexible tool. This tool can aid the analyst in his/her job, allowing for him/her to only be focused on capturing the DM' preferences.

The results of the model are presented in the same *Excel* file used to construct it. It was also defined a new feature to present all the relevant data of the model, including the final results into a web browser. This browser can be accessed at real time by any device, which is advantageous in a situation where there are multiple people that wants to observe this data. To establish this feature, it was used the *Streamlit* and *Pandas python* packages. The second one allows to manipulate the data while the first one allows to define a web browser page, which presents the manipulated data into a specific format that can be easily modified by the analyst. The computer where the model is being executed is the server of that web browser page. This capability was introduced with the objective of further involving the DM in the entire method development, as he/she main gain another insight by observing the multiple data inserted or obtained in the model. Its use may also be interesting when there are multiple DMs that are constructing the model conjointly.

The major concern when developing the *CP* was its capability of executing all the procedures imposed by the method, with any input data defined by the DM. Nevertheless, it was also essential to seek the reduction of the computational effort of the program when it was possible. Specially, when the selected method has several different features that can be incorporated into it, as for instance the possibility of having interactions between the criteria considered. All of these concerns were considered when developing the program, and led to the definition of some assumptions:

- The hierarchical tree of criteria must not have more than three levels;
- There is no interaction between the criteria;
- When applying the SRF weighing procedure, the level of importance assigned to each criterion must not be higher than ten.

These limitations can be overcome with some modification in the *python* code.

4. Case study

As previously mentioned, the model used in this research was the same as defined by Rocha et al. (2021), with the required adjustments for it to be applied in a MCHP. The absence of a DM does not have an impact in this method, because the decision model constructed by Rocha et al. (2021) was already defined by a DM. This section presents the model used in this research and its implementation in the *CP* developed.

4.1 Potential actions and criteria

Since the data related with the performances of each action in each elementary criterion should be reliable, it was considered by Rocha et al. (2021), the data provided by the ACSS Benchmarking Database, available via https://benchmarking-acss.min-saude.pt/. In total, it were defined 25 public hospitals (potential actions) to be evaluated in 24 elementary criteria. A hierarchical tree of

Table 1 - Models' criteria and correspondent information

Criteria	Elementary Criteria	Indicator	Direction of Preference	Scale
Access (g_1)	First medical appointments timeliness ($g_{1,1}$)	Number of non-urgent first medical appointments performed in adequate time per 100 first medical appointments	Maximization	[0; 100]
	Enrolled patients for surgery ($g_{1,2}$)	Number of enrolled in the surgical waiting list within the mean guaranteed response time	Maximization	[0; 100]
	Availability of beds ($g_{1,3}$)	Difference between the real occupancy rate and the ideal occupancy rate	Minimization	[0; 13]
	Availability of doctors ($g_{1,4}$)	Doctors per 1000 inhabitants	Maximization	[0; 5.8]
	Availability of nurses ($g_{1,5}$)	Nurses per 1000 inhabitants	Maximization	[0; 8.2]
Care Appropriateness (g_2)	Minor surgeries appropriateness ($g_{2,1}$)	Number of outpatient surgeries per 100 potential outpatient procedure	Maximization	[0; 100]
	Avoidable re-admission prior 30 days after discharge ($g_{2,2}$)	Number of readmissions in 30 days after discharge per 100 inpatients	Minimization	[0; 13.2]
	Excessive staying delay ($g_{2,3}$)	Number of long-stay inpatients per 100 admissions	Minimization	[0; 6.5]
	Hip surgery timeliness ($g_{2,4}$)	Number of hip surgeries performed in the first 48 hours per 100 hip surgeries	Maximization	[0; 100]
	Delay before surgery ($g_{2,5}$)	Average waiting time before surgery	Minimization	[0; 1.9]
Patient Safety (g_3)	Bedsores ($g_{3,1}$)	Number of bedsores per 100 inpatients	Minimization	[0; 0.2]
	Bloodstream infections related to CVC ($g_{3,2}$)	Bloodstream infection rate related to CVC per 100 inpatients	Minimization	[0; 0.1]
	Postoperative pulmonary embolism or thrombosis ($g_{3,3}$)	Postoperative pulmonary embolism/deep venous thrombosis cases per 100 surgical procedures	Minimization	[0; 0.4]
	Postoperative septicaemia ($g_{3,4}$)	Postoperative septicaemia cases per 100 inpatients	Minimization	[0; 1.4]
	Non-instrumental vaginal deliveries with severe laceration ($g_{3,5}$)	Cases of trauma on vaginal delivery (third and fourth degree lacerations), without instrumentation, per 100 assisted deliveries	Minimization	[0; 1.6]
	Assisted vaginal deliveries with severe laceration ($g_{3,6}$)	Cases of trauma on vaginal delivery (third and fourth degree lacerations), with instrumentation, per 100 assisted deliveries	Minimization	[0; 6.9]
Efficiency (g_4)	Expenses with staff ($g_{4,1}$)	Expenses with staff per severity-adjusted patient	Minimization	[0; 3107.3]
	Expenses with drugs, pharmaceutical products and clinical consumables ($g_{4,2}$)	Expenses with drugs, pharmaceutical products and clinical consumables per severity-adjusted patient	Minimization	[0; 2924.7]
	Expenses with supplies and external services ($g_{4,3}$)	Expenses with supplies and external services per severity-adjusted patient	Minimization	[0; 1032.6]
	Expenses with overtime ($g_{4,4}$)	Expenses with overtime per total expenses with staff	Minimization	[0; 18.4]
	Expenses with outsourcing ($g_{4,5}$)	Expenses with outsourcing per total expenses with staff	Minimization	[0; 16]
Caesarean Appropriateness (g_5)	Volume of caesarean sections ($g_{5,1}$)	Number of caesarean sections per 100 deliveries	Minimization	[0; 43.4]
	Caesarean sections in UCFTPs ($g_{5,2}$)	Number of caesarean sections in UCFTPs per 100 sections in UCFTPs	Minimization	[0; 59.6]
	First caesarean sections in UCFTPs ($g_{5,3}$)	Number of first caesarean sections in UCFTPs per 100 deliveries in UCFTPs without caesarean section before	Minimization	[0; 100]

criteria was also defined, with five criteria in the first level and 24 elementary criteria directly descending from them. Each elementary criterion has an indicator associate with it to determine how to measure its performances in each action.

The ELECTRE TRI-nC method requires the definition of two categories, C_0 and C_{q+1}, characterized by a unique reference action, b_0^1, and b_{q+1}^1, that have the worst and best possible performances in all elementary criteria, respectively. To define these reference actions, a scale of performances was computed for each elementary criterion.

Table 1 presents all the information regarding the model's criteria and Table 2 defines all the 25 public hospitals considered in the study.

4.2 Categories and reference actions

Rocha et al. (2021) defined a set of five pre-ordered categories that represent a certain level of quality and access, and a subset of reference

Table 2 – Potential actions

Name	Code	a_i
Centro Hospitalar do Médio Ave	CHMA	a_1
Centro Hospitalar Póvoa de Varzim/Vila do Conde	CHPV	a_2
Centro Hospitalar Barreiro/Montijo	CHBM	a_3
Centro Hospitalar de Leiria	CHL	a_4
Centro Hospitalar de Setúbal	CHS	a_5
Centro Hospitalar do Baixo Vouga	CHBV	a_6
Centro Hospitalar Entre Douro e Vouga	CHCHDV	a_7
Centro Hospitalar Médio Tejo	CHMT	a_8
Centro Hospitalar Tâmega e Sousa	CHTS	a_9
Centro Hospitalar Universitário Cova da Beira	CHUCB	a_{10}
Hospital da Senhora da Oliveira, Guimarães	HSO	a_{11}
Hospital Distrital de Santarém	HDS	a_{12}
Centro Hospitalar Tondela-Viseu	CHTV	a_{13}
Centro Hospitalar Trás-os-Montes e Alto Douro	CHTAD	a_{14}
Centro Hospitalar Universitário do Algarve	CHUA	a_{15}
Centro Hospitalar Vila Nova de Gaia/Espinho	CHVNG	a_{16}
Hospital Espírito Santo de Évora	HESE	a_{17}
Hospital Fernando da Fonseca	HFF	a_{18}
Hospital Garcia de Orta	HGO	a_{19}
Centro Hospitalar de Lisboa Ocidental	CHLO	a_{20}
Centro Hospitalar e Universitário de Coimbra	CHUCB	a_{21}
Centro Hospitalar Universitário de Lisboa Central	CHULC	a_{22}
Centro Hospitalar Universitário de São João	CHUSJ	a_{23}
Centro Hospitalar Universitário do Porto	CHUP	a_{24}
Centro Hospitalar Universitário Lisboa Norte	CHULN	a_{25}

actions for each of them. In addition to the reference actions defined by that paper, four new ones (b_2^2, b_2^3, b_3^2, and b_4^2) were developed to take into account the uncertainty associated with the

Table 3 - Categories and respective subset of reference actions

Categories	Worst (C_0)	Very Poor (C_1)	Poor (C_2)	Neutral (C_3)	Good (C_4)	Very Good (C_5)	Best (C_6)
Reference actions	$B_0 = \{b_0^1\}$	$B_1 = \{b_1^1\}$	$B_2 = \{b_2^1, b_2^2, b_2^3\}$	$B_3 = \{b_3^1, b_3^2\}$	$B_4 = \{b_4^1, b_4^2\}$	$B_5 = \{b_5^1\}$	$B_6 = \{b_6^1\}$

process of defining reference actions to characterize categories. Those actions concerned the middle categories, and they can be seen in Table 3.

4.3 Criteria' weights

The SRF weighing procedure was also applied by Rocha et al. (2021). The data provided by that procedure was inserted in the *Excel* file and computed by the *CP*, allowing to estimate the weights associated with each criteria. However, the incorporation of the MCHP in the SRF weighing procedure establish the need to compute the value of the globally normalized weight for all criteria descending from the ones located in the first level of the hierarchy. The globally normalized weight is computed by multiplying the value of the normalized weight of a specific subcriterion with the value of the normalized weight of the directly ascending criterion (Corrente et al., 2016).

Table 4 defines the intrinsic weights associated with each criteria in the first level of the hierarchy, and all elementary criteria descending from criterion g_1.

Table 4 - Weights associated with each non-elementary criterion and all subcriteria descending from g_1.

	Weight		
	Non-Normalized	Normalized	Globally Normalized
g_1	7.545	0.236	0.236
g_2	9.182	0.287	0.287
g_3	10	0.313	0.313
g_4	1	0.031	0.031
g_5	4.273	0.134	0.134
$g_{1,1}$	2	0.271	0.064
$g_{1,2}$	1.875	0.254	0.06
$g_{1,3}$	1	0.136	0.032
$g_{1,4}$	1	0.136	0.032
$g_{1,5}$	1.5	0.203	0.048

4.4 Cutting level and thresholds

Rocha et al. (2021) defined a value for the cutting level at the comprehensive level of 0.6. However, in the ELECTRE TRI-nC method with MCHP it is necessary to set cutting levels values for each non-elementary criterion.

The values computed for the five non-elementary criteria in the model were computed in the same proportion (weight/cutting level) as established in the root criterion. The sum of those values represent the cutting level value of the root criterion, which is obviously 0.6.

The indifference and preference thresholds' values for each elementary criterion defined by Rocha et al. (2021) were also used in this model. In that paper, the DM defined veto thresholds in two specific criteria in the first level of the hierarchy, g_2 and g_3. That possibility is denied by the incorporation of the MCHP in the ELECTRE TRI-nC method since it is only possible to associate veto thresholds with elementary criteria. Thus, a process to define veto thresholds in two $(g_{2,2}, g_{2,3})$ and three subcriteria $(g_{3,1}, g_{3,2}, g_{3,3})$ descending from g_2 and g_3, respectively, was developed. The values of each veto threshold were computed in the same proportion (veto threshold value/criterion' scale) as the ones defined by Rocha et al. (2021). Table 5 displays the values of all thresholds associated with the four mentioned subcriteria.

Table 5 - Thresholds values of all elementary criterion with a veto threshold associated

Criterion	q_t	p_t	v_t
$g_{2,2}$	1	2	5.3
$g_{2,3}$	0.3	0.5	2.6
$g_{3,2}$	0.01	0.01	0.04
$g_{3,3}$	0.01	0.01	0.16
$g_{3,4}$	0.01	0.01	0.56

4.5 Assignment procedure

The insertion of all input data in the *Excel* file enable the execution of the assignment procedure and the verification of all properties and structural requirements of the method by the *CP*. Since all the natural requirements imposed by the method were respected, the model was considered valid. The assignment procedure of the ELECTRE TRI-nC method with MCHP allows to assigned each

Table 6 - Assignment procedure for each non-elementary criterion

	Assignment Procedure											
	g_1		g_2		g_3		g_4		g_5		g_0	
Actions	**Lower Category**	**Upper Category**	**Lower Category**	**Upper Category**	**Lower Category**	**Upper Category**	**Lower Category**	**Upper Category**	**Lower Category**	**Upper Category**	**Lower Category**	**Upper Category**
a_1	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_4	C_5	C_3	C_3
a_2	C_3	C_4	C_5	C_5	C_4	C_4	C_2	C_2	C_4	C_5	C_5	C_5
a_3	C_3	C_3	C_1	C_2	C_3	C_3	C_3	C_3	C_4	C_5	C_3	C_3
a_4	C_2	C_2	C_4	C_4	C_5	C_5	C_1	C_2	C_1	C_5	C_4	C_4
a_5	C_2	C_2	C_4	C_4	C_2	C_4	C_3	C_3	C_3	C_5	C_3	C_3
a_6	C_3	C_3	C_3	C_4	C_3	C_4	C_3	C_3	C_4	C_5	C_3	C_4
a_7	C_2	C_2	C_4	C_4	C_3	C_3	C_3	C_3	C_4	C_5	C_3	C_3
a_8	C_2	C_2	C_2	C_2	C_3	C_4	C_1	C_3	C_4	C_5	C_3	C_4
a_9	C_1	C_1	C_3	C_4	C_3	C_3	C_3	C_3	C_5	C_5	C_4	C_4
a_{10}	C_3	C_3	C_2	C_3	C_3	C_3	C_2	C_2	C_1	C_5	C_3	C_3
a_{11}	C_2	C_2	C_2	C_3	C_3	C_4	C_3	C_3	C_4	C_5	C_3	C_3
a_{12}	C_2	C_2	C_3	C_3	C_3	C_3	C_1	C_1	C_4	C_5	C_3	C_3
a_{13}	C_3	C_3	C_3	C_3	C_2	C_4	C_4	C_4	C_5	C_5	C_3	C_4
a_{14}	C_2	C_2	C_3	C_3	C_3	C_4	C_3	C_3	C_1	C_5	C_3	C_3
a_{15}	C_3	C_3	C_2	C_2	C_3	C_4	C_2	C_2	C_5	C_5	C_3	C_3
a_{16}	C_3	C_3	C_3	C_4	C_3	C_3	C_4	C_4	C_4	C_5	C_3	C_3
a_{17}	C_2	C_2	C_3	C_3	C_2	C_2	C_2	C_2	C_3	C_5	C_2	C_2
a_{18}	C_2	C_2	C_3	C_3	C_2	C_4	C_3	C_3	C_1	C_5	C_2	C_4
a_{19}	C_2	C_2	C_2	C_3	C_3	C_3	C_4	C_4	C_5	C_5	C_3	C_3
a_{20}	C_3	C_3	C_2	C_3	C_2	C_2	C_4	C_4	C_4	C_5	C_2	C_2
a_{21}	C_3	C_3	C_2	C_3	C_3	C_3	C_4	C_4	C_4	C_5	C_3	C_3
a_{22}	C_4	C_4	C_2	C_3	C_3	C_3	C_3	C_4	C_4	C_5	C_3	C_3
a_{23}	C_4	C_4	C_4	C_4	C_2	C_2	C_4	C_4	C_4	C_5	C_3	C_3
a_{24}	C_3	C_3	C_5	C_5	C_3	C_3	C_4	C_4	C_4	C_5	C_4	C_4
a_{25}	C_3	C_4	C_2	C_2	C_2	C_3	C_3	C_3	C_4	C_5	C_3	C_3

hospital to one or more continuous categories by considering each non-elementary criterion individually, or all of them combined (g_0). Notice that the assignment procedure of this method defines a lower and upper category in which a certain hospital should be assigned to, if both are equal the hospital is assigned to a unique category, otherwise it is assigned to an interval of continuous categories.

5. Results

5.1 Presentation and discussion of results

The results of the assignment procedure are displayed in Table 6, Table 7 and Figure 2.

The results obtained highlight the lack of public hospitals with high levels of quality and access at the comprehensive level. A single hospital, *Centro Hospitalar da Póvoa do Varzim/Vila do Conde*, was assigned to the maximum level of quality and access, C_5, which corresponds to only 4% of the set of hospitals considered, proving the previously mentioned conclusion. In the opposite view, there are two hospitals, *Hospital Espírito Santo de Évora* and *Centro Hospitalar de Lisboa Ocidental*, that were assigned to category C_2 (poor level of quality and access). From the entire set of hospitals, 60% were assigned at the comprehensive level to a neutral level of quality and access, C_3.

The assignment of the hospitals by considering only a specific criterion in the first level of the hierarchy has also revealed that there is not a single hospital assigned to C_5 in the Access or Efficiency criteria. In fact, 84% of the hospitals were assigned to a category equal to or lower than C_3 considering the criterion Access, which is congruent with the worsening of access to health care services observed due to structural reforms adopted during the external intervention period (Nunes et al., 2019).

The Efficiency criterion is based on the hospitals' expenses. The fact that 24% of the

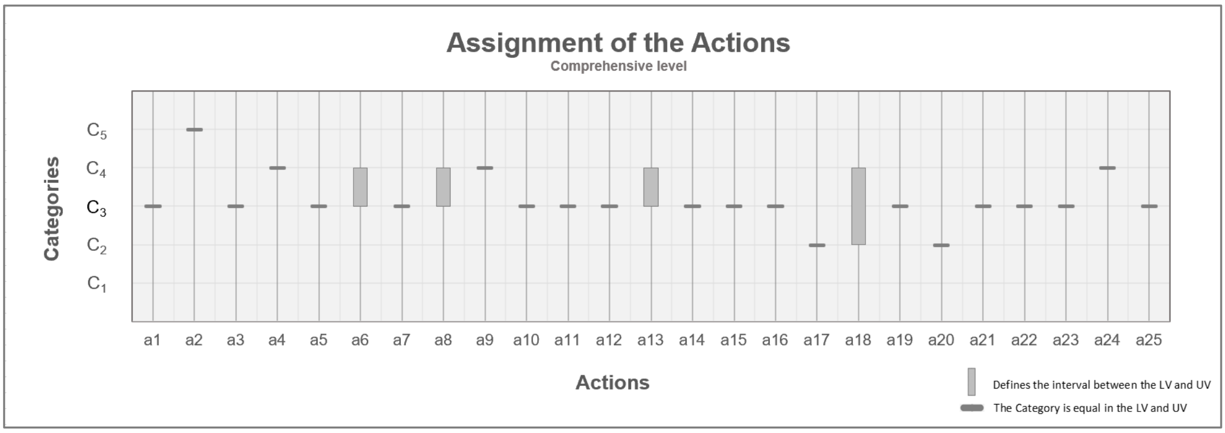

Figure 1 - Graph of the assignment of each action at the comprehensive level

Table 7 - Percentage of hospitals assigned to a certain categories' range in each non-elementary criterion

Categories' Range		Non-elementary criteria					
		g_1	g_2	g_3	g_4	g_5	g_0
C_1	C_1	4%	0%	0%	4%	0%	0%
C_1	C_2	0%	4%	0%	4%	0%	0%
C_1	C_3	0%	0%	0%	4%	0%	0%
C_1	C_5	0%	0%	0%	0%	16%	0%
C_2	C_2	40%	12%	12%	16%	0%	8%
C_2	C_3	0%	24%	4%	0%	0%	0%
C_2	C_4	0%	0%	12%	0%	0%	4%
C_3	C_3	40%	24%	44%	40%	0%	60%
C_3	C_4	8%	12%	20%	4%	0%	12%
C_3	C_5	0%	0%	0%	0%	8%	0%
C_4	C_4	8%	16%	4%	28%	0%	12%
C_4	C_5	0%	0%	0%	0%	60%	0%
C_5	C_5	0%	8%	4%	0%	16%	4%

hospitals were assigned to a category equal to or lower than C_2 in this criterion reveals that the strategies adopted in the next upcoming years (to improve the quality and access to the public), must be implemented without compromising the economic sustainability of the system. The Caesarean Appropriateness criterion was the one that presented the best results, with 74% of the hospitals beeing assigned to a category equal to or higher than C_4 (Good). However, as in other criteria, there is also a considerable discrepancy between some hospitals.

5.2 Robustness analysis

To test the robustness of the model it was made the same robustness analysis described by Rocha et al. (2021). The input parameters modified where the cutting levels' values and two other parameters, related to the SRF weighing procedure, that influence the weight of each non-elementary criterion. In total, 35 new models were tested and 875 hospitals were assigned to one or more continuous categories at the comprehensive level. From those, only 54 (6.3%) were assigned to a different category, when comparing to the original results. This percentage reenforces the robustness of the model to its inputs' fuzziness.

5.3 *Comparison with Rocha et al. (2021)*

As previously mentioned, the model defined in this dissertation was based on the one presented in Rocha et al. (2021). Despite the obvious limitations, arising from the adaptations that had to be made in the model in order for it to be applied in the method proposed in this dissertation, it is relevant to observe the differences between the results obtained with the two different methods. Those results concern the year of 2018, and they can only be compared by considering the assignment of hospitals into a categories' range at the comprehensive level.

The results of the assignment procedure were considerably different between the two different approaches. In fact, only 28% and 20% of the hospitals were assigned to the same categories' range, when comparing the results obtained in this dissertation and the ones obtained in the upper-level and lower-level view in Rocha et al. (2021).

There is a greater similarity between the results obtained in the descending view with the ones obtained with the ELECTRE TRI-nC method with MCHP. Which is justified, not only because there are more hospitals assigned to the same categories' range than in the descending view, but also because 20% of the ones that are not in that list were assigned to an adjacent categories' range. It is also interesting to observe that the two hospitals with the worst assignment results at the comprehensive level in the method proposed in this dissertation, were also two of the worst three in the method used in Rocha et al. (2021). Furthermore, the only hospital assigned to category C_5 in Rocha et al. (2021), was also the Centro Hospitalar da Póvoa do Varzim/Vila do Conde. These informative data reveal a certain degree of similarity between the results obtained in both methods.

6. Conclusions

The possibility of assigning hospitals not only at the comprehensive level, but also considering specific criteria in the hierarchy, has proven to be very useful to observe disparities between the assignment results of different hospitals. These disparities are considerable in this case study, as they reveal the inefficient benchmarking process that is being made in this sector. However, the exact feature that allowed to observe these disparities can also be one of the solutions to the problem. The discovery of the hospital assigned to the highest category in a specific criterion, can be used to position that hospital as a benchmarking for the others, in that criterion. A complementary study can be made to compartmentalize the expenses of a certain hospital per criterion. Despite the obvious difficulties of this process, it would allow to compare the level of expenses in a certain criterion with the assignment results obtained in that same criterion, for any hospital. The results would allow to conclude which is the most cost-efficient hospital considering a certain criterion, thus becoming meaningful to study the behaviors and procedures carried out there, to try to replicate them in the most inefficient ones.

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