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Classification method to classify patients who suffer from cardiac insufficiency

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Master in Management of Services and Technology

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BUSINESS
SCHOOL

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Acknowledgments

I hereby come to write a thank you note to all the people involved in this journey that was writing my dissertation. My deepest gratitude to every single one of you that helped me conclude this very significant step in my life:

- To my Professor advisor, Professora Teresa Sofia Grilo, for her patience and kindness while guiding me throughout this year. Could not have chosen a better Professor advisor.

- To my Professor advisor, Professor José Rui Figueira, for his transmition of knowledge and expertise which were essential for the elaboration of this disseration.

- To the Doctors Carlos Moreira and Cristina Ribeiro, for their availability and helpfulness and whose professional knowledge was fundamental for the nature of this dissertation.

- To my friends and family who have always encouraged me and have a special place in my life.

- To my brother Rodrigo and sister-in-law Joana, for always showing their availability to help and for giving me much needed and important advice.

- To my parents Isabel and Tomás, for their unconditional love and support. For helping me overcome the obstacles faced in my life and constantly believing in me. For always being my greatest supporters.

- To my girlfriend Lara, for her love that brings out the best of me. For being always there to lend a hand and for cheering me as only she can. For making me feel the happiest man on Earth.

Thank you very much!

Resumo

A pandemia de Covid-19 demonstrou que os hospitais portugueses assim como as infraestruturas de saúde não se encontravam preparadas para enfrentar o desafio de lidar com pacientes Covid e pacientes não-Covid. Perante tal limitação de recursos, foi grande o desafio imposto aos médicos e outros especialistas na área da saúde pelo facto de não poderem tratar todos os pacientes.

O contexto de pandemia que enfrentámos com escassos recursos poderá voltar a acontecer no futuro. Assim sendo, será de toda a importância o uso de uma abordagem mais adequada para classificar os pacientes para que seja feita uma priorização dos que devem ser atendidos em primeiro lugar.

Devido à complexidade do sector da saúde, não é possível desenvolver um método classificativo para todos os tipos de pacientes que possuem patologias múltiplas. Daí que este método se deva focar numa patologia/doença especifica.

Segundo a SPC (Sociedade Portuguesa de Cardiologia), em Portugal a insuficiência cardíaca é um problema crescente de saúde pública tendo em conta o envelhecimento da população. A SPC prevê que que a atual percentagem de pacientes diagnosticados com esta doença irá aumentar significativamente nos próximos anos.

Deste modo, este estudo foca-se no desenvolvimento de um método de classificação, ELECTRE TRI-nC, baseado em determinados critérios, com o objetivo de ajudar a apoiar médicos e outros responsáveis a determinar qual a prioridade a dar a doentes com insuficiência cardíaca.

Palavras-chave: Priorização; Insuficiência cardíaca; Classificação; ELECTRE TRI-nC

Abstract

The Covid-19 pandemic showed that Portuguese hospitals and medical facilities were not prepared to face such arduous challenge of dealing with both Covid patients as well as non Covid-19 patients. With such limited resources it was very demanding for doctors and specialized health decision-makers to do their normal job as they could not treat all patients, even if they wanted to.

Scenarios like the pandemic we faced where resources are scarce could possibly happen in the future. And should such event occur it would be quite valuable to have a more adequate approach to classify patients in order to prioritize which patients should be treated first.

As the health sector is very complex it is not possible to develop such classification method for all types of patients who have mulitple pathologies. Hence, this method should be focused on one specific pathology/disease.

According to SPC (Sociedade Portuguesa de Cardiologia), cardiac insufficiency is a continuously worrying disease in Portugal due to the aging of the population. SPC predicts that the current percentage of patients diagnosed with this disease will increase significantly in the upcoming years.

Thus, this study focuses on developing a classification method, ELECTRE TRI-nC, based on specific criteria, in order to help support doctors and decision-makers making their final decision regarding prioritization of patients who suffer from cardiac insufficiency.

Keywords: Prioritization; Cardiac insufficiency; Classification; ELECTRE TRI-nC

JEL Classification System:

I10 General
I18 Government Policy • Regulation • Public Health

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1. Introduction

1.1. Motivation

With the COVID-19 pandemic outbreak in early 2020 throughout the world, it was clear that the health sector was not ready for such an unexpected and arduous challenge, specifically in the Portuguese context. According to INE (2021), the overall number of deaths in 2020 in Portugal increased when compared to previous years. Since the first diagnosis of COVID-19 on the 2nd of March up until the 27th of December, 12852 more deaths were registered in Portugal when compared to the average of the same period in the last 5 years.

Even though medical science has advanced at an extraordinary rate in recent years and despite the fact that we live in a globalized world that allows for constant communication and learning, COVID-19 brought to light multiple fragilities. An example of such a fragility in the Portuguese healthcare sector was the lack of a more adequate approach for medical clinics and hospitals to monitor their patients and analyse which of them should have had prioritized treatment during the pandemic – and this prioritization is critical due to the limited human and physical resources that characterize many areas within the Portuguese healthcare sector.

Although it should be recognized that Portuguese health authorities did the best they could to manage those scarce resources, the pandemic situation made it clear that there is still the need to define clear guidelines for supporting decisions related to the prioritization of patients, being this true for many different healthcare areas. And more than that, such a need for detailed guidelines is also required independently of the pandemics context since the scarcity of resources was already a reality before 2020.

Particularly, it will be helpful to have a structured method that allows the classification of patients according to different severity levels, to depart from that classification to decide which groups of patients should have higher or lower priority. Taking this into account, it is necessary to re-evaluate Portugal's monitoring and prioritization system in healthcare services as to guarantee allocation of available capacity and resources to patients in greater need.

Considering the particular case of cardiac insufficiency which is a common syndrome around the world, according to Cristina Gavina, SPC (Sociedade Portuguesa de Cardiologia) vice-president, about 400.000 people suffer from this syndrome in Portugal. However, SPC believes that these numbers are outdated and a new study should be done. They also predict that with the aging of the Portuguese population, the current percentage of patients who suffer from cardiac insufficiency will rise significantly in the next years. Considering that the current reality in Portugal shown by this pandemic is that there is a scarce capacity to meet the need of these patients, this scarcity will be even more problematic in coming years. Thus, it would be very important to have a methodical way to prioritize patients who suffer from cardiac insufficiency.

According to the scientific literature in the area, sorting methods are a solution for this type of problem. However, there are few studies applying these methods on the health sector and no study of this nature focused on the prioritization of patients was identified.

Hence, the main purpose of this dissertation is the development of an approach that would enable decision-makers, who must bear in mind the hospital's available resources, to make better informed decisions regarding the prioritization of patients who suffer from cardiac insufficiency. Therefore, the research question is as follows: "How can one aid decision-makers to make better informed decisions regarding the prioritization of patients who suffer from cardiac insufficiency, which is particularly relevant within the context of limited healthcare supply?"

1.2. Objectives and methodology

The primary goal of this dissertation is to develop a user-friendly tool based on a classification method that would allow to classify patients that suffer from cardiac insufficiency according to different acuity levels. This classification will be the used to better inform capacity allocation decisions within healthcare services devoted to this type of patients, which is specially relevant under contexts of limited resources. This tool would allow helping decision-makers, but the final decision would always depend on the final verdict of the doctors.

The steps towards the development of this dissertation (methodology) are the following:

- Contextualization of the problem: identification and concerns of stakeholders; establishment of resources available for this dissertation.
- Problem Formulation: identification of potential alternatives and identification of criteria and subcriteria.
- Formal Model: identification of the set of alternatives; an operationalization of the criteria must be developed; the categories are then defined; weight of each subcriteria must be then distributed; and finally, the reference actions are elaborated.

- Final Considerations and Recommendations: short summary of what was done and recommendations.

1.3. Document structure

This dissertation is structured into five chapters, being the first chapter the Introduction. The other chapters are detailed as follows:

- 2nd Chapter – Literature review: its main objective is to present different types of multi-criteria decision analysis methods through the collection and analysis of literature, to present the application of these methods in real-life cases and more specifically in the health sector;
- 3rd Chapter – Methodology: consists of the development and construction of the chosen method;
- 4th Chapter – Analysis of the results: an analysis and discussion of the results is made;
- 5th Chapter – Conclusion: final considerations of the proposed method for this dissertation.

2. Literature Review

Nowadays, companies must deal with complex and diverse problems. To make a more detailed and well-informed decision it is necessary to use decision-aiding tools. Depending on the context under analysis, these tools must frequently take into consideration a multiplicity of factors, aspects, characteristics, or attributes (Costa & Figueira, 2016) as problems can vary. And this is in fact the case of the problem under study in this dissertation, since an adequate classification of patients so as to prioritize the access to healthcare services often depends on the analysis of a variety of criteria. Some approaches are more suitable for some dilemmas and other approaches for other matters but in general terms there is consensus in that Multiple Criteria Decision Analysis (MCDA) is the approach that should be followed under similar circumstances.

MCDA methods may be used for several purposes, such as for description, selection, ranking or sorting (also called classification) purposes (Figueira et al., 2005). When considering the particular case of sorting methods, these may be useful to support decision-makers reaching a conclusion about problems that involve classifying a set of actions according to a predefined preference. And this is the key aim of this dissertation – to classify a set of patients in different severity levels.

There are distinct types of MCDA methods that can be used for sorting purposes that can be divided into subcategories:

I. The UTA (UTilités Additives) methods belong to Multiattribute Utility (MAUT) and Value Theories (MAVT).
II. The Dominance-Based Rough Set Approach (DRSA) and Verbal Decision Analysis that are considered non-classical MCDA approaches.
III. The ELECTRE methods that are a part of the Outranking methods.

These different approaches will be presented in the next chapters.

2.1. MCDA methods used for sorting purposes

2.1.1. UTA Methods

UTA methods aim at assessing a set of values or utility functions, assuming the axiomatic basis of MAUT and adopting the preference disaggregation principle (Greco et al., 2016).

These are regression-based approaches that have emerged as an alternative to a different method (Multiattribute utility theory – MAUT). The UTA methods can be treated as the primary initiatives and the most characteristic examples of preference disaggregation theory.

An approach that belongs to the UTA methods is the UTADIS (UTilités Additives DIScriminantes) approach. In this method, two error variables are employed to measure the dissimilarities between the model's results and the previously defined classification of the reference alternative (the set of options that are supposed to be classified; these correspond to the patients, for the context of this dissertation).

Over the years, different variations of the UTADIS methods have been developed to bear in mind different optimality criteria during the development of the additive value classification models. According to Greco et al. (2016) UTADIS I, UTADIS II and UTADIS III were developed for distinct reasons as they have different objectives and characteristics:

- UTADIS I: considers both the minimization of the classification errors, as well as the maximization of the distances of the correctly classified alternatives from the value thresholds.

- UTADIS II: aims at minimizing the number of misclassified alternatives.

- UTADIS III: combines the minimization of the misclassified alternatives with the maximization of the distances of the correctly classified alternatives from the value thresholds.

Another proposed method is the MHDIS (Multi-group Hierarchical DIScrimination) approach. This method enables the extension of the preference disaggregation analysis framework of the UTADIS method in intricate classification problems regarding multiple groups. MHDIS addresses sorting problems through a hierarchical procedure starting by discriminating group A_1 (group of accepted actions) from all the other rejected actions groups $\{A_2, A_3,..., A_q\}$ and then proceeding to the discrimination between the alternatives belonging to the other groups.

UTA methods have been used in the last years in various decision-making contexts such as in the financial management field where Zopounidis and Doumpos (1999) applied this method for evaluating R&D projects or when these same authors used this method in the business failure prediction. The UTA methods have also been used in marketing when for instance, Siskos et al. (2001) applied this approach for evaluating customer satisfaction.

2.1.2. Dominance-Based Rough Set Approach (DRSA)

The goal of a rough set analysis is the clarification of the reliance between the values of certain decision features, portraying the task of dependent variables, by means of the values of further condition features that play the role of independent variables.

This approach has as an advantage the capability to handle with partly inconsistent examples. Another advantage is how it can supply helpful information regarding the function of distinct features and their subsets and how it enables the preparation of representation of knowledge secluded in the data using "if…, then…" decision rules.

The main foundation of the classical rough set approach is the "indiscernibility principle". According to this, if *x* is indiscernible with *y* (*x* has the same features as *y*) then *x* should be a part of the same class as *y*. Should this not be the case, then there is an inconsistency between *x* and *y*.

An extension of rough set theory based on the dominance principle has been proposed by Greco et al. (2016) that enables the ability to deal with MCDA problems. This extension is essentialy based on the substitution of the indiscernibility relation by a dominance relation in the rough approximation of decision classes (sorting) or preference relations (ranking).

It is possible to create a preference model in form of decision rules by induction of exemplary decisions. This model is expressed through simple language that does not utilize complex analytical formulations and, therefore, its interpretation is easier to understand. It does not depend on technical parameters and this model is also able to consider situations of hesitation which is common for real expression of preferences.

Sometimes decision-makers face some difficulties with decision models since these models usually are viewed as a *black box* in which a complex language is used. With the creation of the preference model in form of decision rules induced on the basis of the rough set theory of the dominance principle (Greco et al., 2016), decision-makers have now a more transparent methodology. It is called a *glass box*. This is the principal advantage of the preference model.

This approach has been used in real life problems like when Greco et al. (1998) applied this method to evaluate bankruptcy risk.

2.1.3. Verbal Decision Analysis

This methodology is used for constructing decision methods with multiple criteria by taking cognitive psychology, applied mathematics and computer science more into account. It derives from accurate and credible data from human preference and relies on the assumption that humans psychologically are more capable of expressing ordinal relationships than cardinal data. (Greco et al., 2016).

Considering that human preference is vital for this approach and according to Greco et al. (2016), this method should:

I. Use language for problem description that is natural to the decision maker;
II. Implement psychologically valid measurement of criteria and psychologically valid preference elicitation procedures;
III. Incorporate means for consistency check of the decision-maker's information;
IV. Be "transparent" to the decision-maker and provide explanations of the result.

This approach should also enable the demonstration of the results of the analysis to the decision maker so that it associates the problem structure and the extracted information with the recomended alternative(s). Another requirement of the Verbal Decision Analysis is that it should allow the decision maker to understand how the information that he provided led to the obtained results.

There are different methods within the Verbal Decision Analysis such as ZAPROS or ZAPROS-LM. According to Greco et al. (2016) both these approaches are based on the implementation of ordinal verbal scales and ordinal tradeoffs on the scales of criteria pairs near two reference situations. The main objective of these methods is the development of the Joint Ordinal Scale (JOS), a complete rank order of vectors from Y, where Y is a subset of vectors from X with all the best values but one, applicable for all criteria.

New evolved approaches have emerged like ZAPROS III that introduced a new concept called Quality Variation that is the outcome of changing one value on the scale of one criteria. This way, the decision-maker can compare all possible Quality Variations for each pair of criteria with the assumption that all other criteria values are at the same level. Another example of an emerging approach is the STEP-ZAPROS that takes into consideration a three-step process (Greco et al., 2016) regarding the general application of ordinal preferences for comparison of real alternatives:

1- use rule of dominance to compare real alternatives on the basis of ordinal scales. If required decision accuracy is obtained, stop here

2- construct Joint Ordinal Scale and use it to compare real alternatives. If required decision accuracy is obtained, stop here

3- use additional ordinal tradeoffs to compare real alternatives as necessary. Use restructuring procedures if the necessary accuracy is not achieved.

ZAPROS methods have been used for different types of diverse decision problems like in R&D planning, job selection or applicants' selection. Flanders et al. (1998) used these methods to analyse and select pipelines and ZAPROS-LM was used by Rodrigues and Cohen (2010) in Brasil to rank ordering retail decisions.

An example of a Verbal Decision Analysis method that is, however, associated with Multiple Criteria Alternatives' Classification, is ORCLASS (ordinal criteria scales and ordinal decision classes – ordinal classification). This method has been used in different situations such as in marketing decision problems when Gomez et al. (2010) applied it when considering the effects of marketing in small businesses. It relies on the maximum "informativeness" of unclassified vectors from X and each class is presented by its average of criteria values of vectors already in the class.

A further approach is the SAC method (Subset of Alternatives Classification) where only the indirectly classified real alternatives are considered. This approach is used when a classification of a somewhat short number of alternatives is needed only once. SAC was useful for instance, when Yevseyeva et al. (2008) applied it in neuropsychology patient diagnosis.

2.1.4. ELECTRE Methods

The ELECTRE (ELimination Et Choix Traduisant la REalité) family belongs to the outranking methods and its origin goes back to the 1960's. According to Greco et al. (2016) the ELECTRE methods comprise two main procedures:

I. A multiple criteria aggregation procedure, allowing for the construction of one or several outranking relation(s) aiming to compare in a comprehensive way each pair of actions.

II. An exploitation procedure that leads to produce results according to the nature of problematic (choosing, ranking or sorting).

According to Greco et al. (2016), these methods are important when facing decision situations in which the decision-maker (DM) wants to include in the model at least three criteria. However, aggregation procedures are particularly adequate in situations when decision models include more than five criteria (up to 12 or 13). Furthermore at least one of the following situations must be also verified.

I. Actions are evaluated (for at least one criterion) on an ordinal scale or on a weakly interval scale. These scales are not suitable for the comparison of differences. Hence, it is difficult and/or artificial to define a coding that makes sense in terms of preference differences of the ratios $\frac{g_j(a)- g_j(b)}{g_j(c)- g_j(d)}$, where a, b, c, and d are four different actions. Let g_j, j = 1, . . ., n denote a coherent family of n criteria and let $a \in A$ denote the set of potential actions; $g_j\ (a)$ thus represents the performance of action a on criterion g_j.

II. A strong heterogeneity related with the nature of the scales associated with the criteria exists (e.g., environment impact, cost, aesthetics, duration, noise, distance, security). This makes it difficult to define a unique and common scale that could be used to substitute the original ones.

III. Compensation of the loss on a given criterion by a gain on another one may not be acceptable for the DM. Therefore, such situations require the use of noncompensatory aggregation procedures.

IV. For at least one criterion the following holds true: small differences of preferences must not be considered as significant. This requires the introduction of discriminating (indifference and preference) thresholds.

Since ELECTRE I (the first created method) appeared in 1965 that new methods have been developed and have evolved. Some examples of developed methods are ELECTRE I, ELECTRE II, ELECTRE IS and ELECTRE A. One of the latest methods that has emerged is the ELECTRE-TRI.

This method can be generalized by two rules: the conjunctive rule and the disjunctive rule (Greco et al., 2016).

- Conjunctive rule: to replace the condition “*on each criterion*” by “*on a sufficient majority of criteria and in absence of veto*”.

- Disjunctive rule: to replace the condition “*on at least one criterion*” by “*on a sufficient minority of criteria and in absence of veto*”.

In the last years ELECTRE methods have been put into use in different fields such as in the transportation sector when Roy et al. (1985) used this method to analyse which Paris metro stations should be renovated or in the military sector where Bana e Costa and Dinis das Neves (1989) used this approach for evaluating the Portuguese navy officers. It has also been applied in other fields such as the environment management where Georgopoulou et al. (2003) put this method into action when defining priorities for greenhouse gas emissions reduction.

2.2. Multiple Criteria Decision Analysis in health sector

MCDA methods have been successfully used in the last decades in various fields including finance, transportation, or sustainability (Doumpos & Zopounidis, 2014). Bearing in mind the nature of this study, it is crucial to understand how and when MCDA methods have been used in the health sector, when considering the case of sorting methods.

After a thorough research using keywords such as “UTA”; “methods”; “health sector” in databases like Z-library it was possible to reach the conclusion that no UTA methods was identified in the health sector.

Nonetheless, in the Rough Set approach, there are many examples where this method was used such as the study conducted by Yang and Wu (2009) that identified, through the application of a Rough Set approach (very helpful dealing with data with uncertainty), a set of serious symptoms that causes diseases in order to help a Taiwan otolaryngology clinic in medical diagnosis. Chen and Cheng (2012) proposed an integrated hybrid alternate approach (Rough Set Theory for classification and Artificial Inteligence techniques) for classifying the quality of medical practice after a total hip arthroplasty procedure. Jarzabek et al. (2014) also used this method to identify which factors tend to incline patients to come back to intensive care units after cardiac surgery. Another example used in the health sector is Blasco et al. (2015) applied a Rough Set Theory to help analyse data so that it is possible to identify metabolites that are usually involved in disease pathogenesis. Finally, another recent study was conducted by Saleh et al. (2018) which, through a classification model merging both the technique of fuzzy random forest and dominance-based rough set balanced rule ensemble, helped doctors to ascertain whether a patient is at risk of developing diabetic retinopathy (disease that damages the retina and has vision loss as a possible consequence) or not, so that patients with lower risk can be screened less often.

The Verbal Decision Analysis method has also been used for applications in the healthcare sector, particularly for areas related to neuropsychology and neurologic diseases. Yevseyeva et al. (2008) proposed a method based on this approach so as to achieve a better decision-support system, since professionals in neuropsychology usually perform diagnoses of patients' behaviour in a verbal way rather than in a numerical one. Tamanini et al. (2011) implemented a method also based on the ZAPROS approach that had as its main aim the improvement of diagnosis of Alzheimer's disease.

In what concerns the ELECTRE model, Gales and Moatti (1990) applied in southeastern France the ELECTRE IS approach to analyse and choose the best procedures for screening hemoglobinopathies. Figueira et al. (2011) applied the ELECTRE TRI-C method to help infertile couples become parents. This method allowed the assignement of each couple to an embryo-transfer category. This method was used by Bennis et al. (2013), in which the ELECTRE III method was applied so as to support decision-making related to the Moroccan blood transfusion system. A study was conducted by Diaby and Goeree (2014) where ELECTRE IS was used and considered as a method to help analyse a Health Technology Assessment (HTA) problem. Debnath et al. (2016) used an integrated Fuzzy-ELECTRE model procedure to evaluate distinct cyanotoxins removal techniques in order to choose the most satisfactory technology. Finally, another study using the ELECTRE II method cojointly with other MCDA approaches was conducted by Chalgham et al. (2019) evaluating the overcrowding of an emergency department and proposing a rational and carefull ranking and assignment of patients to the appropriate ward in the department.

2.3. Comparison of MCDA approaches for sorting problems in healthcare sector

After a thorough and meticulous analysis of different MCDA approaches, the ELECTRE family which belongs to the the outranking methods is the most suitable approach to be used in this study and this is mainly due to the following reasons:

a) Capability of handling with both qualitative and quantitative scales of criteria as these methods enable the consideration of original performances while taking into account that recoding is not necessary;
b) The heterogeneity of scales that can be used to model different concepts;
c) It acknowledges as nonrelevant the compensatory effects, as the Multiple Criteria Aggregation Procedures does not enable the compensation of performances amidst criteria. In other words, the deterioration of performances in one specific criterion cannot be compensated by improvements of performances in other criteria. The

weights of criteria do not bring about substitution rates such as in the case of several other methods;

d) It considers the imperfect knowledge of data that can affect the performances of the actions and some arbitrariness when constructing a family of criteria that is modelled by the indifference and preference thresholds.

The ELECTRE TRI-nC method belongs to the ELECTRE group of decision-aiding approaches. It emerged due to the need to characterize categories through the development of characteristic reference actions.

All these characteristics that the ELECTRE family holds make these outranking methods the most appropriate solution for this specific scenario.

Among the ELECTRE family, the ELECTRE TRI-nC approach shows several interesting features when the purpose is to apply a sorting method for healthcare planning purposes. This method has been applied, for instance, for modelling corporate credit ratings (Doumpos & Figueira, 2018) whose specific characteristics (just previously described) are similar to the ones of this study.

One of the advantages of this method is that the decision-maker can use many reference actions if considered adequate to be allocated to each category. This enables both the decision-maker and the analyst a freer capability to characterize the categories, compared to other ELECTRE methods (Almeida-Dias et al., 2012).

A different point in favor of this method is that it offers the possibility of “approaching” a frontier between two consecutive categories (Almeida-Dias et al., 2012). Another advantage is that ELECTRE TRI-nC allows the decision-maker to keep the merger of characteristic reference actions of two merged categories so that it can determine a new category.

2.4. Conclusion

With the challenges faced during the COVID-19 pandemic and the problems that arose in the health sector concerning prioritization of patients taking into account the allocation of available capacity and resources, it is comprehensible that the utilization of a decision-aiding method would be helpful for healthcare decision-makers. Consequently, in a context where there are scarce resources it would be valuable to use a sorting method as an auxiliary aiding approach to classify patients that suffer from cardiac insufficiency into different levels of severity.

Considering the advantages of this method and the many examples in which this method was used, it is possible to conclude that for this specific problem, the ELECTRE TRI-nC approach is the most appropriate.

3. Methodology

In this chapter, the steps needed to build the decision aiding tool for the prioritization of patients suffering from cardiac insufficiency based on the ELECTRE TRI-nC method will be described. The mathematical formalism and concepts of this model can be found in annex A.

The key steps of the methodology followed in this study can be represented in the figure below, representing the key steps for applying a multicriteria methodology (Roy, 1996):

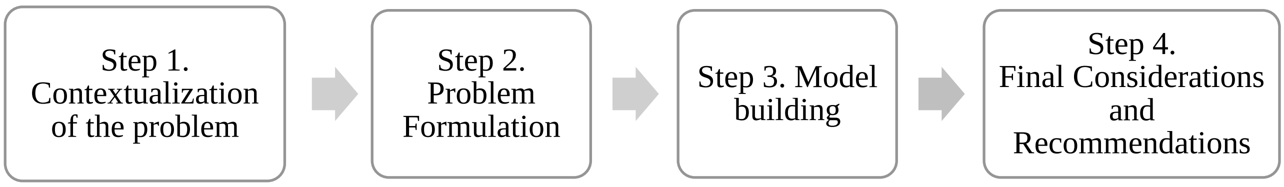

Figure 1: Key steps of methodology

The proposed methodology thus starts by setting the context of the problem, by identifying the key stakehoders and their concerns (Step 1). It then follows to the problem formulation, in which the method to be used to deal with those concerns will be presented (Step 2). Based on the presented context and problem formulation it is possible to proceed for the model building stage (Step 3), followed by the analysis of results and final considerations (Step 4).

3.1. Contextualization of the problem

The first step is the contextualization of the problem in which the stakeholders involved in the study are presented, together with their concerns (Bana e Costa & Beinat, 2005). The resources used within the scope of this study are also herein presented.

3.1.1. Identification of stakeholders

Taking into account the main purpose of this dissertation, it is possible to identify as key stakeholders for this study experts in the health sector such as doctors who work in hospitals and who have clinical experience with patients suffering from cardiac insufficiency, as well as DGS (Direção-Geral de Saúde) professionals who have a comprehensive overview of the healthcare sector as a whole. The chosen stakeholders were Doctor Cristina Ribeiro (from DGS) and Doctor Carlos Moreira (physician at Centro Hospitalar Lisboa Norte specialized in providing care to patients that suffer from cardiac insufficiency problems).

They were picked out based on their professional experience and medical knowledge and reputation. One should take into consideration the availability of the stakeholders as this is a process that requires time, and doctors have naturally limited availability (specially now).

3.1.2. Concerns of the stakeholders and resources presented

An online meeting was organized to identify the concerns of the selected stakeholders.
The main concern of the stakeholders relies on the actual capability to develop a sophisticated approach that would enable decision-makers in the healthcare sector to really make better informed decisions concerning prioritization of patients that suffer from cardiac insufficiency, with the main objective being the welfare of all patients. In order to do so, the stakeholders have to worry about the patients' medical and personal information.

The main resource involved in this process is the medical knowledge and expertise of the chosen stakeholders.

3.2. Problem formulation

The second step is the problem formulation, in which the key aim is to identify the potential alternatives (Stage I, Figure 2), as well as the key criteria and subcriteria along with associated Fundamental points of view (FPV) that need to be considered for prioritization purposes (Stage II, Figure 2) (Roy, 1996).

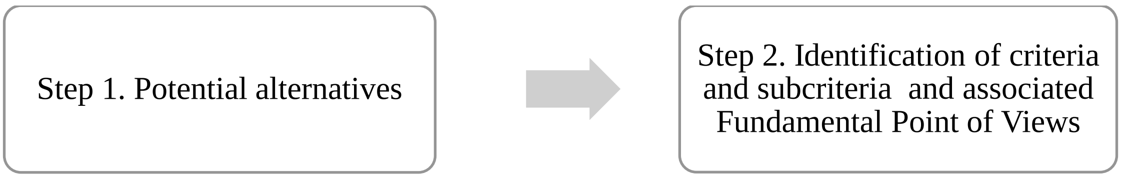

Figure 2: Key steps of problem formulation

3.2.1. Identification of potential alternatives

Considering the problem of this study, the potential alternatives are patients who suffer from cardiac insufficiency that need medical care.

3.2.2. Identification of criteria and subcriteria

The next step of the problem formulation is the careful and methodical identification of the criteria that need to be considered for prioritization purposes. First, it is crucial to identify the fundamental points of view (FPV), that represent the main areas of the problem, which must be recognized in order to select the most fitting criteria.

In this study, the FPV's and criteria were identified through a two-step approach:

- Step 1- A systematic literature review (SLR) was done to identify a first set of potential FPV and criteria.
  - Search and analysis of studies was conducted on different platforms such as Google, Z-Library or PubMed.
  - Different keywords were used in this process such as "criteria", "health-care", "patients", "levels", "cardiac insufficiency".
  - In addition to the articles found in these platforms, data from Portuguese institutions like DGS was obtained to help elaborate the chosen criteria.
  - An assessment of the articles found was made in order to rule out the studies and articles that were not a match for what was intended.

- Step 2 - Departing from the list of criteria identified under Step I, a semi-structured (online) interview with the two experts involved in the study was performed. Based on this interview, it was possible to conclude that the two experts believe that the key FPVs (and associated criteria and subcriteria) that should be considered are presented in Table 1.

It is important to clarify that in the process of identification of criteria, some aspects can be clarified, eliminated, rewritten, grouped, or decomposed so that redundancies or ambiguity can be avoided. (Bana e Costa & Beinat, 2005).

Table 1: Key FPV's, criteria and subcriteria

Fundamental point of view	**Criteria**	**Subcriteria**
Medical history	Clinical history 1	History of coronary artery disease (Acute myocadial infarction or revascularization)
		Arterial hypertension record/history
		Exposure to cardiotoxic drugs or radiation
	Clinical history 2	Use of diuretics
		Nocturnal paroxysmal orthopnea
		Nocturnal paroxysmal dyspnea
	Physical exam 1	Cardiac murmur
		Apical impulse displaced
	Physical exam 2	Bilateral malleolus oedema
		Elevated jugular venous pressure
		Pulmonary crepitations
	Electrocardiogram	Electrocardiogram changes
	Natriuretic peptides	NT-proBNP (N-terminal pro b-type natriuretic peptide)
	Ejection fraction	LVEF (Left ventricular ejection fraction)
	Recommended exams 1	Leukocytes
		Potassium
		C-reactive Proteine
	Recommended exams 2	Creatinine clearence
		HbA1c (glycated haemoglobin)
Health condition	Fragility	Fragility
Sociodemographic information	Age	Age

The Medical history FPV has a total of nine criteria and consists essentialy of medical specificities and aspects that are fundamental for the correct evaluation of a patient who suffers from cardiac insufficiency.

The Health condition FPV only has one criterion (Fragility) that enables Doctors to visualize the patient and understand the state of condition in which the patient finds himself in.

The last FPV is Sociodemographic information that also has only one criterion (Age). This FPV and consequent provides the Doctors with a certain sense of perspective of the patient's future life expectancy.

3.3. Model building

This step of the methodology starts by identifying the set of alternatives to be considered under this case (Stage 1, Figure 3). Then, an operationalization of the criteria presented in section 3.2.2. must be elaborated while bearing in mind the FPV's and the expert judgements from the specialists (Stage 2, Figure 3). Then the categories are defined (Stage 3, Figure 3) and the weight of each subcriterion must be then identified (Stage 4, Figure 3). Finally, the reference actions are elaborated while considering all the previous stages (Stage 5, Figure 3). It is important to emphasise that all these stages should be followed with the close collaboration of the specialists.

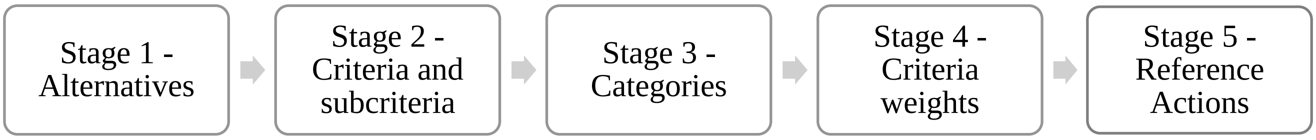

Figure 3: Steps of model building

3.3.1. Identification of alternatives

Considering the problem that concerns the nature of this dissertation, the alternatives determined are a random sample of 20 patients who suffer from cardiac insufficiency, each with his/her own characteristics.

3.3.2. Operationalization of the criteria

In this part of methodology, it is necessary to develop a scale associated with each criterion and its subcriteria.

The scales for each subcriteria can be either qualitative or quantitative, depending on each case. Qualitative scales are organized according to order of preference and quantitative scales are continuous and discreet.

A total number of eleven different criteria and twenty-one subcriteria were found, as shown in Table 1.

In order to develop the scales, an operationalization of the criteria has to be done. This was done together with the two experts via a set of various online meetings.

3.3.2.1. First set of criteria: Medical history FPV

The first nine criteria (Clinical history 1, Clinical history 2, Physical exam 1, Physical exam 2, Electrocardiogram, Natriuretic peptides, Ejection fraction and Recommended exams 1, Recommended exams 2) belong to the Medical history FPV and the levels of each subcriterion of each criterion can be described in Tables 2-10.

So, some of these criteria have more than one subcriterion. Consequently, a final scale cannot be reached in the same way as the other criteria that have only one subcriterion. So, it was necessary to build a profile tree for each criterion that has more than one subcriterion, in order to develop a final scale.

Clinical history 1:

To build a final scale for criterion Clinical history 1, a profile tree that considers all possible combinations between the levels of the different subcriteria (History of CAD, Arterial hypertension history and Cardiotoxic drugs or radiation) was created. The tables defining the scales of each subcriteria and the process that demonstrates the creation of the final scale (exhibited in Table 2) can be found in Annex B as Process 1.

Table 2: Final scale of criterion Clinical history 1

Criterion: Clinical history 1		
Subcriterion: Clinical history 1		
Scale	Levels	Description of levels
Qualitative	1	**1- Excellent**
	2	**2- Good**
	3	**3- Bad**
	4	**4- Very Bad**

Clinical history 2:

To build a final scale for the criterion Clinical history 2, a profile tree that considers all possible combinations between the levels of the different subcriteria (Nocturnal paroxysmal orthopnea, Nocturnal paroxysmal dyspnea and Use of diuretics) was created. The tables defining the scales of each subcriteria and the process that demonstrates the creation of the final scale (exhibited in Table 3) can be found in Annex B as Process 2.

Table 3: Final scale of criterion Clinical history 2

Criterion: Clinical history 2		
Subcriterion: Clinical history 2		
Scale	Levels	Description of levels
Qualitative	1	**1- Good**
	2	**2- Intermediate**
	3	**3- Bad**
	4	**4- Very Bad**

Physical exams 1:

To build a final scale for the criterion Physical exams 1, a profile tree that considers all possible combinations between the levels of the different subcriteria (Cardiac murmur and Apical impulse displaced/increased) was created. The tables defining the scales of each subcriteria and the process that demonstrates the creation of the final scale (exhibited in Table 4) can be found in Annex B as Process 3.

Table 4: Final scale of criterion Physical exams 1

Criterion: Physical exams 1		
Subcriterion: Physical exams 1		
Scale	Levels	Description of levels
Qualitative	1	**1- Excellent**
	2	**2- Intermediate**
	3	**3- Bad**

Physical exams 2:

To build a final scale for the criterion Physical exams 2, a profile tree that considers all possible combinations between the levels of the different subcriteria (Malleoulus edema bilateral, Elevated jugular venous pressure and Pulmonary crepitations) was created. The tables defining the scales of each subcriteria and the process that demonstrates the creation of the final scale (exhibited in Table 5) can be found in Annex B as Process 4.

Table 5: Final scale of criterion Physical exams 2

Criterion: Physical exams 2		
Subcriterion: Physical exams 2		
Scale	Levels	Description of levels
Quantitative	1	**1- Excellent**
	2	**2- Good**
	3	**3- Intermediate**
	4	**4- Bad**
	5	**5- Very Bad**

Electrocardiogram:

As the criterion Electrocardiogram only has one subcriterion, there is no need to build a scale. The final scale is presented in Table 6.

Table 6: Final scale of criterion Electrocardiogram

Criterion: Electrocardiogram		
Subcriterion: Electrocardiogram changes		
Scale	Levels	Description of levels
Qualitative	1	**1- No:** If the patient’s EKG shows no abnormal result that can lead to a medical condition
	2	**2- Yes:** If the patient’s EKG shows any abnormal result that can lead to a medical condition

Natriuretic peptides:

As the criterion Natriuretic peptides only has one subcriterion, there is no need to build a scale. The final scale is presented in Table 7.

Table 7: Final scale of criterion Natriuretic peptides

Criterion: Natriuretic peptides		
Subcriterion: NT-proBNP		
Scale	Levels	Description of levels
Quantitative	1	**1- <125 pg/mL:** Patient presents a normal level of NT-proBNP
	2	**2- >/= 125 pg/mLs:** Patient presents an abnormal level of NT-proBNP

Ejection fraction:

As the criterion Ejection fraction only has one subcriteria, there is no need to build a scale. The final scale is presented in Table 8.

Table 8: Final scale of criterion Ejection fraction

Criterion: Ejection fraction		
Subcriterion: LVEF		
Scale	Levels	Description of levels
Quantitative	1	**1- No cardiac insufficiency:** Patient does not suffer from cardiac insufficiency
	2	**2- <40%:** Cardiac insufficiency with reduced LVEF
	3	**3- 40-49%:** Cardiac insufficiency with intermediate LVEF
	4	**4- >/=50%:** Cardiac insufficiency with preserved/normal LVEF

Recommended exams 1:

To build a final scale for the criterion Recommended exams 1, a profile tree that considers all possible combinations between the levels of the different subcriteria (Leukocytes, Potassium and C-Reactive Protein) was created. The tables defining the scales of each subcriteria and the process that demonstrates the creation of the final scale (exhibited in Table 9) can be found in Annex B as Process 5.

Table 9: Final scale of criterion Recommended exams

Criterion: Recommended exams 1		
Subcriterion: Recommended exams 1		
Scale	Levels	Description of levels
Quantitative	1	**1- Excellent**
	2	**2- Good**
	3	**3- Intermediate**
	4	**4- Bad**
	5	**5- Terrible**

Recommended exams 2:

To build a final scale for the criterion Recommended exams 2, a profile tree that considers all possible combinations between the levels of the different subcriteria (Creatinine clearance and HbA1c) was created. The tables defining the scales of each subcriteria and the process that demonstrates the creation of the final scale (exhibited in Table 10) can be found in Annex B as Process 6.

Table 10: Final scale of criterion Recommended exams 2

Criterion: Recommended exams 2		
Subcriterion: Recommended exams 2		
Scale	Levels	Description of levels
Quantitative	1	**1- Excellent**
	2	**2- Good**
	3	**3- Intermediate**
	4	**4- Bad**
	5	**5- Terribe**

3.3.2.2. Second set of criteria: Health condition FPV

The second set consists of only one criterion that belongs to the Health condition FPV.

As it only has one subcriterion, there is no need to build a scale. The final scale is presented in Table 11.

Table 11: Final scale of criterion Fragility

Criterion: Fragility		
Subcriterion: Fragility		
Scale	Levels	Description of levels
Qualitative	1	**1- Strong** – Active, strong, highly motivated; Regular physical activity; Fit for his/her age.
	2	**2- Healthy –** No symptoms of active illnesses; Lower fitness level compared to the previous category; Seasonal or ocasional variation of physical activity.

	3	**3- Under control –** Active surveillance of comorbidities; Illness symptoms under control; No physical activity besides usual walks.
	4	**4- Vulnerable –** Uncontrolled illness symptoms; Autonomous in daily activities; Change in the walking speed (slowed-down walks); Functional limitation according to the disease symptoms; Tiredness throughout the day.
	5	**5- Mild fragility –** Mild dependence in daily life activities; Supervised medication; Supervised outdoor walks.
	6	**6- Moderate fragility –** Moderate dependence in activities of daily living and instrumental activities of daily living; Assistance and surveillance climbing up and down stairs inside the house or need for a walking assistance device; Need for support and night supervision.
	7	**7- Severe fragility –** Severe dependence in activities of daily living; Dependence on the caregiver due to limitations in physical health and cognitive functioning; Stable and with no risk of dying in the next six months.
	8	**8- Highly severe fragility –** Highly severe dependence in activities of daily living; Near the end of life; May not recover from a minor disease.
	9	**9- Terminal fragility –** Near the end of life; Life expectancy of six months; With no other fragility indicators.

3.3.2.3. Third set of criteria: Sociodemographic information FPV

The third set consists in only one criterion which belongs to the Sociodemographic information FPV.

As it only has one subcriterion, there is no need to build a scale. The final scale is presented in Table 12.

Table 12: Final scale of criterion Age

Criterion: Age		
Subcriterion: Age		
Scale	Levels	Description of levels
Qualitative	1	1- **8-65 years old**
	2	2- **65-80 years old**
	3	3- **>80 years old**

3.3.3. Categories

In view the previous steps and the expertise of the doctors, five categories were obtained based on an additional online interview with the two experts that would be appropriate for this study:

- 1- **Non Urgent:** patient needs to be observed in a non urgent way as his/her health condition is very stable. Patient needs to be observed as in a primary health care situation.
- 2- **Mildly Urgent:** patient needs to be observed in a mildly urgent way as his/her health condition is stable. Patient needs to be observed in the following *two* months.
- 3- **Moderately Urgent:** patient needs medical care in a moderately urgent way as his/her health condition is not the best. Patient needs to be observed in the following *month*.
- 4- **Urgent**: patient needs medical care as in an urgent way as his/her health condition is worrying. Patient needs to be observed in the following *week*.
- 5- **Very Urgent**: patient needs medical care immediately as his/her health condition is very worrying. Patient needs to be observed on that *same day*.

3.3.4. Criteria Weight

As soon as the criteria and subcriteria are determined a distribution of weights for every criteria must be established.

Once again, this step was elaborated with the collaboration of the two experts.

To obtain the weights a cards method that was first proposed by Jean Simos in 1994 and was later adapted by Figueira & Roy (2002) was put into practice.

This method was implemented through the web-based platform DecSpace, in which each of the following steps of the adapted methodology of Figueira & Roy (2002) were followed. Specifically:

- The first phase includes the introduction of the eleven criteria and its subsequent code, which can be found in the Annex C as Process 7.
- Then, the criteria must be established from the least important to the most important. It is relevant to highlight that for instance, two criteria can be included into the same level of importance. In this study and according to the experts, eight levels of

importance were determined in which three of these levels consist of two criteria. This means that the experts believed that two criteria had the same weight. In other words, the most important level has two criteria with the same weight: Natriuretic peptides and Recommended exams 1. The 4th most important level also has two criteria with the same weight: Fragility and Recommended exams 2. And the last important level also has two criteria with the same weight: Clinical history 1 and Electrocardiogram. All the other levels of importance only have one criteria. This step can be found in Annex C as Process 8.

- The next phase is the introduction of blank cards. This enables to further determine the difference of importance from one level to another by applying none, one or more blank cards from one level to another. The more blank cards inserted, the more distant in terms of importance is one level from the other. In this study, the experts used one blank card separating each level. This phase can be found in Annex C as Process 9.
- After all these steps, it is possible to determine both normalized (scale from 0 to 100) and non-normalized (from least important, 1, to most important, 10) weights for the criteria. The final weight distribution can be found in Figure 4:

Criteria Weight

Notation	Code	Name	Non-Normalized Weight	Normalized Weight
Insert value	ch1	Clinical history 1	1	1.6
Insert value	ch2	Clinical history 2	7.75	12.6
Insert value	ph1	Physical exam 1	2.13	3.5
Insert value	ph2	Physical exam 2	8.88	14.4
Insert value	ekg	Electrocardiogram	1	1.6
Insert value	np	Natriuretic peptides	10	16.2
Insert value	ef	Ejection fraction	4.38	7.1
Insert value	re1	Recommended exams 1	10	16.2
Insert value	fg	Fragility	6.63	10.7
Insert value	age	Age	3.25	5.3
Insert value	re2	Recommended exams 2	6.63	10.8

Figure 4: Distribution of Criteria Weight

3.3.5. Reference Actions

The reference actions are also needed to build the ELECTRE TRI-nC method. They allow the possibility of having more than one reference action per category (Almeida-Dias et al., 2012) and are applied with the knowledge and judgement of the experts to each category.

A reference action associated to the respective category is a set of representative characteristics of each criterion for the actions/alternatives allocated to each category. In other words, they represent the most common types of levels of criteria of actions used to characterize a category. For instance, for the category 1 which is Non Urgent and therefore the health condition of the patient associated to this category is normally stable, a possible reference action could be of a patient whose levels of each and every criteria is very good (low levels for criteria). For the category 5 which is Very Urgent and therefore the health condition of the patient associated to this category is normally very unstable, a possible reference action could be of a patient whose levels of each and every criteria is very bad (very high levels for criteria).

According to the specialists, the first four categories have one reference action each and the fifth category has two reference actions.

The final set of reference actions can be found in Figure 5:

Categories	Reference actions	Criteria										
		Clinical history 1	Clinical history 2	Physical exams 1	Physical exams 2	EKG	Natriuretic peptides	Ejection fraction	Recommended exams 1	Recommended exams 2	Fragility	Age
1	b_1^1	1	1	1	1	1	1	1	1	1	2	1
2	b_2^1	2	2	1	2	1	1	2	2	2	4	1
3	b_3^1	2	3	1	3	1	1	2	3	2	5	2
4	b_4^1	3	3	2	4	2	2	3	4	3	6	3
5	b_5^1	3	4	2	5	2	2	4	5	4	9	3
	b_5^2	4	4	2	5	2	2	4	4	5	8	3

Figure 5: Set of reference actions

So, it is possible to check, for instance, that for category 2 there is only one reference action. This means that there is one base type action (patient) whose medical history, health condition and sociodemographic information data and consequent levels of criteria serve as an example for characterizing the types of patients that should be allocated to category 2. The b_2^1 reference action has a value level of 2 for criterion Clinical history 1 (see Table 2), a value level of 2 for criterion Clinical history 2 (see Table 3), a value level of 1 for criterion Physical exams 1 (see Table 4) and so on.

For category 5 there are two reference actions. This means that there are two base type actions (patients) whose medical history, health condition and sociodemographic information data and consequent levels of criteria serve as an example for characterizing the two types of patients that should be allocated to category 5. The b_5^1 reference action has a value level of 3 for criterion Clinical history 1 (see Table 2), a value level of 4 for criterion Clinical history 2 (see Table 3), a value level of 2 for criterion Physical exams 1 (see Table 4) and so on.

3.4. Final considerations and recommendations

The recommendation is that the final output should enable a clear and easy to comprehend language that supports and helps the decision-maker to reach a decision.

In order to do so, this method has to be correctly applied. Meaning that it must be scientifically accurate, and no mistakes or redundancies must be made.

It is also important to make sure that the decision-makers (in this case, healthcare experts) understand the final recommendations and can apply the method to real case scenarios.

4. Analysis of the results and discussion

This section presents and discusses the results obtained through the application of the decision-aiding tool, ELECTRE TRI-nC.

This application was done using the MCDA-ULaval software.

The steps followed in this chapter can be found in Figure 6:

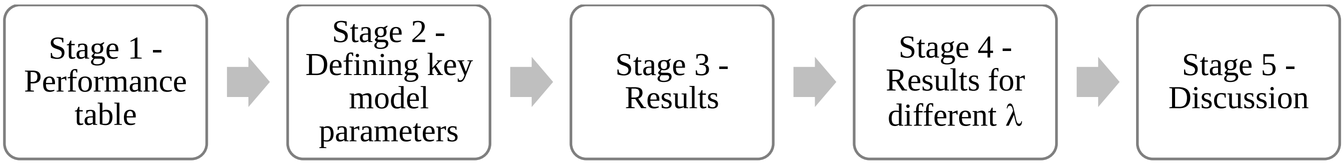

Figure 6: Steps of analysis of the results and discussion

Stage 1 consists on the random assignement of values of criteria to each alternative that is to be evaluated.

The Defining key model parameters stage is an essential step for the application of the ELECTRE TRI-nC method, where key configurations values such as preference, indifference, and veto thresholds as well as the value for the credibility level are defined.

Stage 3 is application of the method which allows the acquisition of the final results for the chosen credibility level and consequent explanation of what the results mean.

The next stage consists of the acquistion of results, but rather for different credibility levels and, also, a comparison of these results to the results obtained on Stage 3 is made.

The final stage is the discussion of the results.

4.1. Performance table

In order to apply the method, it is necessary to assign values of each criteria to every alternative. As the purpose of this thesis is not to evaluate a specific number of alternatives (patients) but rather all possible alternatives, it was determined that a sample of 20 random alternatives were to be evaluated (as previously stated in 3.3.1.).

Thus, a random simulation of performance of 20 alternatives was made which can be found in Table 13:

Table 13: Simulation of performance of 20 alternatives

[Alternative]	Clinical History 1	Clinical History 2	Physical exams 1	Physical exams 2	EKG	Natriuretic peptides	Ejection fraction	Recommended exams 1	Recommended exams 2	Fragility	Age
Extent	3	3	2	4	1	1	3	4	4	7	2
Alternative1	L3	L3	L2	L5	L2	L2	L3	L4	L5	L7	L3
Alternative2	L2	L2	L1	L2	L1	L1	L2	L2	L2	L2	L1
Alternative3	L3	L2	L1	L5	L2	L2	L2	L5	L4	L6	L3
Alternative4	L4	L4	L3	L4	L2	L2	L3	L4	L5	L8	L2
Alternative5	L2	L2	L2	L1	L2	L2	L3	L3	L2	L4	L1
Alternative6	L4	L4	L3	L3	L2	L2	L4	L3	L3	L4	L3
Alternative7	L1	L1	L1	L2	L1	L1	L2	L1	L1	L3	L1
Alternative8	L3	L3	L2	L4	L1	L2	L1	L4	L4	L5	L1
Alternative9	L2	L2	L1	L2	L2	L2	L2	L2	L3	L3	L2
Alternative10	L2	L2	L3	L2	L1	L2	L3	L2	L3	L4	L1
Alternative11	L2	L2	L2	L3	L1	L2	L2	L3	L2	L3	L3
Alternative12	L3	L4	L3	L4	L1	L2	L4	L5	L3	L7	L2
Alternative13	L4	L4	L3	L5	L2	L2	L4	L5	L5	L8	L3
Alternative14	L2	L1	L2	L3	L1	L2	L3	L3	L3	L7	L2
Alternative15	L1	L2	L2	L2	L1	L1	L1	L1	L1	L3	L1
Alternative16	L3	L1	L2	L3	L2	L2	L3	L3	L3	L5	L2
Alternative17	L1	L1	L1	L2	L1	L1	L1	L1	L2	L2	L1
Alternative18	L4	L3	L3	L4	L1	L2	L3	L3	L4	L4	L2
Alternative19	L1	L1	L2	L2	L1	L1	L2	L2	L1	L1	L2
Alternative20	L2	L1	L1	L1	L2	L1	L2	L1	L1	L2	L2

Let's see Alternative 8 as an example:

- Clinical history 1 criterion has a correspondent value of L3. So, it is necessary to check Table 2 and see that L3 is equal to level 3 (Bad) of the Clinical history 1 scale.
- Clinical history 2 criterion has a correspondent value of L3. So, it is necessary to check Table 3 and see that L3 is equal to level 3 (Bad) of the Clinical history 2 scale.
- Physical exams 1 criterion has a correspondent value of L2. So, it is necessary to check Table 4 and see that L2 is equal to level 2 (Intermediate) of the Physical exams 1 scale.
- Physical exams 2 criterion has a correspondent value of L4. So, it is necessary to check Table 5 and see that L4 is equal to level 4 (Bad) of the Physical exams 2 scale.
- And so on for the remaining criteria

4.2. Defining key model parameters

The next step is the definition of a set of key model parameters which are required to run the ELECTRE TRI-nC method (see Annex A) – preference parameters and technical parameters.

Technical parameters include the preference, *p*, and indifference, *q*, thresholds. These are used to bear in mind the imperfect nature of data as well as the arbitrariness in constructing the criteria (Costa & Figueira, 2016). Too see more, check Annex A and Roy et al. (2014)

Preference parameters include the criteria weights (already obtained in 3.3.4.), as well as the veto threshold and the credibility level. The veto threshold, *v*, is able to associate its veto power to a criteria. Meaning that the criterion that has a veto has the power to differ with the attribution of a certain alternative to a given category (Costa & Figueira, 2016).

The credibility level, λ is the minimum credibility index, σ(*a, a'*), that is considered necessary by the decision-maker to validate or not the assertion "*a* outranks *a*', taking all the criteria into account. This credbility level typically takes a value within the range [0.5, 1] (Costa et al., 2018). For this study, and with the input and approval of the experts, a credibility level of 0,65 was chosen.

The *p* and *q* threholds only assign a single value to the criterion Fragility (2 and 1, respectively) since this criterion has a low degree of precision between its levels.

The experts, acknowledging the power of the *v* threshold, considered that a value should be assigned to both Physical exams 2 and Fragility (4 and 6, respectively).

Table 14 presents the defined thresholds:

Table 14: Defined parameters

	Clinical history 1	Clinical history 2	Physical exams 1	Physical exams 2	EKG	Natriuretic peptides	Ejection Fraction	Recommended exams 1	Recommended exams 2	Fragility	Age
p	-	-	-	-	-	-	-	-	-	2	-
q	-	-	-	-	-	-	-	-	-	1	-
v	-	-	-	4	-	-	-	-	-	6	-

4.3. Results

This chapter is divided into two sections.

The first one concerns the results obtained with the previously established parameters. The second section concerns the results that were obtained but with a change as different credibility levels were used, in order to make a more robust analysis.

4.3.1. Results for λ=0,65

Now that the previous steps have been settled it is possible to obtain the final results of the application of the ELECTRE TRI-nC method.

The final results for the chosen credibility level, λ=0,65 can be found in Table 15.

Table 15: Final results for λ=0,65

Action	Minimum	Maximum
Alternative 1	C4 - Urgent	C5 – Very Urgent
Alternative 2	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 3	C5 – Very Urgent	C5 – Very Urgent
Alternative 4	C5 – Very Urgent	C5 – Very Urgent
Alternative 5	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 6	C4 - Urgent	C4 - Urgent
Alternative 7	C1 – Non Urgent	C1 – Non Urgent
Alternative 8	C4 - Urgent	C4 - Urgent
Alternative 9	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 10	C2 – Mildly Urgent	C3 – Moderately Urgent
Alternative 11	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 12	C5 – Very Urgent	C5 – Very Urgent
Alternative 13	C5 – Very Urgent	C5 – Very Urgent
Alternative 14	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 15	C1 – Non Urgent	C1 – Non Urgent
Alternative 16	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 17	C1 – Non Urgent	C1 – Non Urgent
Alternative 18	C4 - Urgent	C4 - Urgent
Alternative 19	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 20	C1 – Non Urgent	C1 – Non Urgent

For the final results of the chosen credibility level λ=0,65 it is possible to reach the following remarks:

1) Four alternatives (7, 15, 17 and 20) have been assigned to both Minimum category C1 Non Urgent and Maximum category C1 Non Urgent.

2) Three alternatives (2, 9 and 19) have been assigned to both Minimum category C2 Mildly Urgent and Maximum category C2 Mildly Urgent.
3) Four alternatives (5, 11, 14 and 16) have been assigned to both Minimum category C3 Moderately Urgent and Maximum category C3 Moderately Urgent.
4) Three alternatives (6, 8 and 18) have been assigned to both Minimum category C4 Urgent and Maximum category C4 Urgent.
5) Four alternatives (3, 4, 12 and 13) have been assigned to both Minimum category C5 Very Urgent and Maximum category C5 Very Urgent.

So, the information gathered from these alternatives is enough to make it possible to assign one alternative to a one and certain category.

This indicates that for example, the patient/alternative 7 has a set of criteria that is clear enough to assign it to the category Non Urgent. Also, patient/alternative 18 has a set of criteria that is clear enough to assign it to the category Urgent and so forth.

Nonetheless, some alternatives may be assigned to different Minimum and Maximum categories since the information regarding these alternatives is not sufficient or clear enough to assign the same Minimum and Maximum categories. For instance, the next two alternatives demonstrate this:

6) Alternative 1 has been assigned to the Minimum category C4 Urgent and to the Maximum category C5 Very Urgent.
7) Alternative 10 has been assigned to the Minimum category C2 Mildly Urgent and to the Maximum category C3 Moderately Urgent.

This means that for both patients the set of criteria is not clear enough to assign them to only one category.

For example, patient/alternative 1 has a set of criteria that is not clear enough to assign to a certain and only category. Thus, it assigns to the Minimum category C4 Urgent and to the Maximum category C5 Very Urgent. As it is a more ambiguous case, the ELECTRE TRI-nC method assigns the alternative to two categories, leaving it up for the final decision-makers to decide to which category the patient/alternative should be assigned.

4.3.2. Analysis of robustness (results for different λ)

The impact of varying the credibility levels is presented in this section where the credibility level was changed to the following values:

- λ=0,6
- λ=0,7

For the first credibility level, λ=0,6 the results can be found in Table 16:

Table 16: Final results for λ=0,6

Action	**Minimum**	**Maximum**
Alternative 1	C4 - Urgent	C5 – Very Urgent
Alternative 2	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 3	C5 – Very Urgent	C5 – Very Urgent
Alternative 4	C4 - Urgent	C5 – Very Urgent
Alternative 5	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 6	C4 - Urgent	C4 - Urgent
Alternative 7	C1 – Non Urgent	C1 – Non Urgent
Alternative 8	C4 - Urgent	C4 - Urgent
Alternative 9	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 10	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 11	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 12	C4 - Urgent	C5 – Very Urgent
Alternative 13	C5 – Very Urgent	C5 – Very Urgent
Alternative 14	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 15	C1 – Non Urgent	C2 – Mildly Urgent
Alternative 16	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 17	C1 – Non Urgent	C1 – Non Urgent
Alternative 18	C4 - Urgent	C4 - Urgent
Alternative 19	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 20	C1 – Non Urgent	C1 – Non Urgent

It is possible to conclude that with the alteration of the value of the credibility level some alternatives have been assigned in a different way when compared to the results with credibility level λ=0,65.

Table 17 shows the differences in the assignement of some alternatives when using λ=0,65 and when using λ=0,6.

Table 17: Differences when using λ=0,65 and λ=0,6

	λ=0,65		λ=0,6	
	Minimum	Maximum	Minimum	Maximum
Alternative 4	C5 - Very Urgent	C5 - Very Urgent	C4 - Urgent	C5 - Very Urgent
Alternative 10	C2 – Mildly Urgent	C3- Moderately Urgent	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 12	C5 - Very Urgent	C5 - Very Urgent	C4 - Urgent	C5 - Very Urgent
Alternative 15	C1 – Non Urgent	C1 – Non Urgent	C1 – Non Urgent	C2 – Mildly Urgent

The remainder of the alternatives did not alter.

For the second credibility level, λ=0,7 the results can be found in Table 18.

Table 18: Final results for λ=0,7

Action	**Minimum**	**Maximum**
Alternative 1	C4 - Urgent	C5 – Very Urgent
Alternative 2	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 3	C5 – Very Urgent	C5 – Very Urgent
Alternative 4	C5 – Very Urgent	C5 – Very Urgent
Alternative 5	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 6	C4 - Urgent	C4 - Urgent
Alternative 7	C1 – Non Urgent	C1 – Non Urgent
Alternative 8	C4 - Urgent	C4 - Urgent
Alternative 9	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 10	C2 – Mildly Urgent	C3 – Moderately Urgent
Alternative 11	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 12	C5 – Very Urgent	C5 – Very Urgent

Alternative 13	C5 – Very Urgent	C5 – Very Urgent
Alternative 14	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 15	C1 – Non Urgent	C1 – Non Urgent
Alternative 16	C3 – Moderately Urgent	C3 – Moderately Urgent
Alternative 17	C1 – Non Urgent	C1 – Non Urgent
Alternative 18	C4 - Urgent	C4 - Urgent
Alternative 19	C2 – Mildly Urgent	C2 – Mildly Urgent
Alternative 20	C1 – Non Urgent	C1 – Non Urgent

In this case it is possible to reach the conclusion that with the alteration of the value of the credibility level the alternatives have been assigned the same way when compared to the results with credibility level λ=0,65.

There are no differences in the assignement of alternatives when using λ=0,65 and when using λ=0,7.

4.4. Discussion

Considering the final results while using a credibility level λ=0,65 it is feasible to see that in a scenario where 20 alternatives (patients that suffer from cardiac insufficiency) have each a different set of criteria, the final outcome of assignement of altenatives to a category would be hopefully of great help for the decision-makers in a real-life scenario.

The usage of different credibility levels allows us to have a more robust analysis and to better comprehend the uncertainty regarding the assignement of alternatives/patients to a category. Considering that every criteria has various levels and as each patient has its own unique set of criteria, sometimes it is arduous for the decision-maker to assign a patient to a certain category. Of course, there are cases where the data is evident enough and it is clear to which category a patient should be assigned to.

However, it is very important to highlight the fact that the objective of this dissertation is to help the decision-maker reach in a more easily way a final decision. The main purpose of the application of the ELECTRE TRI-nC method in the scenario of this dissertation is not to replace the role of the decision-maker but rather being a support tool.

5. Conclusion

The Covid-19 pandemic showed what a great challenge it was for health-care professionals to make their normal job and help all patients when resources were scarce. Hypothetical events like the pandemic we faced where resources are limited could very much possibly happen in times to come. And should such event occur it would be entirely relevant to have a more suitable approach to classify patients in order to prioritize which patients should be treated first.

Thus, as previously stated this dissertation had as its main objective the application of a classification tool that would help support decision-makers, particularly in limited resources situations, in classifying and assigning patients who suffer from cardiac insufficiency (the health sector is highly intricate and so it is not possible to develop such classification method for all types of patients who have diverse pathologies) into distinct acuity levels.

This user-friendly tool could be of great help for doctors specialized in cardiac insufficiency in situations where limited resources are a reality. There are very few studies that focus on this specific problem while using a classification of outranking methods. Hence, it could be a very beneficial approach that would help support the final decision of the doctor as in real life scenarios tough decisions must be made and, thus, all help is valuable.

Nevertheless, it is of the utmost importance to make it clear that this tool would only serve as a support for the decision-makers and is not meant to substitute the role of the doctor.

Naturally some limitations were found when writing this dissertation. First of all, not many studies regarding this specific topic were found which made it a bit difficult to make a more thorough study.

Another difficulty found was the limitation when interacting with the decision-makers. Even though they were always very willing to help, as they are naturally quite busy professionals with a highly active schedule, meetings were sometimes difficult to set up.

Hopefully this method could be applied in real life scenarios and, therefore, a future study applying the tool in a cardiac insufficiency unit in either a hospital or medical facility could be useful and constructive. This way, decision-makers could test the method, check if it is easy to comprehend and to apply and, finally, verify if it does actually support the decision-maker in limited resources case scenarios.

Should this approach be tested and found successful by the doctors/decision-makers in the specific area of cardiac insufficiency, a really interesting idea would be the application of more thoroughly executed studies of this nature but regarding other pathologies.

So, taking into consideration the proposed objectives for this dissertation it is possible to assess that all the objectives were accomplished as a user-friendly classification tool was developed in order to help decison-makers classify patients who suffer from cardiac insufficiency in accordance to different severity levels.

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Annex

Annex A:

ELECTRE TRI-nC concepts:

Let A = $\{a_1$,..., a_i ,...$\}$ be a bundle of potential actions that can either be known a priori or gradually constructed during the decision aiding process and let it be considered a criterion, g, that is constructed with the aim to characterize potential actions in accordance to a certain point of view. The characterization of an action a, *g(a)*, represents the performance of an action, according to a given criterion.

Let F = $\{g_1$,..., g_j ,..., $g_n\}$ be denoted as a family of criteria and let C = $\{C_1$,..., C_h, ..., $C_q\}$ be defined as a set of categories in which B = $\{B_1$,..., B_h, ..., $B_q\}$ is a set of characteristic reference actions that enables the definition of categories. . Let B_h = $\{b_h^r$, r = 1, ..., $m_h\}$ denote a subset of the reference actions introduced in order to characterize category C_h, so that m_h> 1 and h = 1,...,q.

There are two thresholds: preference threshold and indifference threshold. The preference threshold, *p*, corresponds to the smallest difference of performance, that when exceeded, the better performing action is considered as strictly preferable. The indifference threshold, *q*, corresponds to the biggest difference performance that is considered compatible with a situation of indifference between two actions with distinctive performances. It should also be mentioned that a criterion g_j is considered a pseudo-criterion when it is correlated to both preference and indifference thresholds, such that $p_j \geq q_j \geq 0$.

Taking into consideration these thresholds, it is possible to derive these binary relations for each criterion:

– $|g_j$ (*a*) $-g_j$(*a*')$| \leq q_j$, represents an insignificante advantage from a to *a'*, where a is indifferent to *a'* according to criterion g_j, represented by aI_ja' ;

– g_j (*a*) – g_j (*a*') > p_j, represents an advantage *a* over *a*' in which *a* is strictly preferable to *a*' according to the criterion g_j, represented by aP_ja' ;

– q_j < q_j(*a*) – q_j (*a'*) ≤ p_j, represents an ambiguous zone as the advantage of *a* over *a*' is not enough to reach a conclusion about the indifference between *a* and *a*'and it is not enough to reach a conclusion if *a* is strictly preferable. There is a hesitation between indifference and strict preference, which means that *a* is weakly preferable to *a*', that can be represented by aQ_ja'.

An outranking relation, that is represented by aS_ja', is validated only when two conditions happen simultaneously:

– Concordance: for aS_ja' to be accepted most criterions should be in favor of this relation.

– Discordance: when none of the criterions of the minority that opposes aS_ja' puts into use its veto power.

To build an outranking relation it is necessary to take into consideration three main concepts: concordance, discordance and credibility level.

– Concordance: it is required to link to each criterion a weight, w_j, so that $w_j > 0$, with j = 1, ..., n and $\sum_{j=1}^{n} w_j$=1. The concordance is estimated by the global concordance index, c (a, a'):

c (a, a') = $\sum_{j\in C(aPa')} w_j + \sum_{j\in C(aQa')} w_j + \sum_{j\in C(aIa')} w_j + \sum_{j\in C(aQa')} w_j \varphi_j$

Considering

$$\varphi_j = \frac{p_j-(g_j(a')-g_j(a))}{p_j-q_j} \in [0,1[.$$

– Discordance: the discordance index is used to take into account the effect of the criterion's veto. For each criterion the veto effect is modeled through the partial discordance index d_j(a, a') , j = 1, ..., n.

$$d_j(a,a') = \begin{cases} 0 & \text{if } g_j(a) - g_j(a') \geq -p_j \\ \frac{g_j(a)-g_j(a')+p_j}{p_j-v_j} & \text{if } -v_j \leq g_j(a) - g_j(a') < -p_j \\ 1 & \text{if } g_j(a) - g_j(a') \geq -p_j \end{cases}$$

– Credibility level: reflects how "a prevails over a' " is justified when taking into consideration the family of criteria, F.

$\sigma(a, a')$= c(a, a') $\prod_{j=1}^{n} T_{j\ (a,a')}$

In which

$$T_{j\ (a,a')} = \begin{cases} \frac{1-d_j(a,a')}{1-c(a,a')} & \text{if } d_j(a,a') > c(a,a') \\ 1 & \text{otherwise} \end{cases}$$

With the purpose of converting dispersed outranking relations into exact outranking relations it is required to use a credibility level, λ, which can be denoted by the minimum degree of credibility, σ(a, a'). This is necessary to validate "a outranks a' ", while considering the family of criteria, F. Usually, λ, is valued between the range of [0,5; 1,0].

Let it be considered σ ({a},B_h) = $max_{r=1,...,m_h}$ {σ (a, b_h^r)} e σ (B_h,{a}) = $max_{s=1,...,m_h}$ {σ (b_h^s, a)}.

It is possible to identify four binary relations for the credibility level:

1) λ- outranking: $\{a\}S^{\lambda}B_h \Leftrightarrow \sigma(\{a\}, B_h) \geq \lambda$
2) λ- preference: $\{a\}P^{\lambda}B_h \Leftrightarrow \sigma(\{a\}, B_h) \geq \lambda \wedge \sigma(B_h, \{a\}) < \lambda$
3) λ- indifference: $\{a\}I^{\lambda}B_h \Leftrightarrow \sigma(\{a\}, B_h) \geq \lambda \wedge \sigma(B_h, \{a\}) \geq \lambda$
4) λ- incomparability: $\{a\}R^{\lambda}B_h \Leftrightarrow \sigma(\{a\}, B_h) < \lambda \wedge \sigma(B_h, \{a\}) < \lambda$

This method is constituted by two joint rules, descending rule and ascending rule, that can be used simultaneously. These rules enable the attribution of a category or set of categories to an action, a, which is compared to the subsets of reference actions, B_h, while taking into consideration a previously chosen credibility level, λ.

The use of a function, ρ=({a}, B_h) is required as a means to use these two rules. This function enables the selection of one of two consecutive categories to which an action, a, can be assigned.

$\rho = (\{a\}, B_h) = min \{ \sigma(\{a\}, B_h), \sigma(B_h, \{a\})\}$

– Descending rule: choice of a credibility level within the range of ($\frac{1}{2} \leq \lambda \leq 1$). Then lower the value of h from (q + 1) until the first value of t, such that σ ({a}, B_t) ≥ λ:

1- if $t = q$, choose C_q as possible category to assign action a.

2- if $0 < t < q$, if ρ ({a}, B_t) > ρ ({a}, B_{t+1}), select C_t as possible category to assign action a; otherwise select C_{t+1}.

3- if $t = 0$, choose C_1 as possible category to assign action a.

– Ascending rule: choice of a credibility level within the range of ($\frac{1}{2} \leq \lambda \leq 1$). Then increase the value of h from 0 until the first value of k. such that σ (B_k, {a}) ≥ λ.

1- if k = 1, select C_1 as possible category to assign action a.

2- if $1 < k < (q + 1)$, if ρ ({a}, B_k) > ρ ({a}, B_{k-1}), choose C_k as as possible category to assign action a; otherwise select C_{k-1}.

3- if $k = (q + 1)$, choose C_q as possible category to assign action a.

Each of these rules selects one possible category to each action. The simultaneous use of both these rules allows the ascertain of minimum and maximum categories for each action.

If the categories match, then the outcome is of only one possible category. If the categories differ, the assignment of an action to a category can be done by a span of categories.

Annex B:

Process 1:

Criterion: Clinical history 1		
Subcriterion: History of CAD (AMI or revascularization)		
Scale	Levels	Description of levels
Qualitative	1	1- **No:** The patient has not suffered from an AMI or has not had a revascularization procedure.
	2	2- **Yes:** The patient has suffered from an AMI or has had a revascularization procedure

Criterion: Clinical history 1		
Subcriterion: Arterial hypertension record/history		
Scale	Levels	Description of levels
Qualitative	1	1- **No:** The patient has no history of Arterial Hypertension
	2	2- **Yes:** The patient has a history of Arterial Hypertension

Criterion: Clinical history 1		
Subcriterion: Cardiotoxic drugs or thorax radiation		
Scale	Levels	Description of levels
Qualitative	1	1- **No:** The patient was not exposed to cardiotoxic drugs or thorax radiation
	2	2- **Yes:** The patient was exposed to cardiotoxic drugs or thorax radiation

The Clinical history 1 profile tree was elaborated in one step:

- A combination of all possibilities for the three subcriteria (History of CAD, Arterial hypertension history, Cardiotoxic drugs or radiation) that results in a final scale ¥.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	History of CAD	No	1		1	1	1	1		Scale ¥:	Excellent	1	
2		Yes	2			1	2	2			Good	2	
3	Arterial hypertsion history	No	1			2	1	2			Bad	3	
4		Yes	2			2	2	3			Very bad	4	
5	Cardiotoxic drugs or radiation	No	1		2	1	1	2					
6		Yes	2			1	2	3					
7						2	1	3					
8						2	2	4					
9													

Combining the subcriteria History of CAD, Arterial hypertension history and Cardiotoxic drugs or radiation resulted in a final scale ¥.

Process 2:

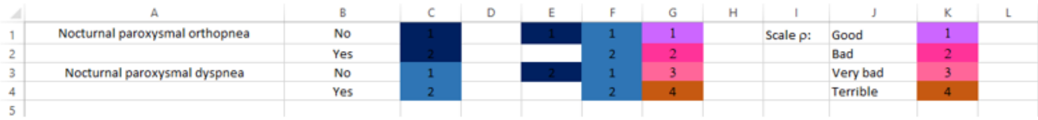
Criterion: Clinical history 2		
Subcriterion: Nocturnal paroxysmal dyspnea		
Scale	Levels	Description of levels
Qualitative	1	1- **No:** The patient has no history of nocturnal paroxysmal dyspnea
	2	2- **Yes:** The patient has a history of nocturnal paroxysmal dyspnea

Criterion: Clinical history 2		
Subcriterion: Nocturnal paroxysmal orthopnea		
Scale	Levels	Description of levels
Qualitative	1	1- **No:** The patient has no history of nocturnal paroxysmal orthopnea
	2	2- **Yes:** The patient has a history of nocturnal paroxysmal orthopnea

Criterion: Clinical history 2		
Subcriterion: Use of diuretics		
Scale	Levels	Description of levels
Qualitative	1	**1- No:** The patient has not used diuretics
	2	**2- Thiazide like:** Increases the elimination of sodium and chloride in approximately equivalent amounts
	3	**3- Loop:** Most potent diuretics as they increase the elimination of sodium and chloride by primarily preventing reabsorption of sodium and chloride.
	4	**4- Potassium-sparing,** if used in combination therapy with thiazide or diuretics**.**

The Clinical history 2 profile tree was elaborated in two step:

- 1ºstep: A combination of all possibilities for the two subcriteria (Nocturnal paroxysmal dyspnea, Nocturnal paroxysmal orthopnea) that results in a certain scale ρ



	A	B	C	D	E	F	G	H	I	J	K	L
1	Nocturnal paroxysmal orthopnea	No	1		1	1	1		Scale ρ:	Good	1	
2		Yes	2			2	2			Bad	2	
3	Nocturnal paroxysmal dyspnea	No	1		2	1	3			Very bad	3	
4		Yes	2			2	4			Terrible	4	
5												

1st step:
Combining the subcriteria Nocturnal paroxysmal orthopnea and Nocturnal paroxysmal dyspnea resulted in a certain scale ρ.

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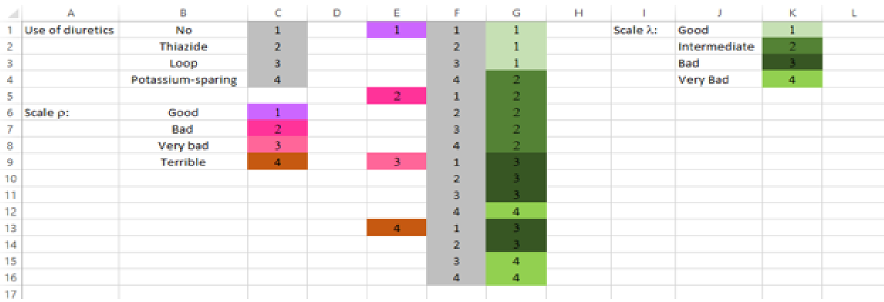
- 2ºstep: a combination of all possibilities for the certain scale ρ and the subcriterion Use of diuretics was made which results in a final scale λ.



	A	B	C	D	E	F	G	H	I	J	K	L
1	Use of diuretics	No	1		1	1	1		Scale λ:	Good	1	
2		Thiazide	2			2	1			Intermediate	2	
3		Loop	3			3	1			Bad	3	
4		Potassium-sparing	4			4	2			Very Bad	4	
5					2	1	2					
6	Scale ρ:	Good	1			2	2					
7		Bad	2			3	2					
8		Very bad	3			4	2					
9		Terrible	4		3	1	3					
10						2	3					
11						3	3					
12						4	4					
13					4	1	3					
14						2	3					
15						3	4					
16						4	4					
17												

2nd step: a combination of all possibilities for the scale ρ and the subcriteria Use of diuretics (that has five levels: No, Thiazide, Loop and Potassium-sparing) which results in a final scale λ.

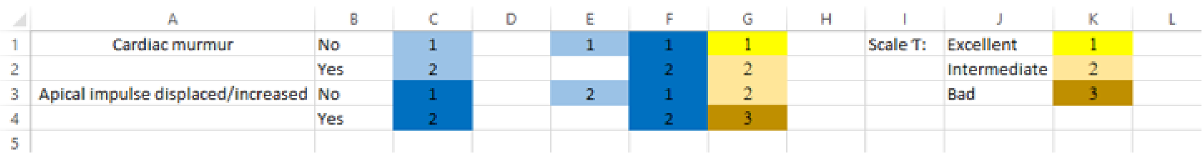
Process 3:

Criterion: Physical exams 1		
Subcriterion: Cardiac murmurs		
Scale	Levels	Description of levels
Qualitative	1	**1- No:** The patient does not have cardiac murmus
	2	**2- Yes:** The patient has cardiac murmus

Criterion: Physical exams 1		
Subcriterion: Apical impulse displaced/increased		
Scale	Levels	Description of levels
Qualitative	1	**1- No:** The patient did not have an apical impulse displaced/increased
	2	**2- Yes:** The patient did have an apical impulse displaced/increased

The Physical exams 1 profile tree was elaborated in one step:

- A combination of all possibilities for the two subcriteria (Cardiac murmurs, Apical impulse displaced/increased) was made that results in a final scale T



	A	B	C	D	E	F	G	H	I	J	K	L
1	Cardiac murmur	No	1		1	1	1		Scale T:	Excellent	1	
2		Yes	2			2	2			Intermediate	2	
3	Apical impulse displaced/increased	No	1		2	1	2			Bad	3	
4		Yes	2			2	3					
5												

Combining the subcriteria Cardiac murmur and Apical impulse displaced/increased resulted in a final scale T.

Process 4:

Criterion: Physical exams 2		
Subcriterion: Malleolus edema bilateral		
Scale	Levels	Description of levels
Quantitative	1	1- **No:** The patient does not have malleolus edema bilateral
	2	2- **Up to 2 mm (+)**: The patient has malleolus edema bilateral up to 2 mm of depth
	3	3- **2 to 4 mm:** The patient has malleolus edema bilateral from 2 mm to 4 mm of depth.
	4	4- **4 to 6 mm:** The patient has malleolus edema bilateral from 4 mm to 6 mm of depth
	5	5- **6 to 8 mm:** The patient has malleolus edema bilateral from 6 mm to 8 mm of depth

Criterion: Physical exams 2		
Subcriterion: Elevated jugular venous pressure		
Scale	Levels	Description of levels
Qualitative	1	1- **No:** The patient has no symptons of jugular engorgement.
	2	2- **<3 cm:** The patient's jugular is <3 cm length.
	3	3- **3 to <7 cm:** The patient's jugular ranges from 3 cm up to <7 cm length.
	4	4- **7 to <10 cm:** The patient's jugular ranges from 7 cm up to <10 cm length.
	5	5- **>10 cm:** The patient's jugular is >10 cm length

Criterion: Physical exams 2		
Subcriterion: Pulmonary crepitations		
Scale	Levels	Description of levels
Qualitative	1	**1- No:** The patient does not have pulmonary crepitations
	2	**2- Yes:** The patient has pulmonary crepitations

The Physical exams 2 profile tree was elaborated in two steps:

- A combination of all possibilities for the two subcriteria (Malleoulus edema bilateral, Elevated jugular venous pressure) was made that results in a certain scale ω.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Malleolus edema bilateral	No	1		1	1	1		Scale ω:	Excellent	1	
2		Up to 2 mm (+)	2			2	2			Good	2	
3		2 to 4 mm (++)	3			3	3			Intermediate	3	
4		4 to 6 mm (+++)	4			4	4			Bad	4	
5		6 to 8 mm (++++)	5			5	5			Very bad	5	
6					2	1	2					
7	Elevated jugular venous pressure	No	1			2	2					
8		<3 cm	2			3	3					
9		3 to <7 cm	3			4	4					
10		7 to <10 cm	4			5	5					
11		>10 cm	5		3	1	2					
12						2	2					
13						3	3					
14						4	4					
15						5	5					
16					4	1	3					
17						2	3					
18						3	3					
19						4	4					
20						5	5					
21					5	1	4					
22						2	4					
23						3	4					
24						4	4					
25						5	5					
26												

1st step - a combination of all possibilities for the two subcriteria (Malleolus edema bilateral and Elevated jugular venous pressure) which results in a certain scale ω.

- 2º step: a combination of all possibilities for the certain scale ω and the subcriterion Pulmonary crepitations was made which results in a final scale ν.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Pulmonary crepitations	No	1		1	1	1		Scale ν:	Excellent	1	
2		Yes	2			2	2			Good	2	
3						3	3			Intermediate	3	
4	Scale ω:	Excellent	1			4	4			Bad	4	
5		Good	2			5	5			Very bad	5	
6		Intermediate	3		2	1	3					
7		Bad	4			2	4					
8		Very bad	5			3	4					
9						4	5					
10						5	5					
11												

2nd step - a combination of all possibilities for the scale ω and the subcriteria Pulmonary crepitations (that has two levels: No, Yes) which results in a final scale ν.

Process 5:

Criterion: Recommended exams 1		
Subcriterion: Leukocytes		
Scale	Levels	Description of levels
Quantitative	1	**1. 4000 to 11000 white blood cells per mL:** Patients present a value of total leukocytes within this range (Normal results)
	2	**2. >11000 white blood cells per mL:** Patients present a value of total leukocytes higher than this value (Abnormal results)
	3	**3. >20000 white blood cells per mL:** Patients present a value of total leukocytes higher than this value (Very abnormal results)

Criterion: Recommended exams 1		
Subcriterion: Potassium		
Scale	Levels	Description of levels
Quantitative	1	**1. 3,5 to 5 mmol/L:** Patients present a potassium value within this range (Normal results)
	2	**2. 5 to 6 mmol/L:** Patients present a potassium value within this range (Abnormal results)
	3	**3. >6 mmol/L:** Patients present a potassium value higher than this value (Very abnormal results)

Criterion: Recommended exams 1		
Subcriterion: C-reactive Protein		
Scale	Levels	Description of levels
Quantitative	1	**1. <5 mg/L:** Patients present a C-reactive protein value lower than this value (Normal results)
	2	**2. 5 to 10 mg/L:** Patients present a C-reactive protein value between this range of values (Abnormal results)
	3	**3. >10 mg/l:** Patients present a C-reactive protein value higher than this value (Very abnormal results)

The Recommended exams 1 profile tree was elaborated in one step:

- A combination of all possibilities for the three subcriteria (Leukocytes, Potassium and C-Reactive protein) was made that results in a final scale κ.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Leukocytes	4000 to 11000	1		1	1	1	1		Scale κ:	Excellent	1	
2		>11000	2			2	1	2			Good	2	
3		>20000	3			1	2	2			Intermediate	3	
4	Potassium	3,5 to 5	1			2	2	3			Bad	4	
5		5 to 6	2			1	3	5			Terrible	5	
6		>6	3			2	3	5					
7	C-Reactive protein	<5	1			3	1	5					
8		5 to 10	2			3	2	5					
9		>10	3			3	3	5					
10					2	1	1	2					
11						2	1	3					
12						1	2	3					
13						2	2	4					
14						1	3	5					
15						2	3	5					
16						3	1	5					
17						3	2	5					
18						3	3	5					
19					3	1	1	5					
20						2	1	5					
21						1	2	5					
22						2	2	5					
23						1	3	5					
24						2	3	5					
25						3	1	5					
26						3	2	5					
27						3	3	5					

Combining the subcriteria Leukocytes, Potassiu, and C-Reactive Protein resulted in a final scale κ.

Process 6:

Criterion: Recommended exams 2		
Subcriterion: Creatinine clearance		
Scale	Levels	Description of levels
Quantitative	1	**1. >90 mg/dL:** Patients present a creatinine clearence value higher than this value (normal results)
	2	**2. 60 to 89 mg/dL**: Patients present a creatinine clearence value between this range of values (slightly diminished results)
	3	**3. 45 to 59 mg/dL:** Patients present a creatinine clearence value between this range of values (moderately diminished results)
	4	**4. 30 to 44 mg/dL**: Patients present a creatinine clearence value between this range of values (moderately/severely diminished results)
	5	**5. 15 to 29 mg/dL:** Patients present a creatinine clearence value between this range of values (severely diminished results)
	6	**6. <15 mg/dL:** Patients present a creatinine clearence value lower than this value (very abnormal results)

Criterion: Recommended exams 2		
Subcriterion: HbA1c		
Scale	Levels	Description of levels
Quantitative	1	**1. 0 to 6%:** Patients present a HbA1c value within this range (Normal results)
	2	**2. >6%:** Patients present a HbA1c value within this range (Abnormal results)
	3	**3. >9%:** Patients present a HbA1c value within this range (Very abnormal results) 1 semana

The Recommended exams 2 profile tree was elaborated in one step:

- A combination of all possibilities for the two subcriteria (Creatinine clearance, HbA1c) was made that results in a final scale φ

	A	B	C	D	E	F	G	H	I	J	K	L
1	HbA1c	0 to 6%	1		1	1	1		Scale ϕ:	Excellent	1	
2		>6%	2			2	2			Good	2	
3		>9%	3			3	2			Intermediate	3	
4	Creatinine clearence	>90	1			4	3			Bad	4	
5		60 to 89	2			5	4			Terrible	5	
6		45 to 59	3			6	5					
7		30 to 44	4		2	1	2					
8		15 to 29	5			2	3					
9		<15	6			3	3					
10						4	4					
11						5	4					
12						6	5					
13					3	1	2					
14						2	3					
15						3	4					
16						4	4					
17						5	5					
18						6	5					
19												

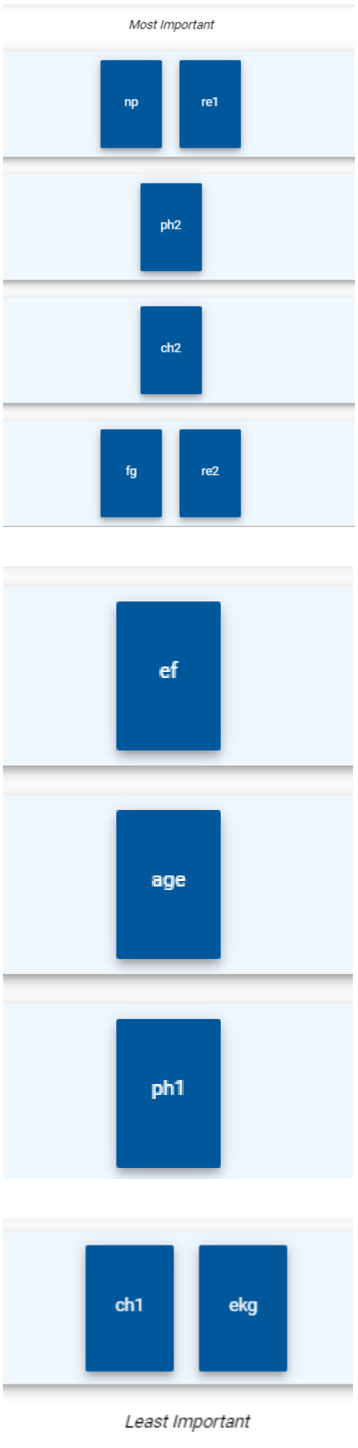
Combining the subcriteria HbA1c and Creatinine clearence resulted in a final scale ϕ.

Annex C:

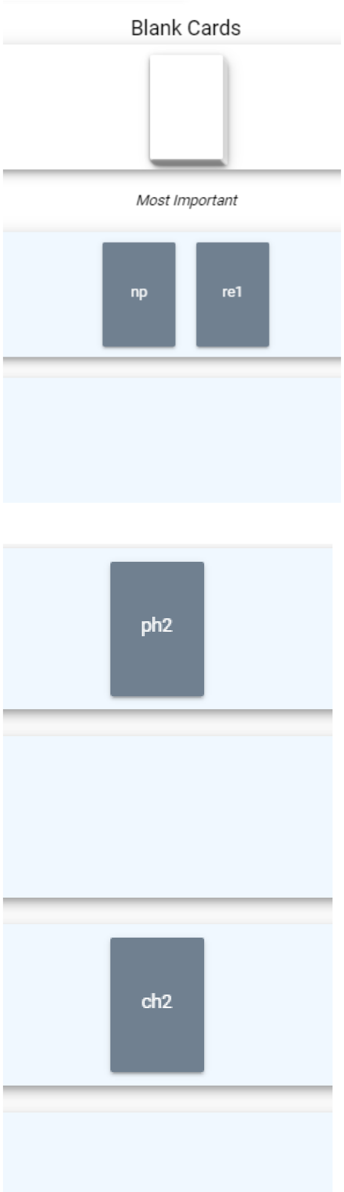
Process 7:

ID	Name	Description	Direction
2	Clinical history 1	Insert value	Maximization
3	Clinical history 2	Insert value	Maximization
4	Physical exam 1	Insert value	Maximization
5	Physical exam 2	Insert value	Maximization
6	Electrocardiogram	Insert value	Maximization
7	Natriuretic peptides	Insert value	Maximization
8	Ejection fraction	Insert value	Maximization
9	Recommended exams 1	Insert value	Maximization
10	Fragility	Insert value	Maximization
11	Age	Insert value	Maximization
13	Recommended exams 2	Insert value	Maximization

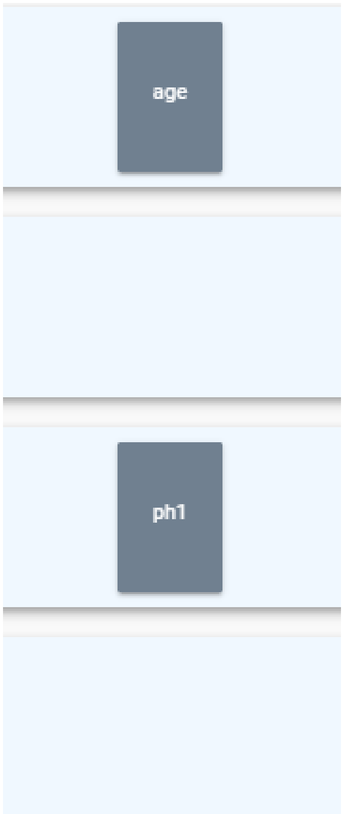
Process 8:


Most Important
np
re1
ph2
ch2
fg
re2
ef
age
ph1
ch1
ekg
Least Important

Process 9:




fg
re2
ef


age
ph1


ch1
ekg
Least Important