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Quality assessment of the Portuguese public hospitals: A multicriteria approach

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Dedicated to the ones who accompany me along this still brief journey, especially my family and friends for always having my back and allow me to follow my dreams.

Declaration

I declare that this document is an original work of my own authorship and that fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Preface

The work presented in this dissertation was performed at CEG-IST Center of Management Studies of Instituto Superior Técnico ,and CERIS during the period from February to October of 2019, under the supervision of Professor José Rui de Matos Figueira and Professor Rui Domingos Ribeiro da Cunha Marques, and within the frame of the hSNS FCT - Research Project (PTDC/EGEOGE/30546/2017).

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This dissertation is not only a work developed over six months, but the culmination of an academic path that began a long time ago. There are countless people in my life who have contributed to my success to whom I am grateful.

The education process starts at home through our first relational ties, our family. I thank the whole family, those who are and those who have left, but especially the five at home. For your unconditional support and love, for the sense of responsibility and integrity that has been instilled in me, values that have accompanied me and will accompany me in this life.

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Abstract

The Portuguese National Health Service (SNS) was created to provide universal, equal and tendentiously free care. There are different levels of care (primary, secondary, continued and palliative), however all should deliver quality care services. Quality in healthcare is composed by several criteria such as patient safety, care appropriateness or access, it should also be efficient non-compromising the other criteria. However, during the last years political and economic events had impact in the SNS. Hence, structural reforms occurred, and new health care policies were implemented, mostly focused in improving efficiency and reducing costs. This allied to divestment can increment barriers to access, compromise infrastructures and equipment and above all quality of the service provided. Thus, this dissertation aims to assess quality of the Portuguese public hospitals (secondary care providers). Here is where the ELECTRE TRI-nC comes in, enabling a multicriteria approach by formulation of a model. The formulation of a criteria tree to represent quality arrives from the literature review and the criteria weight through interactions with a decision maker. The hospital's data was collected and processed, plus a set of parameters were chosen in order to execute the ELECTRE TRI-nC. Finally, each hospital was classified and attributed to a category of existing five respectively ordered. The robustness of the model was tested through a sensitivity analysis. The result was a robust model with some space to improve. The potential application of this dissertation in future research in healthcare policy and hospital funding is high, in a SNS whose sustainability is a permanent challenge.

Keywords: Quality, Hospitals, National Health Service, ELECTRE TRI-nC, Multicriteria approach, Decision analysis

Resumo

O Serviço Nacional de Saúde (SNS) tem como objectivo prestar cuidados aos cidadãos alicerçados na universalidade, equidade, e tendencialmente gratuitos. Existem diferentes níveis de cuidados integrados (primários, secundários, continuados e paliativos), devendo todos prestar serviços com qualidade. A qualidade nos cuidados de saúde é composta por diversos critérios, como a segurança do paciente, os cuidados apropriados, o acesso e a eficiência não devendo comprometer os outros critérios. No entanto, os recentes eventos políticos e económicos têm tido impacto no SNS, levando a reformas estruturais e à implementação de novas políticas de saúde, maioritariamente focadas na melhoria da eficiência e redução de custos. Isto, aliado ao desinvestimento pode aumentar as barreiras ao acesso, comprometendo infraestruturas e equipamentos, e sobretudo condicionar a qualidade dos serviços prestados. Assim, esta dissertação pretende avaliar a qualidade dos hospitais públicos Portugueses (cuidadores secundários), através do método ELECTRE TRI-nC, que permite uma abordagem multicritério. Para representar a qualidade foi criada uma árvore de critérios validada pela literatura e pelo decisor, responsável também pela atribuição dos pesos dos mesmos. Os dados dos hospitais foram recolhidos e processados, bem como, outros parâmetros que são necessários para a execução do ELECTRE TRI-nC. Finalmente, cada hospital é classificado sendo-lhe afectada uma categoria (de cinco categorias ordenadas existentes) ou um intervalo de categorias. O resultado é um modelo robusto, ainda que com espaço para melhorias. O potencial de aplicação desta dissertação no futuro em políticas de saúde e no financiamento hospitalar é alto, num SNS cuja sustentabilidade é um desafio permanente.

Palavras-chave: Qualidade, Hospitais, Serviço Nacional de Saúde, ELECTRE TRI-nC, Abordagem Multicritério, Análise de decisão

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Nomenclature

Greek symbols

Γ	Interval of categories assigned to an action.
λ	Index of credibility.
ρ	Categorical credibility indices.

Subscripts

a	Action.
B	Reference action.
b	Subset of reference actions.
C	Category.
g	Criteria.
p	Preference threshold.
v	Veto threshold.

Glossary

AHRQ - American Agency for Healthcare Research and Quality

CPE - Corporate Public Entity

CVC - Catheter-related bloodstream infection

DA - Decision Aiding

DM - Decision Maker

E.U. - European Union

GDP - Gross Domestic Product

IOM - Institute of Medicine

MoU - Memorandum of Understanding

MCDA - Multicriteria decision aiding

NHS - National Health Service

NPM - New Public Management

OECD - Economic Co-operation and Development

RHA - Regional Health Administration

SNS - *Serviço Nacional de Saúde*

SRF - Simon Roy Figueira procedure

UCFTP - Unifetal, cephalic and full-term pregnancy

VHI - Voluntary Health Insurance

WHO - World Health Organization

Chapter 1

Introduction

The first chapter of this dissertation consists of four sections. The first section, section 1.2, explains the motivation for the problem that this dissertation deals with. The second, section 1.2, clarifies the objectives to be achieved with this study. The third, section 1.3, presents the methodology to be used that allows the resolution of the problem. The fourth and last section, 1.4 outlines the structure of the dissertation.

1.1 Motivation

No one chooses where to born. I was fortunate to be born in Portugal, a sovereign country whose Republic is based on human dignity and popular will and committed on building a free, just and supportive society. In many countries around the world this is far from being a reality, so I consider myself lucky for being treated with dignity and allowed to choose my own path, as my fellow citizens too.

The Portuguese Constitution, that grounds and governs the principles and organization of the Portuguese State, declares in the article 64,*"Todos têm direito à protecção da saúde e o dever de a defender e promover"* [1], which means "Everyone has the right to health protection and the duty to defend and promote it". The right to health is ensured through a National Health Service (SNS, from the Portuguese abbreviation *Serviço Nacional de Saúde*) created in 1976, which aims to promote a suitable and equitable care, tendentiously free to its citizens. The SNS is one of the oldest in the world, but nowadays is not meeting the needs of its population [2].

In the year of 2018, 9% of Portugal's gross domestic product (GDP) was devoted to health, more than the average of the Organization for Economic Co-operation and Development (OECD) with 8.8%. Even though this attempt to maintain the investment in health, the system is struggling to accomplish its goals in a sector full of new and complex challenges, such as, aging, demographic increase and chronic diseases. To oppose this policy-makers and healthcare managers are applying measures to improve efficiency, mostly through cost containment, that must never compromise the quality of the services provided, if possible maximizing it. However, the Portuguese hospitals are funded based on contracts that do not bear in mind the quality of the services provided. As for that, it is essential to assess the

quality of the Portuguese public hospitals, making room to uncover effects of scarifying it and possible setting benchmarks later to be inserted on funding.

Finally, the quality assessment of hospitals will be made using a multicriteria approach. The method to be used is the ELECTRE TRI-nC, allowing to use several criteria and subcriteria that best represent quality. Hopefully this will result in a robust approach capable of representing the reality of the SNS and its hospitals.

Life is not just about rights, but mostly duties, as pointed out, in the Portuguese Constitution it is declared *one must defend and promote the right to health*, make this my humble contribution, so others can also feel lucky to live in Portugal.

1.2 Objectives

This dissertation aims to evaluate the quality of Portuguese public hospitals. Quality in health is composed of various indicators that must be integrated into families of criteria to which they correspond. It is necessary to study indicators, criteria and all the variables that are related to health so a proper evaluation can be performed. Thus, in order to assess quality over its full extent, this study is supported by a multicriteria decision analysis model, the ELECTRE Tri-nC. The model allows to attribute different weights to criteria, different types of scale and preference to the inputs, in an attempt to approximate the studies to reality. To achieve the final goal, this dissertation passed by previous ones that helped us to contextualize and understand better the topic proposed.

Therefore, the objectives that were set for this work are:

- Contextualize the state of the health sector and how its variables are related;
- Define quality in the healthcare services and how it can be measured;
- Understand and describe all concepts related to multicriteria decision aiding (MCDA), especially ELECTRE TRi-nC that will be used to solve the study;
- Conceive and describe the model developed and finally the results obtained.
- Finally describe future studies, where this evaluation could have major impact.

1.3 Methodology

The methodology chosen for the approach of the present dissertation is composed by five stages schematized in figure 1.1.

The first step is to define and describe the problem, as well as, its contextualization in the health sector.

The second stage is the literature review, which is required for a better understanding of the problem and to confer it a solid theoretical basis. This stage is divided in two steps, one regarding the literature

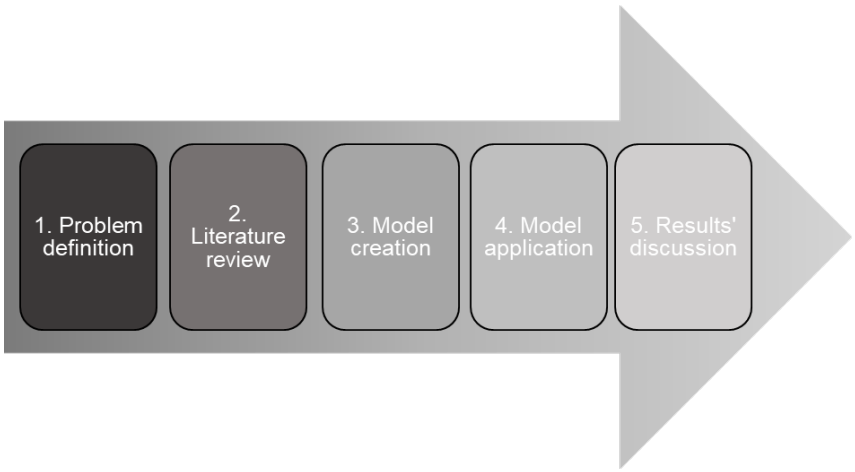


Figure 1.1: Research methodological sequential stages.

to apply in the case study and the other regarding the literature where the model constructed is based on.

The third stage is the creation of a model, that better fits the problem defined. Therefore, it is necessary to collect and process the data set, as well as, defining other parameters such as criteria, subcriteria and indicators.

The fourth stage is the application of the model, in other words, the integration of the problem in our built model to produce results. Moreover, one tests the robustness of the model.

The fifth stage one discusses and analyses the results produced, withdraw conclusions of the problem and suggests future research to be developed.

1.4 Structure of the dissertation

This dissertation has a structure of eight chapters, that follow the ideas presented in this introductory chapter. The second chapter contextualizes the problem providing information about the health sector in general, before entering in the domains of the SNS and its hospitals. The third chapter is the literature review a vital one to support our study with scientific basis, where it is defined quality in the healthcare services, as well as, how it can be measured. It ends, by defining composite indicators and how they can be built. The fourth chapter introduces decision aiding, before presenting the method used to develop our model, the ELECTRE TRI-nC. The fifth chapter unveils the case study firstly by presenting an overview of the situation, followed by the presentation of the decision maker (DM) and data set with respective processing. Furthermore, the construction of the criteria tree, criteria scales and criteria performance tables are present in this fifth chapter. In the sixth chapter the final variables of the model are defined, beginning with the weight attributed to criteria obtained with the application of the revised Simos procedure (SRF) and then the model elements with help of the DM. This sixth chapter is completed with the execution of the ELECTRE TRI-nC. In chapter seven, one presents the results obtained through the execution of the model and also by performing a sensitivity analysis to confer robustness to our model. Finally, in chapter eight one includes the conclusions of the dissertation, as well as, limitations found

during the approach and some future prospects are suggested.

Chapter 2

Problem definition

This second chapter introduces the problem and its context, from the general to specific. Firstly there is a short description of the health sector and afterwards the health sector in Portugal, especially describing the SNS characteristics and its major reforms through the years.

2.1 The health sector

The health sector assumes a highly important position among other sectors, since it is related to both social and economic reasons [3]. This combination makes it a very sensitive sector because the right to health is one of the fundamental rights of any world citizen. However, to assure this right the health expenditure has been increasing during the last decades. Some of the reasons for this rise concern demography shifts, increasing life expectancy of population, complex and chronic diseases, expansion of coverage by public health service and technology improvements [4]. Furthermore, inefficient management of resources by governments, healthcare institutions and even from their workforce is also related to increasing health expenditure [5].

The existing resources to allocate to healthcare are scarce, although the needs are virtually unlimited. Thus, the increasing of health expenditure raises issues related to the sustainability of the system and equity in access to health care.

In 2015, the United Nations declared the goal to achieve universal health coverage by 2030, “so that all people and communities receive the quality services they need, and are protected from health threats, without suffering financial hardship” [6]. However, it is vital not just to guarantee universal access, but to assure that it follows safety and appropriate guidelines to provide care with quality. One might think that lack of quality services is only related to poor countries, however OECD concluded that 15% of all hospital costs in OECD nations (not poor countries) were consequence of patient harm from adverse events [6].

All in all, this can be seen as an optimization problem where is necessary to reduce costs without compromising quality, or in other words, guaranteeing the sustainability of the health system and quality care to its patients. One of the main care providers are hospitals, thus it becomes essential to assess

the quality of care provided by them so the best practices can be adopted.

2.2 Portuguese NHS and its hospitals

For the development of this dissertation, it is critical to briefly describe the health system in Portugal, since a proper evaluation of its system and hospitals is fully related its characteristics.

In the last fifty year, Portugal has suffered a big transformation due to its political changes which have influenced the track of the health sector. It is clear that the health sector depends on internal and external factors that have been influencing its evolution. There were four episodes that caused the major reforms in the health sector:

- In 1974, when a military coup happened freeing the country from his dictatorial regime, turning it into a democratic one;
- In 1986, when Portugal joined the European Union (E.U.);
- In 2002, when there was the adoption and adaption of New Public Management principles to the health sector;
- In 2010, when Portugal faced a critical economic and financial crisis and later asked for an external intervention.

Before 1974

Before the military coup in 1974 the Portuguese health sector was divided in several entities, where most of the times functions were overlapped far from achieving a universal access to its citizens or providing a service of quality. The entities and their functions are subsequently described [7]:

- The Houses of Mercy, social solidarity independent institutions of public utility. Their aim was to improve the quality of the population and contribute for their well-being, mainly helping the mostly needed. They were the main providers of the health sector, managing hospital institutions among other services;
- The Public Health Services, focused on health protection (vaccinations, maternity protection, environmental sanitation, among others);
- The state Hospitals, which were localized in the major urban centers;
- The private services, ruled by higher socio-economics classes.

The system was fragmented and little intervened by the state, who had a very secondary role in provision and spending mostly on preventive care services (more specialized curative services such as maternal and child health, certain infectious diseases and mental health) and the civil servants care expenses. At the same time of the payments were carried by individuals.

The results obtained were discouraging especially when looking at the traditionally worst indicators in table 2.1, where Portugal was leading some of them comparing to the actual E.U. countries. In terms of health population cover about 18% of the all population was covered, facing 70.9%, the average of the E.U.; the infant mortality was 55.8% in 1969, comparing to E.U.'s 26.8%. In what comes to health public expenses, in 1969, Portugal was spending 1.7% of its GDP, facing 3.8% as the average of E.U., what suggested a low investment in healthcare [8].

Finally, in its last years the regime tried to improve the previously stated indicators introducing reforms in its health system. It was given more power to the state, being this one responsible for defining and executing health policies [9]. As a result, in 1971 it was decreed by law, the right to health to all Portuguese citizens [1].

After the revolution of 1974

This period was marked by the change of political regime, as for that large reforms were made in every sector, including health. Starting from the mode state intervenes in the sector, the democratic conception of Social State and the recognition of health as a right.

In 1976, the new and democratic Portuguese Constitution ensured in its article nr.64 the legal expression of the claim to the right to health protection. In line with, in 1979 it the SNS was fully established and described as "a universal, comprehensive and free-of-charge National Health Service" [10]. In better detail, this values of the SNS can be described as [11]:

- Universality, meaning no one is left without access to health care independently from ability or willingness to pay;
- Equity, all citizens have equal access to health care and the right to the best treatments, regardless their gender, religion, ethnic origin, social status or ability to pay for such care;
- Free, even though later on it became tendentiously free, due to the application of user co-payments.

The SNS was a complex organization structure with a decentralized management financed by the State [12]:

- Integration of the different healthcare structures in a unique system. Although, administrative and financial autonomy was structured in a decentralized and deconcentrated organization comprising central, regional and local bodies and providing primary health care services (community health centers) and health services;
- Funding from the state's general budget, where funds were collected via taxation, as usual in a Beveridge-like system.

The creation of the SNS induced positive changes in the evolution of some health indicators: the infant mortality decreased from 37.9% in 1974 to 10.8% in 1991; life expectancy increased from 68.2 average years of life in 1974 to 74.1 years in 1991, as it can be seen in table 2.1. Furthermore, in terms of efficacy the coverage of the population increased almost 100% between the years of 1974 to 1978, mostly due to the creation of Health Centers between [8].

Table 2.1: Evolution of social-demographic and health indicators in Portugal.

	1960	1974	1981	1991	2001	2011	2014	2017
Population	8.889.392	8.754.365	9.833.014	9.867.147	10.356.117	10.562.178	10.401.062	10.300.300
65 years old or plus	708.569	855.780	1.125.458	1.342.744	1.693.493	2.010.064	2.087.505	2.194.957
Index of aging (Seniors per 100 youth)	27.5	34.9	45.4	70.0	101.6	125.8	138.6	153.2
Birth rate	24.1%	19.6%	15.4%	11.7%	10.9%	9.2%	7.9%	8.4%
Mortality rate	10.7%	11.1%	9.7%	10.4%	10.1%	9.7%	10.1%	10.7%
Infant mortality rate	77.5%	37.9%	21.8%	10.8%	5.0%	3.1%	2.9%	2.7%
Life expectancy at birth (Women)	66.4	71.4	75.2	77.6	80.1	82.6	83.2	83.4
Life expectancy at birth (Men)	60.7	64.8	68.2	70.6	73.3	76.7	77.4	77.8

Integration in E.U., 1986

It was in 1986 that Portugal became a member of the current E.U. The social infrastructures were developed through access to European funding, allowing the access and expansion to equipment.

In 1990, the Basic Law on Health was decreed, being a decisive turning point in the SNS, as it redefined the state's role as responsible for health care, operating through the creation of its own services, agreements with private partnerships to provide health care and support [13]. As a consequence, some of the most important actions are reported below:

- The regionalization of health service administration, by creating the Regional Health Administrations (RHA);
- The possibility of privatizing sectors of healthcare provision, by allowing the state to promote the development of the private sector and the private management of public health care facilities;
- The possibility of privatizing sectors of health care financing, by promoting the option for private Voluntary Health Insurance (VHI);
- The possibility of creating an alternative health insurance (opting out);
- The integration of health care, with the possibility of creating health care units that would assemble hospitals and primary care units within a single region.

New Public Management, 2002

By the beginning of the new millennium and related to the preceding years, the care delivered was inefficient and ineffective [12]. From 2002 until 2009, a New Public Management (NMP) paradigm was carried out, focused on achieving better efficiency and quality health outcomes [14]. It was an attempt to reduce public resources waste, deficits and cumulative debts in hospitals. The main features of the NPM, passed by introducing new measures: contracting health care (later presented in this section), increasing the autonomy of managers, promoting transparency, managerial accountability and establishment of public-private partnerships.

Until then, public hospitals had a limited administrative and financial autonomy, being totally controlled by the Ministry of Health. Therefore with the new measures, all the major public hospitals (secondary and tertiary care) were transformed into State-owned hospital enterprises (SA), basically equivalent to private companies being subjected to the commercial/private law, although the State owns

all the shares [15]. The aim was to provide a higher autonomy associated with new payment model (contracting). However SA's did not last long, since in 2005 they were transformed into Corporate Public Entities (CPE's), in order to guarantee their public nature and a better control from both the Ministry of Health and the Ministry of Finance [3].

Concerning the organization of the health units, until then they were distinguished between primary health care and in hospital health care, in this period emerged the post-hospital care (continued care) and end-of-life care (palliative care). Additionally, there were changes in the organizational model, with the creation of hospital centers and local health units. These entities resulted from merges between hospitals and primary care centers, that had a common aim of improving efficiency through better coordination between institutions providing hospital care in the same geographical area [14].

The NPM also promoted that the health sector became a mixed system, based on the interaction between the public and private sector integrating primary, secondary and long-term care [12]. There were three co-existing and overlapping services: the SNS, the public health subsystems and VHI's.

Financial Crisis, 2010

In 2009, Portugal in line with worldwide tendency entered in recession leading into a financial crisis, between the financial year of 2010 and the financial year of 2011, the Portuguese GDP decreased nearly 4.4% [16]. By that reason, in 2011 the Portuguese state and the European triumvirate – composed of the European Commission, the International Monetary Fund, and the European Central Bank – signed the Memorandum of Understanding (MoU). This Economic and Financial Adjustment Programme brought several cost containment measures, also to be applied in the health sector.

The policies that were implemented by the agreement were austerity-based and aimed to improve the operational efficiency of public services. These policies were included in the following dimensions: (1) regulation and governance, (2) health promotion, (3) pharmaceutical market, (4) long-term and palliative care and (5) primary and hospital care.

First, unit costs were forced down as the government negotiated lower prices for drugs and cut salaries of health workers. Second, more cuts were introduced in prevention, public health and research. Third, measures were implemented to reduce demand for care, mainly by increasing co-payments [17].

These measures show that healthcare was affected by both demand-side and supply-side behaviors. On one hand, there was a rationalization of resources, with efficiency gains namely in the drug market and in the reduction of the debt of the SNS; and on the other hand, blind cuts in spending had negative impacts such as an increment of the barriers to access to health care, as well as divestment in equipment and infrastructures [16]. In addition, the crisis affected the population's health indirectly by reducing disposable household's income, the same for physicians and nurses [18].

Post-crisis

The period followed after the crisis it is still very recent, however, the previous period was marked by weak definition regarding public health policies and lack of reforms and investment in the sector, mostly

due to the scarcity of resources resulting in a worsening of the health sector [19]. Hence, the Portuguese health status suffered serious health problems and inequalities in access. The Portuguese became more vulnerable and have felt the lack of accessibility, dehumanization and the loss of quality of services.

In an attempt to revert the situation, the post MoU government, invested in policies to improve the efficiency and increase the access without jeopardizing the SNS sustainability. The new policies passed by reducing the patient fees, shortening the waiting lists, introducing new areas in the SNS (namely oral, mental and visual health), promoting public health through health education and adoption of anti-fraud and transparency measures [14].

There is still lack of literature to judge on the effectiveness of these measures since little time has passed. Although, there is still a fact that might compromise the SNS performance: the under-financing of the sector since 2010, where divestment can worsen efficiency, equity, access and quality [14].

Since this period is the most recent, lets synthesize the SNS main important features. It is characterized as a complex organization structure, with decentralized management. There are five RHAs that regionally manage public health care providers. The SNS complements the public service with the social and private systems. The Ministry of Health is responsible for the planning, organization, and regulation of the health sector in Portugal. The provision of health care is made by public entities (primary care centers, hospitals, continued, and palliative care) and by some private partners (consultations, diagnostic and therapeutic examinations, hospitals, and other private clinics). The financing of health care in Portugal is predominantly based on taxes covering most of the citizens based on a Beveridge model.

Ministry of Health

One of the main characters of the SNS is the Ministry of Health, who is responsible for exercising regulatory, planning, financing, guidance, monitoring, evaluation, audit and inspection functions related to the SNS [20]. The Ministry of Health is a governmental department, whose mission is to define and guide the national health policies, assuring the application and sustainable utilization of the resources and evaluation of the results.

The Ministry of Health is a hierarchic and complex structure headed by the Minister of Health, supported directly by two state secretaries, whose function resides in the first level of coordination. The actions and decisions taken by the Health Ministry are regulated by an independent organ called the Health Regulatory Agency (*Entidade Reguladora da Saúde* in Portuguese).

The Ministry of Health resorts to four different structures that through specific entities perform his functions: (1) direct administration of the State, (2) indirect administration of the State, (3) consultative body and (4) public enterprises, structures and entities integrated in the State business sector [20].

- (1) Direct administration:
  - The Secretariat-General for Health (*Secretaria-Geral da Saúde* in Portuguese), provides technical and administrative support to other Ministry areas;
  - The Inspectorate-General of Health-related Activities (*Inspecção- Geral das Actividades em Saúde* in Portuguese), performs the audit, supervision and disciplinary function across the

health sector not only in the SNS;

  - The Directorate-General of Health (*Direcção-Geral da Saúde* in Portuguese), which plans, directs, regulates and supervises all health promotion, disease prevention and health care activities, institutions and services, across all the health sector. Also responsible for public health programmes, quality and epidemiological surveillance, health statistics and studies;
  - The Directorate-General for Intervention on Addictive Behaviors and Dependencies (*Serviço de Intervenção nos Comportamentos Adictivos e nas Dependências* in Portuguese), acts to promote the reduction of both legal and illegal drugs consumption, the prevention and treatment of addictive behaviors, and the decrease of dependencies.

- (2) Indirect administration:

  - Central Administration of the Health Service (*Administração Central do Sistema de Saúde* or ACSS, in Portuguese), in charge of managing financial and human resources, facilities and equipment, systems and information technology of the SNS. Also responsible for implementation of health policies, regulation and planning, along with the RHAs;
  - The National Authority on Drugs and Health Products (INFARMED, as it known in Portugal), as the name suggests is responsible for the regulation and supervision of the pharmaceutical and health products sector. The objective is to ensure that all health care professionals and patients have access to safe, efficient and quality pharmaceuticals and other health products;
  - The National Institute for Medical Emergencies (INEM, as it known in Portugal), responsible for the strategy, participation and assess the activities and performance of the Integrated System of Medical Emergency, guaranteeing immediate assistance to injured and severely ill patients;
  - The Portuguese Institute for Blood and Transplantation (*Instituto Português do Sangue e da Transplantação* in Portuguese), responsible for regulating the activity of transfusions and transplantation, doing a safety collection, processing and storage of blood and its components, as well as human organs, tissues and cells.
  - Institute for Protection and Assistance in Illness (ADSE, as it known in Portugal), has the mission of guaranteeing the effective access to social protection regarding health care services to Public Administration workers and their families, supporting them in prevention, care and rehabilitation;
  - National Institute of Health (*Instituto Nacional de Saúde Doutor Ricardo Jorge* as it known in Portugal), is the reference laboratory of the SNS producing evidence for policy and action in public health through investigation and technological development, health monitoring or quality assessment;
  - Regional Health Administrations (RHAs), have their respective area of intervention with the mission of guaranteeing access to health care to the population, matching the resources available to the needs and enforcing health policies and programs. There are five different

regions: North, Centre, Lisbon and the Tagus Valley, Alentejo, and Algarve. The management responsibilities of these boards are a blend of strategic population health management, hospital supervision and control, and centralized direct management responsibilities for SNS primary care.

- Hospitals belonging to the Public Administrative Sector (*Hospitais do Sector Público Administrativo* in Portuguese), which currently are a minority of public hospitals that were not converted into Public Enterprises. In other words, these are public institutions without an enterprise status and continue to be managed by civil service rules.

- (3) Consultative bodies:

  - Health Regulatory Agency, which is an independent public entity with the mission of regulating the health care sector activity. It comprehends functions like the supervision of health care providers operating requirements, patients' defence regarding rights and access in health care, quality of health care provision, legality and transparency of economic operations, and promotion of competition in the health care sector [21];

  - National Health Council (*Conselho Nacional de Saúde* in Portuguese), a consultative and independent body from the Health Ministry. It is required, that by own initiative or by Government request, to advice and give opinions and recommendations on issues related to the implementation of health policy [22].

(4) The public enterprise sector:

- Shared Services of the Ministry of Health (*SPMS*, as known in Portugal), which provides specific shared health related services in matters of purchasing and logistics, financial management, human resources, information and communications systems, and other supplementary and subsidiary activities to organizations that are part of the SNS, irrespective of their legal nature, as well as to bodies and services of the Ministry of Health and any other organizations, as long as they carry out activities specific to the health field;

- Local Health Units (*Unidades Locais de Saúde*in Portuguese), which were created in 1999 to generate greater and better communication between primary care and hospitals, through a vertical integration of different levels of care. Currently, there are eight local health units in Portugal;

- Hospital Centers and other Public Enterprise Hospitals, which include the CPE's. Hospitals are spread through-out the country taking in account the number of residents and the health needs. These entities are classified depending on the available services provided, depending in terms of hospitalization (inpatient services), follow-up in specialty medical appointments, complementary diagnostic and therapeutic exams, timely scheduled assistance in day hospital, and unscheduled emergency service [23].

Management and Financing

As stated previously in this section, planning and regulation are mainly performed by the Ministry of Health, whereas the management of the SNS takes place at the regional level, performed by the RHA's. There are five RHA's, each of them having its own health administration council that answers to the Ministry of Health with the objective of implementing national health policies. Councils are responsible for strategic management of the delivered health care services to population, control and supervision secondary care providers (hospitals) and administer and participation in the annual financing process carried out for each primary health care centre [24].

On one hand, hospitals are responsible for delivering mainly secondary and tertiary care. In terms of administration, hospitals and hospital centers have councils with some level of autonomy and management accountability. On the other hand, primary care centers in terms of financial and administration autonomy, answer to the RHA which receives funds from the Health Ministry and allocates them between its region centers known as *Agrupamentos de Centros de Saúde*.

In terms of financing the Ministry of Health receives funds annually from the Ministry of Finance (attributed by the State budget) and allocates them to SNS institutions. The hospital global budgets are based on program-contracts (*contractos-programa* in Portuguese), that are negotiated between the Health Regulatory Agency and the Ministry of Health, the RHA's and the hospital. Through these contracts it is intended to provide health care in the SNS, "upon payment of financial compensation in accordance with the expected conditions and results obtained" [25]. These financial compensations are guided by a remuneration based on contracted production and through a convergence value, to compensate hospitals of deviation between production costs and remuneration of contracted production. These contracts follow a prospective payment system where hospitals are financed according to their dimension, past expenditures and production (volume of delivered services) [26].

The contract values are defined by clustering hospitals according to a set of size and complexity-related variables. First, it is chosen the most efficient hospital among each cluster, and finally assessing their associated unitary cost which is used as a reference value for all the others among the cluster [16]. Thus, this model is based on the distribution of resources with an incentive to efficiency, however it must not compromise equity in access or quality of service [3].

2.3 Summary

This chapter served to present the context where this dissertation lies on. First by characterizing the health sector and then entering in the particular domain of the health sector in Portugal. This domain includes the Portuguese NHS and its evolution through the time, as well as, the tools that operationalize healthcare the hospitals. We get to know how the system works and especially how is it financed by the state. Program contracts play an important role in establishing hospital funding and efficiency is their base.

Important questions can be raised regarding the hospital funding, namely, to what extent should the

efficiency of one hospital compromise the funding of another? Can a less efficient hospital provide more effective and quality care that should be considered in contracting? Perhaps the under-funding of these units is conditioning their good performance. Thereby, should quality not be taken into account as a criterion in contracting? Thus, it is extremely important to understand and assess the quality of hospitals considering their performance.

In the future perhaps through the confrontation of the actual program contracts mainly based on efficiency with others where quality is also present, may result in significant changes to the actual funding system. By now let's start by evaluating the quality of the Portuguese hospitals the aim of this dissertation.

Chapter 3

Literature review

The word quality is used in many cases with different perspectives and meanings for different people, which resulted in multiple definitions for the same concept. In this chapter the objective is to define quality in the healthcare domain, so that we can later compare the Portuguese public hospitals regarding this concept.

3.1 Quality in healthcare services

People are continuously seeking for quality, whether they refer to services or products, which are all important part of our lives. However, the perspective of the meaning of quality may be different for everyone. Quality assumes a subjective nature that depends on someone's perspective and varies within the context considered. For instance, in an international standard context, the ISO 8402:1994, quality is defined as the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs. Additionally quality has been defined as ”value” or ”excellence”, acting as a strategic differentiator tool for sustaining competitive advantage for companies as it results in waste reduction, lower costs, higher market share and a positive image [27]. Thus, in the case of this dissertation it is critical to define quality in the healthcare services to later measure and compare the distinct public hospitals performance.

If a generic definition of quality is difficult to formulate, even more is to do the same but concerning the healthcare services, which have also been defined in many ways resulting in complex and non-consensual definitions. On one hand, some authors used generic approaches which resulted in non-sensitive and non-specific definitions. On the other hand, some authors follow disaggregated approaches based on multidimensionality and selected criteria [28]. In this case each dimension provides an evaluation of quality on its own view, however when combining all the dimensions it results in a complex and more specific evaluation.

An example of this approach is Donabedian's definition of quality in healthcare, as a product of three interrelated categories in his Structure-Process-Outcome model [29]:

– Structure category denoted the attributes in which care occurs, including the material resources

(*e.g.* infrastructures and equipment).

- Process category denoted the actions performed by the staff to deliver care services (*e.g.* interactions between clinicians and patients). The best process measures are the ones that follow clinical evidence to achieve better outcomes.

- Outcome category denoted the effects of the care services delivered on patients' quality of life. The best outcome measures are the ones which are related to the care provided.

All the dimensions provide valuable information for measuring quality, however most of the literature suggests that they are not used together for several reasons [30]. Some authors question the usage of the outcome category to characterize the quality of hospitals. Yet, outcomes offer evidence about changes in patients' health status, since outcomes tend to be genuinely concrete willingly to more precise measurement. As for that, outcomes can work as the ultimate validators of the quality of medical care and have been continuously applied when defining quality [31]. Moreover, patients offer a complementary perspective comparing to care providers and policy makers and should therefore be involved in a quality assessment process[32]. Nevertheless, there are some precautions to considered regarding the use of outcomes as quality indicators due to intrinsic limitations, namely whether the outcome itself is a relevant measure of quality, how difficult it is to measure that outcome (*e.g.*patient satisfaction or social restoration are difficult to measure), or simply the fact that non-medical care factors vary and influence the outcomes, so outcomes should be used with discrimination [31]. Above all, it is still difficult to collect data regarding outcomes comparing to structure and process categories, where indicators are easier to collect and be accessed.

There are two categories, care appropriateness and clinical safety, that represent outcome and process categories that can be identified.

Clinical safety concerns the absence of preventable adverse effects during the medical acts, *i.e.*, prevent harm to a patient and reduce the risk of unnecessary harm during the process of healthcare. Medical choices and acts often involve some risks for the patient, which increases with the coexistence and severity of the disease. As for that, some medical complications such as bloodstream infections and postoperative pulmonary embolisms can be preventable or not [30]. Thus, in these situations where unless the events are preventable, the adverse effects happen due to staff errors resulting in lack of care safety. Furthermore, these situations are related to patients discomfort emotionally and physically, loss of trust in the healthcare system and also related to financial waste since additional care to correct errors is needed.

The other category, care appropriateness, concerns whether the services provided are considered appropriate, *i.e.*, based on evidence guidelines and existing scientific knowledge. The process of evidence based medicine is conscientious, explicit, and judicious using the best evidence in making decisions about the care of individual patients [33]. Evidence based medicine integrates the individual clinical expertise with the best available external clinical evidence. Despite some procedures performed may not harm the patient, if they are not recognized as scientific knowledge, then they are not considered appropriate care and must be avoided. Situations when care appropriateness is not followed

can result in avoidable re-admissions after inpatient discharge, excessive staying delay and also in a decrease in the number of minor procedures that are harmlessly to patients comparing to major surgeries [30]. Furthermore, re-admissions may result from poor resolution of the health problem, unstable therapy at discharge and inadequate post-discharge care [34]. Nevertheless, care appropriateness and clinical safety are two related dimensions, since whenever the care provided is not appropriate, it can result in negative outcomes regarding the safety of the patient. Finally, it is cross-dimension that the health workforce to achieve high-quality health care requires skilled health care workers [35].

Another multidimensional definition of quality care arises from the Institute of Medicine (IOM) 2001 seminal report, *Crossing the Quality Chasm: A New Health System for the 21st Century* that defined it as ”the degree to which health care services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge”. Moreover, the same report defined quality as having six dimensions, however the report was revised in 2018 originating modifications. The resulting six dimensions are presented below [6]:

- Safety: Avoiding harm to patients from the care that is intended to help them.
- Effectiveness: Providing services based on scientific knowledge to all who could benefit and refraining from providing services to those not likely to benefit (avoiding overuse and underuse, respectively).
- Person-centeredness: Providing care that is respectful and responsive to individual patient preferences, needs, and values and ensuring that patient values guide all clinical decisions. Care transitions and coordination should not be centered on health care providers, but on beneficiaries. Note that in 2001 the dimension was ”patient-centeredness” however the care nature evolved in the last years and is now organized to the extent possible around the needs and goals of each individual person rather than around disease categories or homogeneous groups.
- Accessibility, Timeliness, Affordability: Reducing waits and sometimes harmful delays for both those who receive and those who give care; reducing access barriers and financial risk for patients, families, and communities; and promoting care that is affordable for the system.
- Efficiency: Avoiding waste, including waste of equipment, supplies, ideas, and energy. Additionally, including waste resulting from poor management, fraud, corruption, and abusive practices.
- Equity: Providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socioeconomic status.

Both models present similarities in two dimensions: clinical safety and safety, as well as care appropriateness and effectiveness, suggesting the importance of both categories previously described. Besides, the IOM considered four more dimensions. Accessibility, timeliness and affordability to healthcare is one of them, and it is considered that a citizen has access to healthcare services whenever they can use it. According to Gulliford, access is composed by four dimensions [36]:

– Service ability, since to guarantee access to health care it is required an adequate supply of health services. It is commonly measured as the available hospital resources per inhabitant, such as the number of doctors or nurses.

– Personal barriers, it concerns the recognition of patients' of their need for care, followed by their demand. It is usually the first phase in the process of accessing health services.

– Financial barriers, considering that they influence patients' utilization of services, even though in health systems are essentially free like Portugal. Patients may experience costs due to the travel to and from the healthcare service location and charged fees for specific services. The magnitude of this barrier depends on the users' willingness and ability to pay. Note that this dimension is related to the affordability dimension.

– Organizational barriers, where the lack of timely care reflected in long waiting lists and waiting times decreases the access.

Regarding the equity dimension, ideally, the quality of care should vary little among subgroups according to gender, ethnicity, religion, geographic location, socioeconomic status, and so on [6]. Thus, in case of significant variance existence it is possible to characterize which patients' sociodemographic characteristics influence the quality of care they receive.

The efficiency dimension concerns reducing or ideally avoid waste of equipment, supplies, ideas and energy, allowing to obtain the best health outcomes at the minimum possible cost. Health care providers are considered technically efficient, when using the minimum number of inputs for a given number of outputs. Hospital consume financial resources, such as expenses with staff, drugs, pharmaceutical products, clinical consumables and outsourcing; and physical resources regard the workload of clinical staff, especially doctors and nurses [30]. However, there are several entities considered technically efficient simply because they divest on the safety of their patients, care appropriateness and access, to achieve a major number of treated patients, with several problems for the institution and patients. On one hand patients receive poor treatment, sometimes undertreatment, resulting in the development of complications for them or others around. On the other hand, those complications can result in more costly treatments for the entity. As for that a saying fits nicely in this situation, *it is better a well-treated patient, than two half treated*. Also, the divestment in infrastructures and equipment are responsible for increasing the barriers to access resulting in the problems previously described, as long waiting lists and times [16].

The last dimension that defines quality care for the IOM, Person-centeredness. This dimension suggests that care should be organized around the needs and goals of each individual, instead of disease categories or homogeneous groups, as for instance the Diagnosis Related Groups (DRG) used in the Portuguese NHS. In addition, for WHO, improving health literacy and requiring active participation of users in their care process results in a better perception for them of services received as more responsive, effective and acceptable. The participation of the target population in service delivery design and assessment makes people partners of their own health care [37].

Finally, to sum and as it was said in the beginning of this section, defining quality is complex and it is seen to be multidimensional, being the reason why we present both Donabedian's and IOM's points of view, that seem complete and correlated. Furthermore, both definitions meet the principles of medical ethics: beneficence, non-maleficence, autonomy and justice. Therefore, the dimensions are embodied in the highest guidelines of care. High quality care needs to be accessible, effective, safe, centred on patient's needs and given in a timely manner. Once defined a unifying conceptual framework, one needs to choose metrics that better represent and measure the performance of each quality dimension.

3.2 Measuring quality in healthcare services

Once quality is defined, it is important to explain how it is possible to evaluate the quality of a healthcare entity. The evaluation is done using a set of indicators, where each of them is related to one of the quality dimensions. The indicators need to be contextually appropriated before measured, in other words, integrated to the real situation. The measurement is essential, as it will provide information to evaluate if the health systems and the health policy followed are producing the best results for people. Even though it is good to have many indicators capable of assessing quality, if not contextually integrated the conclusions might be wrong and biased. Also, in case of choosing poor indicators, it becomes difficult to measure their baseline and progress regarding quality. As a consequence, entities can't identify what is working or not and in which circumstances, therefore they are not able to understand where benchmarks should be set.

During the past decades, the attention to performance measurement in the delivery of medical care has increased. This has been centered on the several relationships between the three Donabedian dimensions, structure, processes and outcomes, with the strong recognition that the practice of medicine should be evidence based. Several entities, such as both the American Agency for Healthcare Research and Quality (AHRQ) and the IOM, or the international OECD and World Health Organization (WHO), have developed efforts towards validating indicators to measure the performance of the quality of medical care provided by the healthcare entities [38].

According to the IOM, indicators are stronger if they assess processes and moreover, if they measure outcomes [6]. However, most current indicators are mainly focused on structural and process inputs, rather than in outcomes. This can be explained, since it is more difficult to have access to the information that patients can provide, as well as, the outcomes can result from multiple care interventions and poor integration between systems or entities databases result in poor information.

For the AHRQ, quality measurements imply that the approach followed is rigorous, systematic and quantifiable, so that the measurements obtained are reliable, valid and standardized. Hence, the reality is fairly represented allowing comparisons between cases or even among different entities.

The indicators that will later be used for the development of this dissertation were integrated in their dimensions according to the AHRQ and IOM standards.

3.3 Composite indicators and their importance

Defined the concept of quality in healthcare and how indicators can be used to measured it, for health entities or groups of them it is vital to link the indicators to the health dimensions and take conclusions from the information generated. As said in the previous section 3.2, it is possible to identify what is working or not and in which context. Yet, it is possible to go further and define benchmarks among different healthcare entities, with the aim of increasing simultaneously their performances regarding for instance quality, or other topics. Another level, would be using this analysis to drive or monitor policies, what is possible by using composite indicators.

The use of composite indicators for designing and monitoring policies has gained much interest in recent decades. According to OECD, a composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured[39]. According to El Gibari, some authors believe that MCDA approaches are highly suitable in multidimensional frameworks when aggregating single indicators into a composite one, as this process involves making decisions when it comes to combine criteria of different nature [40]. There is an increasing tendency towards using MCDA methods to construct composite indicators.

Composite indicators main virtue is their powerful usage for policy analysis being able to summarize complex issues and interdependent phenomena in wide ranging fields, e.g., health, environment or economy. It is easier to interpret composite indicators since they are able to provide a bigger picture, rather than finding a common trend in many distinct indicators, being also useful in benchmarking performances [41]. Additionally, they are drivers of behavior and of change by forcing institutions and governments to question their standards.

Nevertheless, composite indicators are confronted by statisticians, economists, among others who sometimes are skeptic due to the lack of transparency of some indicators, methodologies and data concerns [42]. So, caution is needed in order to avoid situations where composite indicators may send misleading or non-robust policy messages due to poorly constructed indicators or misinterpreted.

Together OECD and Applied Statistics Unit of the Joint Research Centre (JRC), developed a methodological work of good practices for creating composite indicators that suggests following the next steps [42]:

- Theoretical framework, it should be developed creating the basis for the selection and combination of single indicators in order to build relevant composite indicator under a fitness-for-purpose principle.

- Data selection, for the selection of indicators characteristics like analytical soundness, measurability, coverage, relevance to the phenomenon being measured and relationship to each other should be taken in account. It is suggested the use of proxy variables in case of scarcity of data;

- Multivariate analysis, it is applied to the overall structure of the indicators for evaluating the suitability of the data set and describe subsequent methodological choices, like weighting and aggregation;

- Imputation of missing data, although different methods can be used for imputing missing values and provide a complete data set. Regarding extreme values they should be examined to avoid unintentional benchmarks errors;
- Normalization, as indicators should be normalized in order to make them comparable;
- Weighting and aggregation, where indicators in this task should be aggregated and weighted according to the underlying theoretical framework;
- Robustness and sensitivity, the resulting analysis should be carried out to evaluate the robustness of the composite indicator in terms of selection of the indicators, normalization, imputation of data and weights;
- Links to other variables, efforts should be made to correlate the composite indicator with existing indicators as well as to identify linkages through regressions;
- Visualization, it should receive proper attention, taking in account that the visualization can influence interpretations;
- Back to the real data, since composite indicators should be transparent and be able to be decomposed into their underlying indicators or values.

The previous framework steps are present in some of the MCDA methods that can be used to construct composite indicators. One of the most used methods are the ELECTRE family. Before getting into details of the methods, since it will be addressed in the next chapter, the most important is to say that the application of these family of methods results in final values (when well performed) taken as the composite indicator [40]. Therefore, one will make use of ELECTRE methods to construct the composite indicators that will allow us to assess quality in healthcare entities.

3.4 Summary

This chapter introduced the concept of quality in healthcare, which is composed by several dimensions: safety, effectiveness, person-centeredness, accessibility, efficiency and equity. There was a need of reviewing all the dimensions and how they are connected, since a proper evaluation of the hospital's quality is fully related to them. Furthermore, understanding how quality can be measured and what could be built through the measurement (composite indicators), opened space for the next chapter where one will review the MCDA methods and especially the ELECTRE TRI-nC.

Chapter 4

Multicriteria decision aiding

This chapter introduces the Multiple Criteria Decision Aiding, first by describing its utility and then its characteristics and methodology. Afterwards this chapter focuses in presenting the existing literature on the MCDA method chosen for the development of this dissertation, the ELECTRE TRI-nC. The literature review covers topics as the method's foundation, methodology and application.

4.1 Decision aiding

There is an old saying in Portuguese that says "Life is made of choices", this suggests there are decisions to be taken no matter how simple or complex they are part of our daily life. Decisions have consequences, some good and some bad, they also have conflicting points of view or criteria that one considers when the time for deciding arrives. As for that, it was since the very beginning that mankind started developing methodologies to help them taking the best decisions according to their objectives. Even though I found older examples of these approaches, Benjamin Franklin's procedure called "Moral Algebra" caught my attention due to its iconic figure [43]. Whenever Franklin was trying to decide his position on a serious matter, he would write on opposite sides of a sheet of paper arguments in favor or against that matter. Afterwards he would struggle to estimate the respective weights of each argument and following this estimation he would cross out the arguments on each side of the paper. If two arguments on each side were equally weighted, he would cross both out, however if there were arguments in each side differently weighted, he would cross as much arguments until the balance was reached. Later, it would happen that one of the sides would run out of arguments (all crossed out), then Franklin would support the side where there were still arguments left standing as the best option. This procedure was clearly an early Decision Aiding (DA) approach, where Franklin would not only take a decision, but also weight his arguments.

According to Roy, one makes use of DA models when is trying to obtain elements of responses, that can help answering the stakeholder's questions [44]. These elements strive to clarify a decision, or merely recommend a behavior to increase the consistency between the evolution of the process and the stakeholder's goals and value system. In the end, the resulting information of the model is evaluated

taking into consideration the subjective preferences of the decision-maker [45]. The DA approach is grounded in three pillars which characters bear in mind when performing the analysis [46]:

1. The *actions*, that refer to the objects of the decision, the same are called alternatives whenever it is not possible to execute them together;
2. The *consequences*, that refer to the aspects, attributes or characteristics of the action, that make possible comparisons between actions;
3. The *modelling of on or several preference systems*, where for each pair of actions envisioned, designates one and only one of the three situations: *indifference*, *preference* or *incomparability*. Hereby given two possible actions, the user considering their consequences and their value system may: opt for one action over another (revealing *preference*), or express indifference in the choice between both actions, or state he is unable to compare the two actions (*incomparability*).

When Franklin was splitting arguments as pros or cons, he was taking in mind different points of view, which can be roughly described as criteria and are fundamental for the application of DA models. Bouyssou defines a criterion as "a real-valued function on the set A of alternatives, such that it appears meaningful to compare two alternatives a and b according to a particular point of view" [47]. In case the user is only using one criterion for the comparison between the alternatives, then the DA approach is monocriterion. But, if it is unusual that the DM only has one single clear criterion to guide the process, it is even rarer when there is more than one decision-maker [44]. Therefore, in this type of situations, we are in the domain fields of multicriteria decision aiding, which as the name suggests more than one criteria is used. Each criterion is considered independently from the others and is used to evaluate any potential action according to their *performance*. A performance is a score attributed to potential actions that allows to make comparisons and establish *preferences* between one or more potential action, according to a certain criterion. The scores or degrees can be represented by a number, a verbal statement or a pictogram and can be bounded by various types of scales [44]:

(a) Purely ordinal scale or qualitative scale, where the gap between two degrees does not have a clear meaning in terms of difference preferences. On one hand this can happen in a *verbal scale*, when it is impossible to declare that the pairs of consecutive degrees reflect equal preference differences all along the scale; on the other hand, it can happen in a *numerical scale*, when it is impossible to declare that a given difference x between two degrees reflects an invariant preference difference when we move the pair of degrees considered along the scale.

(b) Cardinal scale or quantitative scale, it is a numerical scale whose degrees are clearly and quantitatively defined, in a way that it gives sense to the absence of quantity (degree 0) and to the existence of a unit allowing us to clarify each degree as the addition of a given number of such units. Therefore, the difference between two scores can receive a value which does not depend on the two particular degrees considered.

The quality of the MCDA depends on the quality of the construction of the criteria, thereby to increase quality Roy determines three conditions concerning the relationships of criteria [44]:

1. Exhaustiveness, which avoids the loss of information;

2. Cohesiveness, which considers the compatibility that must be present between the role of each criterion when considering preferences;

3. Nonredundancy, this means none of the criteria should be considered redundant.

Decision Aiding is a helpful tool, especially when one wants to solve the three MCDA major problematics [48]: ranking, sorting and choice. In a ranking problematic we are interested in ranking all the alternatives, meaning we want to order a given set of actions from the best to the worst taking into account their importance on a considered criterion. In a sorting problematic one wants to assign each alternative to a set of categories *a priori* defined according to norms or typical elements of the referred category. At last, the choice problematic consists of aiding the DMs in selecting a subset of alternatives, as small as possible, considered as the best so he/she can finally choose.

Therefore, once defined DA and hence MCDA and the problematics where it is applied, let us identify the two key characters, who are responsible for building and performing it: the decision maker, who has been talked about, in whose name or for whom this decision aiding is to be given; and not least important, the analyst who is responsible for giving the decision aiding through developing the models and all the computational skills of the process [46]. It is requested that the two characters cooperate to enable them reaching a decision, by empowering their capability of understanding the problem, objectives and values being faced. The empowerment is achieved as a result of organizing and synthesizing complex and conflicting information, where the most useful approaches result from simple and transparent applications [49]. The approach framework can be simplified in four fundamental steps [45]:

1. Structuring, which consists in defining the decision problem encompassing the choosing of the DM;

2. Evaluating, which consists on attributing scores and weights to the criteria; Scores are achieved creating a model of intra-criteria preferences, that values the performance of different options for each criterion, while weights are achieved by elicitation of the scaling constants that reflect the difference of attractiveness between criteria;

3. Testing, which consists in the sensitivity analysis and robustness of the model;

4. Decision making, the final step that ends with a choice of the best alternatives.

Note that analyst should particularly assist the DM, both in obtaining judgments of value and preference information, as in the interpretation of computational results, live up to its skills.

Beware that although DA procedures main objective is to help identifying and providing the best decisions, users are free to follow the recommendation made by the models, like George E. P. Box once said ”All models are wrong, but some are useful”; in other words models are representations of reality, by that it is recommended that users never lose their critical sense.

The application of MCDA in solving real-world problems is vast and covers a wide range of areas from finance, to energy planning among many others [46]. Also in healthcare they already started to be

applied, which is very logical since healthcare decisions are complex and involve confronting different points of view [50]. Although it is possible to find articles about the allocation of resource along medical treatments, or the choice of the best alternative for a certain patient, until now MCDA was never used to create composite indicators to evaluate hospital access or quality. Thus, in this dissertation it was developed a model using a MCDA method later to applied in a case study whose mission is to assess the quality and access of the Portuguese public hospitals. The chosen method, ELECTRE TRI-nC is subsequently presented.

4.2 The ELECTRE TRI-nC method

The ELECTRE family of methods, stands for ELimination and Choice Expressing the REality (in French ELimination Et Choix Traduisant la REalité), is used to deal with real-world MCDA situations with the following characteristics [46]:

- The DM wishes to include in the model a minimum of three criteria.
- Actions are evaluated either on a purely ordinal scale or on a weak interval scale. These scales are not suitable for the comparison of differences.
- There is a strong heterogeneity related to the nature of the scales associated with the criteria, which makes harder to define a single and common scale that could be used to replace the originals;
- Compensation of the loss on a given criterion by a gain on another one may not be acceptable for the DM. Therefore, aforementioned situations require the use of non-compensatory aggregation procedures;
- The presence of small differences of preferences may not be considered significant, as a result it is required the addition of discriminating (indifference and preference) thresholds.

Most of the collected literature about the ELECTRE family methods arises from France, since it was Bernard Roy and his colleagues from Paris-Dauphine University who developed them. During the 60s Roy created ELECTRE I, which was the first preference model based on outranking relations. An outranking relation is a binary relation,*S*, defined on the set of potential actions, *A*, such that *a* is preferred to *b* (aSb) if there are enough arguments to decide that *a* is at least as good as *b*, while there is no essential argument to refute that statement [51], this subject was deeper addressed in the section 4.2.2. The application of the ELECTRE methods is based on two main components:

- A multiple criteria aggregation procedure, which allows to build one or more outranking relations based on the performances of each action on each criterion with the perspective of comparing in a more comprehensive way each pair of actions;
- An exploitation procedure, which is used to obtain adequate results, meaning that they bear in mind the nature of the problematic (choosing, ranking or sorting).

There are several ELECTRE methods designed with different features and variants in order to face the three main problematics defined before. One of them is the ELECTRE TRI-C method, which is appropriate for MCDA sorting problems where the set of categories is ordered and each of them is defined through a single characteristic reference action. Moreover, this method was conceived to verify a set of fundamental structural requirements (conformity, homogeneity, monotonicity and stability) [52]. Although ELECTRE TRI-C was first developed it is a generalization of ELECTRE TRI-nC method, since in the last one there are no constraint for the number, *n*, of reference actions as typical of each category [53]. Note that an increase of the reference actions for a same category contributes for enriching the definition of each category and allows to obtain more narrow intervals of categories to which an action can be assigned to [46]. ELECTRE TRI-nC allows the DM and the analyst in the co-construction decision process to characterize the categories with a major freedom comparatively to ELECTRE TRI-C; furthermore it allows the DM not only to merge two consecutive categories through keeping the union of the characteristic reference actions of the two merged categories, but also to split a category through making an ordered partition of the reference actions, resulting in two new consecutive categories. Thereby, ELECTRE TRI-nC is not merely a generalization, also presenting advantages and including more features comparing to ELECTRE TRI-C.

4.2.1 Concepts, definition and notation

Let $A = \{a_1, a_2, ..., a_i, ...\}$ denote the set of potential actions, which can be fully known *a priori* or be progressively built up during the decision aiding process. The method intends to assign these actions to a set of completely ordered categories, defined as $C = \{C_1, C_2, ..., C_h, ..., C_q, ...\}$ being $q \geqslant 2$. As for that, it is necessary, a family of criteria, denoted $G = \{g_1, g_2, ..., g_j, ..., g_n\}$ which will characterize the potential actions, to assign them to a certain category, note that if $n \geqslant 3$, the concept of concordance is not pertinent. In some cases each criterion g_j, also possesses a set of sub-criteria, $G_j = \{g_{j,1}, ..., g_{i,j}, ..., g_{j,n_j}\}$, for $j = 1, ..., n$. To represent the performance of an action, *a*, according to a given criterion, *g*, one uses $g(a)$. As for the set of reference actions, which define the categories it is denoted $B = \{B_1, B_2, ..., B_h, ..., B_q, ...\}$. Let $B_h = \{b_h^r, r = 1, ..., m_h\}$ be a subset of the reference actions introduced to characterize category C_h, such that $m_h \geqslant 1$ and $h = 1$,...,q [53].

Each criterion, g_j, is considered a pseudo-criterion or criterion with thresholds, since it is associated with two thresholds: (1) the preference threshold, (p_j), between the performance of two actions, corresponds to the smallest performance difference that, when exceeded, the best performing action is considered to be strictly preferable; and (2) the indifference threshold, (q_j), between the performance of two actions, corresponds to the largest performance difference that is judged compatible, with a situation of indifference between two actions, with different performances. Notice that $p_j \geqslant q_j \geqslant 0$. The purpose of these thresholds is to take in account the imperfect character of the data from the computation of the performances $g_j(a)$, for all $a \in A$, as well as the arbitrariness that affects the definition of the criteria. It is expected that all criteria $g_j \in G$ are to be maximized, thus the preferences increase when the criteria performances increase too [52]. When using the mentioned thresholds, the following binary relations

can be derived for each criterion:

- $|g_j(a) - g_j(a')| \leqslant q_j$, where a is indifferent to a' according to criterion g_j, in the right notation written aI_ja';

- $g_j(a) - g_j(a') > p_j$, where a is strictly preferable to a' according to criterion g_j, represented by aP_ja';

- $q_j < q_j(a) - q_j(a') \leqslant p_j$, where the judgment is ambiguous, and there are no sufficient reasons to conclude an indifference situation, nor a strict preference between the two action. There is a hesitation between indifference and strict preference, meaning that a it is weakly preferable to a', represented by aQ_ja'.

Regarding the statement, $p_j \geqslant q_j \geqslant 0$, q_j may be equal to 0 and/or equal to p_j. If $p_j = 0$, any difference of performances in favor of one action over another can be considered as significant for a strict preference on criterion g_j. On the other hand, this is not always true as a result of the imperfect data characteristics or to arbitrariness that may affect the definition of the criteria.

4.2.2 Outranking relations

As previously stated, an outranking relation is represented by aS_ja', which means that "the action a is at least as good as a'", according to a criterion g_j. For the construction of outranking relations one needs to consider three concepts that allow to justify the same construction: agreement, non-disagreement and degree of credibility [54]:

- Concordance: refers to the conformity between criteria that favors aS_ja' to be accepted, meaning a sufficient majority of criteria must be in favor of this relation. The concordance is estimated by the global concordance index, $c(a, a')$, that associates each criterion to a weight w_j, such that $w_j > 0$, with $j = 1, ..., n$ and $\sum_{j=1}^{n} w_j = 1$(assuming the sum of all weights is 1). By definition:

$$c(a, a') = \sum_{j \in C(aPa')} w_j + \sum_{j \in C(aQa')} w_j + \sum_{j \in C(aIa')} w_j + \sum_{j \in C(aQa')} w_j \varphi_j \tag{4.1}$$

  being the parameter φ_j defined by:

$$\varphi_j = \frac{p_j - (g_j(a') - g_j(a))}{p_j - q_j} \in [0, 1[\tag{4.2}$$

- Non-discordance: when none of the minority criteria that opposes aS_ja' exercises its power to veto this assertion, in other words refuting it. The discordance is estimated by the discordance index, that associates each criterion to a veto power, v_j, such that $v_j > p_j$. The veto effect is modeled

using the partial discordance index, $d_j(a, a')$, $j = 1, ..., n$, and is defined as:

$$d_j(a,a') = \begin{cases} 0 & \text{if } g_j(a) - g_j(a') \geqslant -p_j, \\ \dfrac{g_j(a) - g_j(a') + p_j}{p_j - v_j} & \text{if } -v_j \leqslant g_j(a) - g_j(a') < -p_j, \\ 1 & \text{if } g_j(a) - g_j(a') < -v_j, \end{cases} \tag{4.3}$$

– The credibility index: denoted by $\sigma(a, a')$, is the degree of credibility to consider that the action "a is at least as good as the action a' ", taking into account the family of criteria, defined by F. To estimate this index is considered the global concordance index and the partial discordance index, following expression:

$$\sigma(a,a') = c(a,a') \prod_{j=1}^{n} T_j(a,a') \tag{4.4}$$

being $T_j(a, a')$ defined by:

$$T_j(a,a') = \begin{cases} \dfrac{1 - d_j(a,a')}{1 - c(a,a')} & \text{if } d_j(a,a') > c(a,a'), \\ 1 & \text{otherwise.} \end{cases} \tag{4.5}$$

The ELECTRE TRI-nC method, defines a credibility level as the minimum degree of credibility denoted by λ, which is necessarily considered by the DM for validating or not an outranking statement taking in account all criteria from F. The credibility level can be seen as a cutting level, since it converts a fuzzy relation into a crisp outranking relation [55]. Typically λ, takes a value within the range $[0.5, 1[$ [54]. For the definition of the following outranking relations, the credibility level λ is compared to the credibility indices of the different actions and to the set of reference actions of each category, where $\sigma(\{a\}, B_h) = max_{r=1,...,m_h}\{\sigma(a, b_h^r)\}$ and $\sigma(B_h, \{a\}) = max_{s=1,...,m_h}\{\sigma(b_h^s, a)\}$. The credibility level allows to define four λ-binary relations that later assume a role to propose an assignment, the relations are presented below:

a) λ-outranking: $\{a\} S^{\lambda} B_h \Leftrightarrow \sigma(\{a\}, B_h) \geqslant \lambda$;

b) λ-preference:$\{a\} P^{\lambda} B_h \Leftrightarrow \sigma(\{a\}, B_h) \geqslant \lambda \ \wedge \ \sigma(B_h, \{a\}) < \lambda$

c) λ-indifference: $\{a\} I^{\lambda} B_h \Leftrightarrow \sigma(\{a\}, B_h) \geqslant \lambda \ \wedge \ \sigma(B_h, \{a\}) \geqslant \lambda$

d) λ-incomparability:$\{a\} R^{\lambda} B_h \Leftrightarrow \sigma(\{a\}, B_h) < \lambda \ \wedge \ \sigma(B_h, \{a\}) < \lambda$

4.2.3 Assignment procedure

The assignment procedure is performed to attribute one category or an interval of categories, to an action a, which is compared to the reference actions B_h considering the level of credibility λ. As for that, the ELECTRE TRI-nC method makes use of two joint rules: the ascending rule and the descending rule. Both rules include a function $\rho(\{a\}, B_h)$, that allows the choice of one of two consecutive categories to

be assigned to an action a. The selection function is following presented:

$$\rho(\{a\}, B_h) = min\{\sigma(\{a\}, B_h), \sigma(B_h, \{a\})\} \tag{4.6}$$

Explained the selection function, it is of interest describe how the two joint rules are defined in order to assign one or more possible categories to an action a [56]:

- Descending rule: choose a credibility level λ in the range of $[0.5, 1]$; and decrease h from $(q+1)$ until the first value, t, such that $\sigma(\{a\}, B_t) \geqslant \lambda$ (C_t is called the descending pre-selected category):
  a) If $t = q$, select C_q as possible category to assign action a;
  b) For $0 < t < q$, if $\rho(\{a\}, B_t) > \rho(\{a\}, B_{t+1})$, then select C_t as a possible category to assign a; otherwise, select C_{t+1};
  c) For $t = 0$, select C_1 as possible category to assign a.
- Ascending rule: choose a credibility level λ in the range of $[0.5, 1]$; and increase h from 0 until the first value of k, such that $\sigma(B_k, \{a\}) \geqslant \lambda$ (C_k is called the ascending pre-selected category):
  a) For $k = 1$, select C_1 as a possible category to assign action a;
  b) For $1 < k < (q+1)$, if $\rho(\{a\}, B_k) > \rho(\{a\}, B_{k-1})$, then select C_k as a possible category to assign a; otherwise, select C_{k-1};
  c) For $k = (q+1)$, select C_1 as a possible category to assign a.

Each rule selects one possible category to each action. However, the fact that rules act simultaneously, can result in two different possibilities: the minimum and maximum categories are overlapped that results in the attribution of one single category; or the minimum and maximum categories are different, which results in an interval of categories. The interval of categories to which an action a can be assigned to by ELECTRE methods is denoted $\Gamma(a)$.

4.2.4 Application of the ELECTRE TRI-nC

In the development of this dissertation, the application of the ELECTRE TRI-nC was performed with help of a software tool, MCDA-ULaval. This allowed to save time with the performance of all the computational calculus.

The MCDA-ULaval tool is a free and open-source desktop application developed ate Université Laval [55] containing all the ELECTRE family methods. This tool allows to create projects that can deal with multiple data sets, containing the criteria, actions, performance tables and decision configurations. Regarding technology it was written in Java and uses several external libraries. The main benefits of this tool besides the time that saves users are: (1) the possibility of importing and exporting data, such as pre-defined performed tables with all the parameters defined, (2) the possibility of automatically normalize weights, (3) the possibility of using criteria in ordinal scales or cardinal scales, (4) the possibility of performing sensitivity analysis of the decision parameters and finally (5) the presentation of the scenario analysis, under diagrams, for the incorporation of the same in the results.

4.2.5 Method strong features and limitations

There are different MCDA methods where each of them presents their advantages and limitations, even inside the ELECTRE family. According to Costa et al., the ELECTRE TRI-nC provides several advantages for sorting problems [54]:

- Existence of quantitative and qualitative scales, that allow to consider the original performances with no need of recoding. Another advantage regarding scales is that they can be heterogeneous, thus there is no need to normalized data preserving original performances of the actions on the criteria;
- Different criteria can have distinct weight;
- The method is non-compensatory, which means that worst performances on certain criteria can't be systematically compensated by better performances on other criteria;
- The consideration of imperfect knowledge and arbitrariness when building the criteria is taken into account by adding the indifference and preference thresholds;
- ELECTRE methods can model the reasons in favor (agreement) and the reasons against (disagreement) in comparing two actions, and use a veto threshold, which reinforces the non-compensatory character of the method;
- It is possible to classify suppliers into various categories (more than two);
- A category can be defined by one or more reference actions, in ELECTRE TRI-C only one is reference action is possible.

The previously presented advantages, give support to the ELECTRE TRI-nC in its mission of assigning actions to corresponding ordered categories, taking into account the chosen set of criteria. Also, note that when assessing actions they are compared with reference actions that characterize each category, thus providing the advantage of an absolute comparison rather than a relative comparison [54].

Nonetheless, the ELECTRE TRI-nC presents some limitations or weaknesses, which indeed are also present in other ELECTRE methods. One of them is the fact of not being adequate to assign a performance to each action, whenever the DM feel s necessary to attribute a performance to an action. If all the scales of the criteria are quantitative it is more appropriate to use other methods, unless the user wants to use a non-compensatory method in that case it is recommended. Finally, the last weakness concerns transitivity. Typically methods based on outranking relations do not need to satisfy the transitivity property, however if it is *a priori* defined that preferences should be transitive it represents a weakness [54].

4.3 Summary

In this chapter one presented MCDA methods, which as the name suggests call upon multicriteria to solve decision analysis problems. These methods first identify problems, which are applied to models

designed to simulate situations. Models are tested using sensitivity analyzes to provide robustness to the model, so that it can provide reliable results that aid in the decision making process.

The ELECTRE TRI-nC is a sorting MCDA method, that assigns a set of actions to a set of ordered and pre-defined categories, according to the performance of each action in a set of criteria. Categories can be defined by one or more reference actions, which consists in an advantage for ordinal problems and a different feature comparing to ELECTRE TRI-C (where only one reference action per category is possible). The method uses two joint rules (the ascending and the descending rules), each of them responsible for attributing one category to an action, what can result in one single category, or, an interval of categories in case both rules do not coincide.

In the method application there are two main components: the construction of outranking relations, through comparing the level of credibility with the credibility index, calculated between each action and the set of reference actions of each category; and the exploitation of the outranking relations through the two joint rules, that assigned each action to a category.

The next chapter will be devoted to our case study.

Chapter 5

Case study

Chapter five starts by providing in section 5.1, an overview of the case study under analysis and in section 5.2 the DM is presented. The following sections present the inputs to be introduced in the ELECTRE TRI-nC. Section 5.3, describes the process of data gathering and handling, while in section 5.4 the actions are itemized, in section 5.5 it is built the criteria tree with corresponding criteria and subcriteria. Finally in section 5.6 and 5.7, the criteria scales and performance tables are presented.

5.1 Overview

As described in section 2.2 and to recap, the SNS was implemented in 1979 after the transition between political regimes. The system is mainly based on the Beveridge model, where the Portuguese Government is responsible for managing the primary and secondary healthcare providers both public entities sustained predominantly by public taxes distributed by different ministries including the Ministry of Health. The NHS is an instrument of the state to ensure the right to health protection under the Constitution, it provides a suitable and equitable care to its beneficiaries and it is tendentiously free in order to provide access to all the citizens, although user fees maybe charged depending on the economic and social conditions of the citizen. In the last decades, there has been an increase of pressure in the system through different factors: demographic shifts, drugs due to the emergence of increasingly complex diseases and chronic diseases, an increase in life expectancy and advances technology being expensive and therefore of limited access. Due to these events the health expenditure in Portugal is rising, where for instance the value of the health expenditure *per capita* is approximately €1500, one of the highest in the E.U. compromising the existence of the SNS [57]. Thereby, it is essential the financial sustainability of every healthcare entity.

In order to preserve the SNS and therefore its beneficiaries, policy reforms have been implemented to reduce costs and the waste of financial resources, with the intention of turning health care organizations more efficient and effective. Some of the last reforms proposed, evolved several hospital mergers, corporatization of the entities and also the creation of public-private partnerships. The merges created hospital centers, as a result of horizontal mergers of secondary health care centers and local health care

units as a result of vertical mergers of both primary and secondary health care centers.

The corporatisation of the health care units produced serious changes in how the entities were financed. Before, the allocation of the funds was retrospective meaning the entities were financed based on its latest year expenses, that only considered fixed amounts according to the medical diagnosis, regardless of the costs incurred [3]. Although the payment model predicted the compensation for the real costs of care, the institutions did not have concrete and accurate ways of calculating the actual costs, in some cases they did not even know, or in others the estimated value was higher than the real value [58]. Thus, it is clear that the retrospective model was not efficient, as providers with higher costs would obtain more resources not even being attributed responsibilities to units or managers, furthermore existing serious failures in the control of services and costs actually incurred [59]. In case there were budgetary constraints, hospitals had less funding than expected. However since the corporatisation took place in 2003, the financing of the entities changed to a prospective model, meaning the health care providers were, from that moment on financed according to its activity, taking into account its levels of production[58]. The model includes a contract between hospitals and the Portuguese state named *contrato-programa* (as previously mentioned), being negotiated between each hospital's Administrative Council and the Ministry of Health. The budget attributed to each entity considers the delivered health care services. The objective of this new financing methodology was based on the promotion of an efficiency gain, given the attribution of a value considered sufficient for each intervention. In this model, the type, volume and prices of services to be executed are fixed prior to their realization and independent of the actual cost. Thus, the financial risk of the hospital units depends on a sustainable management requiring the good use of their resources. This creates an incentive for a better management through the accountability of the various actors to promote efficiency, however it should not discourage quality.

Nevertheless, the payments made by the Ministry of Health to hospitals are determined by the most efficient hospital of the same group, through averaging the unitary costs of that hospital. It is assumed that hospitals that belong to the same group have analogous production technologies. The problem arrives when the concept of efficiency is not totally clear, neither the criteria used for the hospitals clustering correctly reflect both the environment and the quality either of the provided services and management of the institutions [60]. This means that the process followed to finance hospitals is likely to produce inefficient payments. It is important that hospital clustering includes not only the number of services and their prices, but also reflecting the quality of the services and management provided, which is where this dissertation emerges on. Therefore, it is requested a detailed study about the quality of the SNS entities what is possible through building an MCDA model. Note that it is crucial that this model presents a non-compensatory character to better represent quality (such as ELECTRE TRI-nC), as positive performances in a criteria do not compensate weak performances in other criteria, especially looking to life threatening ones, where for instance a poor patient safety resulting in death can't be compensated by other criteria [61].

5.2 Decision maker

Before proceeding with the case study, let us recap that the ELECTRE family of methods requires two entities, the analyst and the decision maker, therefore it is now the moment to present himself and the functions developed with his cooperation.

The DM, as presented in section 4.1, represents those in whose name or for whom the decision aiding must be given [52]. Fortunately, the DM convened is a former expert from the Ministry of Health, that possesses know-how in the healthcare sector and performance assessment, adding on to his knowledge in health policy-making and administration. The possibility of having access and cooperating with such a trustworthy source, allows the analyst to avoid any possible ambiguity or bias during the study, providing more reliable and solid results. The DM accompanied and cooperated in several steps of the study: selecting the hospital entities to be object of study, benchmarking data handling specially concerning the selection of indicators to formulate the criteria, weight attribution to criteria and subcriteria, definition of thresholds and co-conceiving the reference actions appropriate to be assigned to each category.

5.3 Data and sample

This dissertation is focused on assessing the quality of the Portuguese public hospitals, as for that it was important that the data was reliable and significant, what is expected when data belongs to an official source. The Portuguese Central Health System Administration (ACSS) created a benchmarking among the hospitals of the SNS, where the main reasons were: on one hand to improve economic performance and on the other increase the transparency of its operations. The benchmarking is publicly available via website[1] and can be easily exported as an excel file, making it the an advantage in terms of accessibility for developing this dissertation. Each health entity indicator and the respective value is organized according to month and year providing data from January of 2013 to March of 2019.

5.3.1 Sample handling

The first task of the data processing was selecting the time interval. Even though, at the time of this study the information in the benchmarking already included data until May of 2019, it was not available for many entities. Therefore, since the data from 2018 was far more complete, one decided that it would be interesting to use that years data because it is the most recent completed year. Also, it was defined as object of this study the year of 2017 for possible contrast, considering that according to the DM this time interval does not contain significant technology alterations that would influence the results. Although the information is provided in months, it is simple to produce the accumulated results for each year and institution, allowing to compare the performance between the two whole years.

The second task of the data processing consisted in selecting the public secondary healthcare providers out of the 43 institutions that originally composed the benchmarking. The excluded institutions from the sample and the respective reasons for the exclusion, are the following presented:

[1] `http://benchmarking.acss.min-saude.pt`(accessed in 29th May, 2019)

– All four public private partnerships, since the benchmarking's data is not completed;

– *Figueira da Foz District Hospital, CPE* and *Santa Maria Maior Hospital, CPE*, were excluded as both do not provide birthday deliveries, being impossible to compare them to others in this criterion;

– *Oeste Hospital Centre, CPE*, since the entity did not report its data set for the year of 2017;

– All three oncology centers, who have specific technology of production (directed to cancer) [62];

– All eight local health units described in section 1.1, that are the result of a vertical integration between one hospital and several primary healthcare centers. Comparing them with public hospitals and hospital centers, would produce biased and untrustworthy results.

This data selection resulted in a total of twenty-five institutions, being five hospitals and twenty hospital centers. Also, to mention that in the used benchmarking the institutions were categorized using hierarchical clustering, presenting six different groups from Group A to F. However for this study that clustering was discarded, as one of our objectives is looking at each hospital and assigning them to a category, considering the quality of the services and not previously formed clusters.

The third task was selecting the indicators of interest, between the thirty-four present in the benchmarking. The benchmarking indicators were categorized in six dimensions: Access, Performance Assistance, Productivity, Economic-Financial, Safety and Volume and Usage. These six dimensions were different from the ones presented in the literature review in section3.2. Thereby there was the need of selecting the indicators bearing in mind that later they would be integrated in our six dimensions according to the IOM and the AHRQ standards. Besides this, other aspects were important for the selection of the indicators, as the completeness of the data and the DM viewpoint. The result was the selection of twenty-four indicators, at the moment still presented according to the ACSS dimensions, however the dimensions suffered alterations and exclusions their indicators. Access and safety indicators did not change, the indicators change in the other four dimensions are following described:

– Productivity - the *standard patient per doctor* and *standard patient per nurse* indicators, were converted in *doctor per 1000 inhabitants* and *nurse per 1000 inhabitants*, where using the influence region of a specific secondary healthcare providers' presented in the SNS data was possible to estimate the number of inhabitants served by that specific entity. Lastly the *annual occupancy rate* was converted into the absolute value between the each entity occupancy rate and the ideal value of occupancy rate 85% according to the decision-maker.

– Economic-Financial - the *operational expenses per standard patient* indicator was excluded as its value is the sum of other indicators which would lead to biased results; all the 9 cost indicators were excluded since the decision-maker recommended the use of the expenses; additionally, 3 other cost indicators (*Expenses with Pharmaceutical products, Expenses with drugs and Expenses with clinical consumption material per standard patient* due to their complementary were merged in a new indicator to be called *Expenses with drugs, pharmaceutical products and clinical consumables per standard patient*;

– Performance Assistance - the *percentage of vaginal deliveries after cesarean section in unifetal, cephalic and full-term pregnancy (UCFTPs)*, due to the lack of data;

– Volume and Usage - all the indicators were excluded, in concordance with the decision-maker this dimension was eliminated from the study due to its lack of meaning in this analysis besides the lack of data concerning some entities.

Finally, after processing the data the result was twenty-five hospitals operating during 2017 and 2018 according to twenty-four indicators. All in all this represents a 600-entry sample per year, therefore a total of 1200-entry sample. It was expected that this sample processing resulted in a reduced and more relevant database able to produce more trustworthy and conclusive results.

5.4 Actions

In section 4.2.1, one can find information concerning the ELECTRE TRI-nC method that includes the literature review about actions, which in this case study are the health entities (hospitals or hospital centers). In section 5.3.1, one described the process of selecting the health institutions to be included in this case study. In respect to that, we present the twenty-five institutions or actions from the original forty-three, a_m for m=1,...,25:

- a_1 - *Médio Ave Hospital Centre, CPE*;
- a_2 - *Póvoa do Varzim/Vila do Conde Hospital Centre, CPE*;
- a_3 - *Barreiro/Montijo Hospital Centre, CPE*;
- a_4 - *Leiria Hospital Centre, CPE*;
- a_5 - *Setúbal Hospital Centre, CPE*;
- a_6 - *Baixo Vouga Hospital Centre, CPE*;
- a_7 - *Entre Douro e Vouga Hospital Centre, CPE*;
- a_8 - *Médio Tejo Hospital Centre, CPE*;
- a_9 - *Tâmega e Sousa Hospital Centre, CPE*;
- a_{10} - *Cova da Beira University Hospital Centre, CPE*;
- a_{11} - *Senhora da Oliveira (Guimarães) Hospital, CPE*;
- a_{12} - *Santarém District Hospital, CPE*;
- a_{13} - *Tondela-Viseu Hospital Centre, CPE*;
- a_{14} - *Trás-os-Montes e Alto Douro Hospital Centre, CPE*;
- a_{15} - *Algarve University Hospital Centre, CPE*;

- a_{16} - *Vila Nova de Gaia/Espinho Hospital Centre, CPE*;
- a_{17} - *Espírito Santo de Évora Hospital, CPE*;
- a_{18} - *Fernando da Fonseca Hospital, CPE*;
- a_{19} - *Garcia de Orta Hospital, CPE*;
- a_{20} - *Lisboa Ocidental Hospital Centre, CPE*;
- a_{21} - *Coimbra University Hospital Centre, CPE*;
- a_{22} - *Lisboa Central Hospital Centre, CPE*;
- a_{23} - *São João Hospital Centre, CPE*;
- a_{24} - *Porto University Hospital Centre, CPE*;
- a_{25} - *Lisboa Norte Hospital Centre, CPE*.

5.5 Construction of the criteria tree

In this section the objective was to construct a criteria tree that allowed to evaluate the quality domain of the health entities or actions. In MCDA there is a chance of choosing between a bottom-up approach or a top-down approach [63]. Yet in this case, the formulation of a tree was limited by the information provided by our source, the ACSS benchmarking. Thus, a pseudo bottom-up approach was used, in other words, we used the collected indicators as a start for our study and only afterwards we defined the tree by defining criteria and subcriteria respectively. The reason why it was called a pseudo bottom-up derives from the fact that the selection of the indicators was not completely independently formulated, but also bearing in mind which were the most appropriate indicators in terms of reflecting a quality vision, that resulted from the literature review. Subsequently, the criteria were chosen also according to the literature review in the light of the IOM and the AHRQ, as well as the collected indicators. Afterwards the subcriteria were defined, based on the indicators as they are responsible for operationalizing the subcriteria. Finally, the subcriteria were grouped and included on an appropriated criterion.

It is important to mention that even though a bottom-up approach was implemented it did not compromise the case study of this dissertation, as the benchmarking is in line with internationally adopted methodologies to compare the performance of Portuguese hospitals in an international context[2], including indicators that allow a consistent construction of the subcriteria also presented in the AHRQ and Quality list of quality variables[3].

[2] `http://benchmarking.acss.min-saude.pt/BH_Enquadramento/Objetivos`(accessed in 29th Jun, 2019)
[3] `https://www.qualityindicators.ahrq.gov/`(accessed in 29th Jun, 2019)

5.5.1 Indicators

As mentioned in the subsection 5.3.1, firstly there were thirty-four indicators distributed in six dimensions. From this moment on discard these six dimensions proposed by the benchmarking, since each of the indicators will be allocated to the subcriterion for them operationalized in subsection 5.5.3. The selected twenty-four indicators that resulted from the sample processing are presented and characterized below:

- *Number of non-urgent first medical appointments performed in adequate time per 100 first medical appointments* - quantifies in percentage the first medical appointments executed in tolerable time compared to the total number of first medical appointments;
- *Number of enrolled in the surgical waiting list within the mean guaranteed response time* - quantifies in percentage the patients enrolled in the surgical waiting list within the mean guaranteed response time compared to the total number of patients enrolled in the surgical waiting list;
- *Number of outpatient surgeries per 100 potential outpatient procedure* - quantifies in percentage the amount of outpatient surgeries within the total of outpatient procedures;
- *Number of readmissions in 30 days after discharge per 100 inpatients* - represents in percentage the ratio between patients readmitted within 30 days after discharge and the total number of inpatient episodes;
- *Number of long-stay inpatients per 100 admissions* - is the fraction between inpatient admissions longer than 30 days and the total number of inpatient episodes represented in percentage;
- *Number of hip surgeries performed in the first 48 hours per 100 hip surgeries* - rate that represents hip surgical procedures on elderly, in the first 48 hours, compared to the total number of elderly patients with hip surgeries;
- *Number of cesarean sections per 100 deliveries* - is the percentage of cesarean deliveries in the universe of deliveries;
- *Number of cesarean sections in UCFTPs per 100 sections in UCFTPs* - represents in percentage the number of cesarean sections in UCFTPs in the universe of deliveries;
- *Number of first cesarean sections in UCFTPs per 100 deliveries in UCFTPs without cesarean section before* - rate of first cesarean sections in UCFTPs with no cesarean section before within the universe of deliveries;
- *Occupancy rate* - rate that associates the number of acute admissions and the number of acute inpatient beds over time;
- *Doctors per 1000 inhabitants* - represents the number of doctors in a hospital per 1000 inhabitants in the influence area of that hospital;
- *Nurses per 1000 inhabitants* - represents the number of nurses in a hospital per 1000 inhabitants in the influence area of that hospital;

- *Average waiting time before surgery* - relates the number of days until a surgical episode occurs with the total number of scheduled surgical episodes;
- *Expenses with staff per standard patient*- represents in euros the value of expenses with staff per standard patient;
- *Expenses with drugs, pharmaceutical products and clinical consumables per standard patient* - represents in euros the value of the expenses with drugs, pharmaceutical products and clinical consumables per standard patient;
- *Expenses with supplies and external services per standard patient* - describes the value in euros of the expenses with supplies and external services per standard patient;
- *Expenses with overtime per total expenses with staff* - represents the percentage of the value in euros of the expenses with overtime within the value of expenses with staff;
- *Expenses with outsourcing per total expenses with staff* - shows the percentage of the value in euros of outsourcing expenses within the value of expenses with staff;
- *Number of bedsores per 100 inpatients* - represents the percentage of bedsore episodes in relation to the episodes where exclusion of bedsore has occurred;
- *Bloodstream infection rate related to CVC per 100 inpatients* - represents the percentage of bloodstreams infection related to CVC episodes in relation to the episodes where exclusion of the infection has occurred;
- *Postoperative pulmonary embolism/deep venous thrombosis cases per 100 surgical procedures* - represents the percentage of postoperative pulmonary embolism/deep venous thrombosis episodes in relation to the episodes where exclusion has occurred;
- *Postoperative septicaemia cases per 100 inpatients* - represents the percentage of postoperative septicaemia episodes in relation to the episodes where exclusion has occurred;
- *Cases of trauma on vaginal delivery (third and fourth degree lacerations), with instrumentation, per 100 assisted deliveries* - represents the percentage of vaginal trauma in assisted delivery episodes in relation to the episodes where exclusion of trauma has occurred;
- *Cases of trauma on vaginal delivery (third and fourth degree lacerations), without instrumentation, per 100 assisted deliveries* - represents the percentage of vaginal trauma in non-assisted delivery episodes in relation to the episodes where exclusion of trauma has occurred;

5.5.2 Criteria

Once presented the indicators chosen, we present the family of criteria first, to afterwards present their corresponding family of subcriteria.

The criteria according to Roy, are a tool built to evaluate and compare potential actions according to points of view that should be well defined [44]. Thus, $g(a)$ defines the performance of the potential action a on a criterion g. As described in subsection 4.2.1, a set of criteria selected to evaluate actions is considered a coherent family of criteria when it is exhaustive and cohesive. By exhaustiveness works towards achieving that all the relevant points of view are taken into account for a proper evaluation of the actions. By cohesiveness one wants to be sure that the aggregation of the DM preferences is consistent with the partial preference considering each criterion. In case a criterion is no longer cohesive and exhaustive, than it is excluded [44].

In this dissertation the family of criteria and also the subcriteria, were built based on the literature review and discussed with the DM. During this process the criteria were validated, but some subcriteria changed from family of criteria, some were merged and others were excluded. Therefore, the resulting family of criteria considered for this assessment consists of five criteria, denoted g_n, for $n = 1, ..., 5$:

- Access, g_1: measures the system's ability of providing care services to any citizen if he/she demands or requires. It is expected that an accessible health care services displays adequate levels of resources per user or per demanded care act in order to preserve or improve their health, it covers aspects as, application of fees per medical/nursing act to the users considering their willingness to pay (affordability), the location and distance to the user (physical accessibility), deals with its patients in a fair timely manner and presents short waiting lists and low waiting times (timeliness) [6, 36].

- Care Appropriateness, g_2: measures the ability of delivering patient-centred care services supported by evidence-based guidelines or scientific knowledge [30]. It is expected that when following evidence-base guidelines, the intervention or service results in health benefits (e.g., increased life expectancy, improved functional capacity, pain relief) exceeding the expected health risks (e.g., mortality, morbidity, pain resulting from the intervention) by a wide fair enough margin to take the intervention or service worth doing [64]. Whether the healthcare services are not appropriate one anticipates poor resolution of the patient's main problem, resulting in excessive staying delay which can also result in other diseases appearances (e.g.*pressure ulcers* and *hospital-acquired infections*, unstable therapy at discharge, unsuitable postdischarge care and of course the last scenario a readmission of the patient [30].

- Patients Safety, g_3: measures the absence of preventable harm to a patient during the process of health care and reduction of risk of unnecessary harm associated with health care to an acceptable minimum [65]. Therefore, it is expected that health care process's do not harm patients, also not exposing them to chemicals, foreign bodies, trauma or infectious agents [64].

- Efficiency, g_4: measures the system's ability to achieve the objectives in relation to the resources consumed, meaning it bears in mind the various costly consume inputs (labour, capital, etc.) to produce valued outputs. The health care systems providers have a natural interest in seeking out best practice and identifying scope for improvement. However, there are some cases where that health care providers are technically efficient not because the best practices are being followed,

but because they divest on safety, care appropriateness and access to increase the quantity of treated patients mitigating the lack of investment. The main goal of the health entities should be a financially sustainable manage of the resources, but at the same time delivering the best care possible being cost-effective. Therefore it is expected that an efficiency analysis covers aspects as the purchasing organizations, hospitals, physician practices and individual physicians and their ability in avoiding waste, including waste of equipment, supplies and energy [6, 66].

– Caesarean Appropriateness, g_5: measures the ability of delivering patient-centered care services in caesarean sections supported by evidence-based guidelines. Although this criterion is related to Care Appropriateness, g_2, the fact that it has its own technology of production made us opt for separating them. A caesarean section, when medically justified, can effectively prevent and decrease maternal and perinatal mortality and morbidity. Yet, there is no evidence describing the benefits of caesarean delivery for women or infants who do not require the procedure. Caesarean sections can cause significant and sometimes permanent complications, disability or even death, especially in situations related to lack the facilities and/or capacity to properly conduct safe surgery and treat surgical complications [67]. Nonetheless, the rates of caesarean delivery have increased over time in nearly all OECD countries and globally, WHO reported that annually there is an overuse of ineffective care of more than six million caesarean sections [6, 68]. This led us to consider Caesarean Appropriateness a criterion, since its practice commits quality in cases where it is not medically justified.

5.5.3 Subcriteria

This subsection presents the family of subcriteria that belongs to each criterion, which allowed us to present the final built tree. The subcriteria allows to build multidimensional impact levels describing plausible policy scenarios [63]. When it comes to attributing a subcriterion to a criterion, some reasons are more direct, other request a deeper analysis and co-interaction with the DM. The five criteria and their family of subcriteria resulted from the decisions taken during this process and are described below, as well as the indicator that operationalizes each subcriteria:

Access,g_1:

– First medical appointments timeliness, $g_{1,1}$:

  According to what was said in subsection 5.5.2, an accessible healthcare service handles its patients in a fairly timely manner whenever required. There is a legislated maximum guaranteed time for the first medical appointments in hospitals that makes possible considerations about accessibility. The indicator that represents this subcriterion is to be maximized and named as *Number of non-urgent first medical appointments performed in adequate time per 100 first medical appointments*;

– Enrolled patient for surgery, $g_{1,2}$:

The reason for including this subcriterion in the Access's family is in line with the previous subcriteria inclusion, being a matter of time and the ability of the healthcare service to deal with its surgical waiting list without compromising in this case its maximum legislated time for surgery. The corresponding indicator to this subcriterion is to be maximized and named as *Number of enrolled in the surgical waiting list within the mean guaranteed response time*;

– Availability of beds, $g_{1,3}$:

This subcriterion concerns the occupancy rate of the healthcare entities which is fully related with its accessibility and equity of services. The number of hospital beds provides a measure of the resources available to deliver services to inpatients. The beds must be maintained, staffed and immediately available to use [68]. According to the DM the ideal value for occupancy rate is 85%, as for that the absolute of the difference to the ideal value 85% was used to measure the hospital performance, since the distance is to be minimized. This subcriterion is operationalized by the indicator of *Occupancy rate*;

– Availability of doctors, $g_{1,4}$:

The access to medical care demands the existence of a vital characters, doctors. Also, their presence in healthcare providers to achieve higher quality must be in adequate number and properly distributed through different especialities in a same hospital. Another important aspect is their geographic distribution, since concentrations in one region and shortages in other can lead to inequities in access. Thereby the indicator which represents this subcriterion is to be maximized and named *Doctors per 1000 inhabitants*. Note that it could also be used the indicator *Doctors per standard patient*, but it would not take into account the geographic distribution of the populations and access should be equal to all citizens;

– Availability of nurses, $g_{1,5}$:

Regarding care delivery, no less important is the presence of nurses, also fundamental to provide accessible care. Moreover in primary care where trained nurses can produce high quality care [69]. Therefore this subcriterion is to be maximized and operationalized by *Nurses per 1000 inhabitants*. Once again, note that it could also be used the indicator *Nurses per standard patient*, but for the same reason as for, $g_{1,4}$, it was not;

Care Appropriateness, g_2:

– Minor surgeries appropriateness, $g_{2,1}$:

The fact that some major surgeries can be executed as minor procedures supported by clinical evidence without resulting in harm to the patient is a subcriterion that truly indicates for care appropriateness. The corresponding indicator to this subcriterion is to be maximized and named as, *Number of outpatient surgeries per 100 potential outpatient procedure*;

– Avoidable re-admission prior 30 days after discharge, $g_{2,2}$:

As a result of lack of care appropriateness and/or inappropriate post-discharge care a readmission after inpatient discharge is an unwanted effect for this subcriterion, so to be minimized

This subcriterion is accounted by the indicator *Number of readmissions in 30 days after discharge per 100 inpatients*;

- Excessive staying delay, $g_{2,3}$:

  Considered another unwanted subcriterion that reflects inadequacy of the provided care, thus to be minimized. This subcriterion is measured by the indicator *Number of long-stay inpatients per 100 admissions*;

- Hip surgeries timeliness, $g_{2,4}$:

  This subcriterion was firstly included in the Access family of criteria, however after a discussion with the DM it resulted the conclusion that this subcriterion should be seen as of appropriate care nature. The DM in his expert vision suggested that even though hip fractures especially in elderly patients represent a significant cause of morbidity and mortality, there is still no consensus about the optimal waiting time for the proceeding, however it is said to be within two days [68]. As for that, it is still difficult to identify whether the timeliness in this type of procedures conditions access or only patient's health status specially unnecessary pain and for that reason in this study it is considered as a measure of care appropriateness. In line with the previously decided the responsible indicator is to be minimized and operationalized by *Number of hip surgeries performed in the first 48 hours per 100 hip surgeries*;

- Delay before surgery, $g_{2,4}$:

  Concerns the time between the patient's admission and the surgery. Also, this subcriterion was first included in the Access family, yet after a discussion with the DM, it resulted in the inclusion of this subcriterion in care appropriateness. The reason pointed out was the same as the previous subcriterion, bearing in mind whether timeliness conditions access or patients health. Thus the DM, decided to consider it a measure of care appropriateness, since delaying surgeries directly interferes with the medical guidelines. The indicator that measures this subcriterion is to be minimized and it is called the *Average waiting time before surgery*;

Patient safety, g_3:

- Bedsores, $g_{3,1}$:

  These episodes are preventable, which results in less harm or no harm to the patients, therefore the presence of bedsores indicates lack of clinical safety, thus to be minimized [70]. Bedsores are measured through the indicator *Number of bedsores per 100 inpatients*;

- Bloodstream infections related to CVC, $g_{3,2}$:

  Validated by the literature is directly related to lack of clinical safety. These episodes to be minimized and are measured by the indicator *Bloodstream infection rate related to CVC per 100 inpatients*;

- Postoperative pulmonary embolisms or thrombosis, $g_{3,3}$:

  Also validated by the literature as related to the lack of clinical safety and to be minimized. This subcriterion is operationalized by the indicator *Postoperative pulmonary embolism/deep*

venous thrombosis cases per 100 surgical procedures;

– Postoperative septicaemia, $g_{3,4}$:

Episodes as postoperative septicaemia are directly related to lack of clinical safety, thus to be minimized. For instance sepsis events after surgery, which may lead to organ failure and death [68]. To measure this subcriterion one uses the indicative *Postoperative septicaemia cases per 100 inpatients*;

– Non-instrumental vaginal deliveries with severe laceration, $g_{3,5}$:

During childbirth the patient safety can be assessed by bearing in mind the potentially avoidable tearing of the perineum during vaginal delivery [71]. Thus, vaginal lacerations are directly related to lack of clinical safety, therefore to be minimized. This subcriterion is operationalized by the indicator *Cases of trauma on vaginal delivery (third and fourth degree lacerations), without instrumentation, per 100 assisted deliveries*.

– Assisted vaginal deliveries with severe laceration, $g_{3,6}$:

Confirmed by the literature is related to lack of clinical safety, therefore to be minimized. Note that the risk of a perineal laceration is significantly increased when instruments are used to assist the delivery [71]. The representing indicator for this subcriteria is *Cases of trauma on vaginal delivery (third and fourth degree lacerations), with instrumentation, per100 assisted deliveries*

Efficiency, g_4:

– Expenses with staff, $g_{4,1}$:

This subcriterion is related to efficiency because it can be seen as a costly consume input to deliver care, since staff is required to these situations. In an efficient vision this expense indicator is to be minimized. The expenses with staff are measured by the indicator *Expenses with staff per standard patient*.

– Expenses with drugs, pharmaceutical products and clinical consumables, $g_{4,2}$:

First the three types of expenses were being considered independently. However, and with the DM's endorsement, it was considered that the data was far more complete in case the three were evaluated together. Nonetheless, the three are belong to the domain of efficiency where a careful managing of the resources must be performed, and the value expense is to be minimized. The indicator responsible for quantifying this subcriterion is the *Expenses with drugs, pharmaceutical products and clinical consumables per standard patient*;

– Expenses with supplies and external services, $g_{4,3}$:

This subcriterion is directly related to efficiency since it demands a careful manage of the resources that ideally should be the minimum value without compromising the patients. The subcriterion is measured by the indicator *Expenses with supplies and external services per standard patient*;

- Expenses with overtime, $g_{4,4}$:

  This subcriterion is directly related to inefficiency, since the health professionals work extra hours to fulfill the needs of that a certain hospital entity. This overtime is measured by the indicator *Expenses with overtime per total expenses with staff*;

- Expenses with outsourcing, $g_{4,5}$:

  The need of requiring to outsourcing entities to fulfill the needs of a certain hospital entity is linked to inefficiency. Beware, that according to the DM the cost per hour of outsourcing services in health are much higher than with overtime and of course new hires. This subcriterion is represented by the indicator *Expenses with outsourcing per total expenses with staff*;

– Caesarean Appropriateness, g_5:

  - Volume of caesarean sections, $g_{5,1}$:

    According to the literature, the performance of caesarean sections is related to inadequate care. The indicator used to measure this subcriterion is the *Number of cesarean sections per 100 deliveries*;

  - Caesarean sections in UCFTPs, $g_{5,2}$:

    According to the literature, the performance of caesarean sections in UCFTPs is related to inadequate care. This subcriterion is represented by the indicator *Number of cesarean sections in UCFTPs per 100 sections in UCFTPs*;

  - First caesarean sections in UCFTPs, $g_{5,3}$:

    According to the literature, the performance of first caesarean sections in UCFTPs is related to inadequate care. This subcriterion is represented by the indicator *Number of first cesarean sections in UCFTPs per 100 deliveries in UCFTPs without cesarean section before*;

Once described the indicators and defined the families of criteria and subcriteria, the criteria tree is finally completed as shown in table 5.1.

5.6 Construction of criteria scales

According to the previously described in subsection 4.2.1, to represent the performance of an action, a, according to a given criterion, g, one uses $g(a)$. Thereby it is explicitly necessary to define all the set of performances that an action a may have on a criterion g represented by X_g, which means a completely ordered set. As for that each criterion is composed by the following characteristics: a scale, a preference direction, a weight, a preference and an indifference threshold and finally a veto threshold [44]. In this section the characteristics for each of the five criteria and the twenty-four subcriteria are presented.

A scale is composed by a set of levels fully ordered and each level must be characterized by a number, a verbal statement or even a pictogram. When the objective is comparing two actions according to a criterion g, one compares the two scores of a scale for evaluating their respective performance

Table 5.1: Criteria, subcriteria, and corresponding indicators.

Criteria	Subcriteria	Indicator
g1, Access	g1,1: First medical appointments timeliness	Number of non-urgent first medical appointments performed in adequate time per 100 first medical appointments
	g1,2: Enrolled patients for surgery	Number of enrolled in the surgical waiting list within the mean guaranteed response time
	g1,3: Availability of beds	Occupancy rate
	g1,4: Availability of doctors	Doctors per 1000 inhabitants
	g1,5: Availability of nurses	Nurses per 1000 inhabitants
g2, Care Appropriateness	g2,1: Minor surgeries appropriateness	Number of outpatient surgeries per 100 potential outpatient procedure
	g2,2: Avoidable re-admission prior 30 days after discharge	Number of readmissions in 30 days after discharge per 100 inpatients
	g2,3: Excessive staying delay	Number of long-stay inpatients per 100 admissions
	g2,4: Hip surgery timeliness	Number of hip surgeries performed in the first 48 hours per 100 hip surgeries
	g2,5: Delay before surgery	Average waiting time before surgery
g3, Patient Safety	g3,1: Bedsores	Number of bedsores per 100 inpatients
	g3,2: Bloodstream infections related to CVC	Bloodstream infection rate related to CVC per 100 inpatients
	g3,3: Postoperative pulmonary embolisms or thrombosis	Postoperative pulmonary embolism/deep venous thrombosis cases per 100 surgical procedures
	g3,4: Postopertative septicaemia	Postoperative septicemia cases per 100 inpatients
	g3,5: Non-instrumental vaginal deliveries with severe laceration	Cases of trauma on vaginal delivery (third and fourth degree lacerations), without instrumentation, per 100 assisted deliveries
	g3,6: Assisted vaginal deliveries with severe laceration	Cases of trauma on vaginal delivery (third and fourth degree lacerations), with instrumentation, per 100 assisted deliveries
g4, Efficiency	g4,1: Expenses with staff	Expenses with staff per standard patient
	g4,2: Expenses with drugs, pharmaceutical products and clinical consumables	Expenses with drugs, pharmaceutical products and clinical consumables per standard patient
	g4,3: Expenses with supplies and external services	Expenses with supplies and external services per standard patient
	g4,4: Expenses with overtime	Expenses with overtime per total expenses with staff
	g4,5: Expenses with outsourcing	Expenses with outsourcing per total expenses with staff
g5, Caesarean Appropriateness	g5,1: Volume of caesarean sections	Number of cesarean sections per 100 deliveries
	g5,2: Caesarean sections in UCFTPs	Number of cesarean sections in UCFTPs per 100 sections in UCFTPs
	g5,3: First caesarean sections in UCFTPs	Number of first cesarean sections in UCFTPs per 100 deliveries in UCFTPs without cesarean section before

making possible to assess the performance of each action. Following this idea it becomes essential to define the type of scale for each criteria and a proper understanding of its levels [44].

Concerning the types of scales, as described in subsection 4.2.1, there are two major types: the purely ordinal scale and the quantitative scale, in this dissertation both will be used.

Another characteristic is the preference direction, which implies the direction to which the preferences increase along the scale [44]. Concerning this aspect there are only two options, or the objective is maximizing, and the preference increases with an increasing performance, or the objective is minimizing and the preference increases with a decreasing performance. Both cases will happen in this dissertation, as already suggested when presenting the subcriteria.

A criterion can have one dimension, that is to say only one corresponding subcriterion, or they can have more than one subcriterion. In this case the criteria are known as built-in criteria, where there is the need of building scales to cover the multidimensionality of the criterion. Concerning our subcriteria, with the help of the DM it was easy to create quantitative continuous scales and to define

Table 5.2: Example of conversion from categories to viewpoint for three actions of criterion g_2 in 2018

Action	Categories		Viewpoint	
	Minimum	Maximum	Ascendant	Descendant
a_2	C_3	C_4	3	4
a_3	C_1	C_2	1	2
a_4	C_4	C_4	4	4

the different reference levels, since all the subcriteria are one-dimensional cases and the indicators already express quantitative continuous scales. However, in what concerns to criteria, the fact that each of them have more than two subcriteria (multidimensional) consists in one of the major problems to tackle in this dissertation. Although some approaches have been suggested through the years to build scales combining multiple dimensions, as the one suggested by Bana e Costa & Beinat, none of them was applicable to our case. This arrives from the fact that each criterion aggregates several subcriteria and each of them have several levels, then there were multiple possible combinations to establish between the levels of the subcriteria, what makes this approach not-feasible [63]. As for that we opt for an innovative approach, that uses the results of the application of the ELECTRE Tri-C method to the subcriteria set, since the DM was only able to define one reference action per category, to define the levels for the criteria set.

1. Define the levels for all the subcriteria, considering the information presented in the previous paragraph;

2. Execute the method ELECTRE TRI-C to assess the *a priori* chosen categories to the twenty-five actions;

3. Convert the categories assessed to each action to a level between 1 to 5 in an ordinal scale, where one is the minimum and five is the best. As we defined five categories this conversion is direct (a C_1 represents a level 1, a C_2 represents a level 2, until C_5 that represents a level 5), unless the ELECTRE method had assessed an interval of categories and in case of that, we decided to create a descendant view and an ascendant view. Both these views include the cases where only one category was assigned to an action, presenting that same category, and also in one hand for the descendant view it includes the best category of an interval of categories (or maximum) attributed to an action; on the other hand, the ascendant view includes the worst category of an interval of categories (minimum) attributed to an action. Note that this process was performed for each of the five families of subcriteria, an example of this procedure was illustrated in table 5.2, where it is shown the conversion of the assigned categories concerning the criterion Care Appropriateness, g_2, in 2018 for four actions into the two different viewpoints.

Once introduced the scales and the approach to build them, below it is described the scale for each of the criteria and subcriteria:

– Access, g_1: is a criterion with an ordinal scale composed by five integrated subcriteria. There are five levels for each of the subcriteria described in table 5.3 together with the preference direction.

Table 5.3: Construction and scale characterization of the Access criterion

Criteria	Subcriteria	Preference Direction	Level				
			Very Poor	Poor	Neutral	Good	Very Good
g_1, Access	$g_{1,1}$: First medical appointments timeliness	Maximize	50	70	85	90	95
	$g_{1,2}$: Enrolled patients for surgery	Maximize	70	75	80	90	95
	$g_{1,3}$: Availability of beds	Minimize	12	9	6	3	0
	$g_{1,4}$: Availability of doctors	Maximize	1	1.2	2.1	2.7	4.3
	$g_{1,5}$: Availability of nurses	Maximize	1.7	2.1	3.5	4.8	6.4

– Care Appropriateness, g_2: is an ordinal scale criterion composed by five integrated subcriteria and respective preference direction. There are five levels for each of the subcriteria described in table 5.4.

Table 5.4: Construction and scale characterization of the Care Appropriateness criterion

Criteria	Subcriteria	Preference Direction	Level				
			Very Poor	Poor	Neutral	Good	Very Good
g_2, Care Appropriateness	$g_{2,1}$: Minor surgeries appropriateness	Maximize	70	75	80	85	90
	$g_{2,2}$: Avoidable re-admission prior to 30 days after discharge	Minimize	9.8	8.3	7.4	6.5	5
	$g_{2,3}$: Excessive staying delay	Minimize	5.2	4.5	3.7	3.2	2.7
	$g_{2,4}$: Hip surgery timeliness	Maximize	20	30	50	80	90
	$g_{2,5}$: Delay before surgery	Minimize	1.4	1.1	0.9	0.6	0.5

– Patient Safety, g_3: is a criterion with an ordinal scale composed by six integrated subcriteria. There are five levels for each of the subcriteria presented in table 5.5, as well as the preference direction.

Table 5.5: Construction and scale characterization of the Patient Safety criterion

Criteria	Subcriteria	Preference Direction	Level				
			Very Poor	Poor	Neutral	Good	Very Good
g_3, Patient Safety	$g_{3,1}$: Bedsores	Minimize	0.12	0.1	0.05	0.03	0
	$g_{3,2}$: Bloodstream infections related to CVC	Minimize	0.09	0.06	0.04	0.02	0
	$g_{3,3}$: Postoperative pulmonary embolisms or thrombosis	Minimize	0.31	0.21	0.15	0.08	0
	$g_{3,4}$: Postoperative septicaemia	Minimize	1.2	0.76	0.06	0.03	0
	$g_{3,5}$: Non-instrumental vaginal deliveries with severe laceration	Minimize	0.81	0.64	0.33	0.16	0.05
	$g_{3,6}$: Assisted vaginal deliveries with severe laceration	Minimize	2.05	1	0.64	0.35	0.15

– Efficiency, g_4: is an ordinal scale criterion composed by five integrated subcriteria with a preference direction. There are five levels for each subcriterion as described in table 5.6.

– Caesarean Appropriateness, g_5: is an ordinal scale criterion composed by three integrated subcriteria with a preference direction. There are five levels for each subcriterion present in table 5.7.

Table 5.6: Construction and scale characterization of the Efficiency criterion

Criteria	Subcriteria	Preference Direction	Level				
			Very Poor	Poor	Neutral	Good	Very Good
g_4, Efficiency	$g_{4,1}$: Expenses with staff	Minimize	2381	2039	1829	1536	1408
	$g_{4,2}$:Expenses with drugs, pharmaceutical problems and clinical consumables	Minimize	1287	1082	847	689	537
	$g_{4,3}$: Expenses with supplies and external services	Minimize	660	605	509	407	348
	$g_{4,4}$: Expenses with overtime	Minimize	14.82	13.98	12.08	11.6	10.6
	$g_{3,5}$: Expenses with outsourcing	Minimize	8.51	7.29	5.22	2.62	1.14

Table 5.7: Construction and scale characterization of the Caesarean Appropriateness criterion

Criteria	Subcriteria	Preference Direction	Level				
			Very Poor	Poor	Neutral	Good	Very Good
g_5, Caesarean Appropriateness	$g_{5,1}$: Volume of caesarean sections	Minimize	35	30	28	20	15
	$g_{5,2}$: Caesarean sections in UCFTPs	Minimize	35	30	31	20	15
	$g_{5,3}$: First caesarean sections in UCFTPs	Minimize	100	95	90	85	80

5.7 Construction of criteria performance tables

In the previous sections one presented the twenty-five hospitals, the criteria tree and the data set object of study, it is now time to display the criteria performances tables. The tables 5.8 and 5.9 represent the performance values of each hospital for the years of 2017 and 2018 respectively, both were built with help of excel and will be used as input for the model next chapter.

5.8 Summary

This chapter introduced the case study and the approach to solve it, by building a model using ELECTRE TRI-nC method. The first task was collecting data from a trusted source, the ACSS benchmark, then through data processing one selected twenty-five hospitals to be studied in 2017 and 2018.

The criteria tree was based on the literature review and using the indicators present in the ACSS benchmark. The result was a criteria tree with a family of five criteria, each of them with a family of subcriteria. To assess the performance of an action according to a criterion, one needs to define the criterion scale and its preference direction. All subcriteria were associated to cardinal scales, based on the indicator's values. However all criteria were multidimensional, presenting a family of subcriteria which forced us to innovate and create a methodology to build scales for this multiple dimension problem. This methodology consisted of using the results of the method execution in the subcriterion set to create the scales for the criteria set. Executing the method in the subcriterion set, assigns actions to a category from C_1 to C_5, the attributed categories are converted in values from 1 to 5, that will be used as an ordinal scale for the criteria. To outline the possibility of an action being assigned to an interval of categories (not a unique category), one created two different viewpoints: the descendant that assumes the best category assigned to an action and the ascendant that assumes the worst.

Lastly, criteria performance tables were built representing performance values per action and year.

Table 5.8: Performance table for 2017

Action	$g_{1,1}$	$g_{1,2}$	$g_{1,3}$	$g_{1,4}$	$g_{1,5}$	$g_{2,1}$	$g_{2,2}$	$g_{2,3}$	$g_{2,4}$	$g_{2,5}$	$g_{3,1}$	$g_{3,2}$	$g_{3,3}$	$g_{3,4}$	$g_{3,5}$	$g_{3,6}$	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$	$g_{4,4}$	$g_{4,5}$	$g_{5,1}$	$g_{5,2}$	$g_{5,3}$
a_1	69.2	94.58	2.6	1.13	1.68	82.37	7.46	3.18	52.84	0.75	0.00	0.00	0.10	0.33	0.47	0.64	2089	544.99	649.00	13.4	7.80	31.7	33.0	33.0
a_2	96.8	97.75	7.9	1.16	1.80	70.26	6.36	0.85	92.17	0.61	0.00	0.00	0.00	0.18	0.21	8.80	2298	334.63	660.00	14.4	8.40	29.0	26.1	26.1
a_3	76.2	59.81	2.9	1.60	3.08	66.44	7.81	4.47	51.14	0.90	0.04	0.06	0.11	0.59	0.37	3.16	1941	699.15	511.00	11.6	6.20	29.1	29.9	29.9
a_4	65.6	77.74	7.1	1.03	2.14	82.13	9.22	2.19	32.38	0.79	0.00	0.00	0.00	0.05	0.08	0.79	1745	578.45	519.00	11.0	8.00	28.7	48.3	53.4
a_5	75.0	61.97	0.8	1.72	3.07	88.25	4.94	3.90	67.09	1.03	0.02	0.00	0.09	0.34	1.36	3.21	1866	1153.02	572.00	13.2	8.90	31.9	40.6	41.8
a_6	61.3	76.14	0.6	1.36	2.44	82.28	7.22	2.72	58.29	0.52	0.17	0.00	0.15	0.67	1.41	2.22	2030	746.17	488.00	12.0	5.60	23.5	29.0	28.2
a_7	57.6	78.79	1.0	1.27	2.05	80.03	6.29	2.68	22.11	0.59	0.00	0.01	0.05	0.10	0.62	3.18	1799	689.04	468.00	14.8	7.90	25.2	28.0	28.0
a_8	67.4	73.84	5.9	1.38	3.19	82.07	9.83	3.36	36.06	0.74	0.00	0.39	0.03	0.45	0.63	1.53	2042	670.77	846.00	11.7	16.10	27.4	28.2	28.2
a_9	47.2	83.25	6.8	0.79	1.26	83.41	6.31	3.17	53.31	0.89	0.03	0.01	0.15	0.12	0.41	1.51	1535	539.33	546.00	12.0	9.30	22.7	22.8	22.8
a_{10}	69.8	77.59	6.8	2.40	4.78	73.22	8.74	3.52	63.36	0.64	0.32	57.16	1.52	9.23	1.76	3.24	2286	766.22	619.00	13.9	2.90	36.7	48.0	48.0
a_{11}	60.9	63.64	14.7	1.01	1.59	80.73	8.27	4.10	49.03	0.63	0.00	0.02	0.11	0.27	0.49	3.79	1402	988.09	449.00	11.0	5.20	28.5	29.5	29.5
a_{12}	67.8	54.71	4.4	1.82	3.61	85.56	10.43	3.27	25.25	0.67	0.01	0.00	0.08	0.37	1.14	4.31	1945	843.51	653.00	15.0	5.70	28.2	29.6	29.5
a_{13}	67.9	57.80	9.6	2.83	3.48	90.96	8.42	4.48	34.64	1.86	0.03	0.02	0.07	0.43	0.78	4.65	1695	754.83	374.00	12.6	2.20	22.4	28.3	28.3
a_{14}	67.5	70.91	1.5	1.20	2.12	88.84	10.78	2.99	78.56	0.98	0.01	0.09	0.04	0.21	0.14	0.59	1719	709.42	515.00	14.0	4.20	37.7	48.7	48.7
a_{15}	74.0	60.24	5.2	2.01	3.72	73.76	7.30	5.76	23.42	1.46	0.08	1.80	0.21	0.69	0.42	1.94	1977	920.05	608.00	14.6	7.00	26.6	25.8	25.5
a_{16}	59.1	81.58	1.6	2.90	3.69	75.98	7.49	3.61	60.36	0.83	0.03	0.03	0.15	0.82	0.66	1.67	1540	991.53	306.00	12.0	3.10	29.4	30.6	30.6
a_{17}	61.1	65.29	5.1	2.37	3.42	71.80	6.42	3.41	24.34	0.52	0.14	0.03	0.04	1.22	0.49	4.63	1687	850.57	661.00	14.0	4.70	34.0	38.8	31.0
a_{18}	54.9	59.55	3.9	1.39	1.80	72.88	8.32	5.04	32.69	0.69	0.06	0.11	0.42	1.29	0.79	2.76	1363	826.27	569.00	15.5	7.30	31.6	51.8	38.0
a_{19}	90.2	54.20	2.5	1.48	2.57	85.50	7.44	4.03	9.00	1.05	0.01	0.04	0.31	0.70	0.87	4.70	1413	903.95	411.00	12.1	5.60	26.3	25.8	25.4
a_{20}	77.2	64.81	4.4	3.88	5.73	76.74	8.16	5.14	35.43	1.39	0.09	0.08	0.18	0.48	0.37	0.00	1575	1220.87	405.00	10.6	3.00	27.5	31.7	31.7
a_{21}	73.3	66.10	8.6	3.38	5.23	79.04	9.15	4.14	39.04	1.30	0.02	0.03	0.10	0.34	0.23	0.34	1530	1023.26	416.00	12.4	0.60	29.9	33.2	33.2
a_{22}	82.6	59.31	4.2	4.93	7.19	84.83	7.90	5.26	29.99	1.31	0.04	0.01	0.16	0.72	0.55	2.67	1640	1101.73	383.00	13.7	1.00	30.9	30.8	30.7
a_{23}	61.2	78.34	3.4	4.64	7.09	77.67	6.83	3.35	55.60	0.95	0.09	0.04	0.23	0.61	0.70	2.21	1317	1012.11	339.00	13.8	1.40	28.0	27.2	26.7
a_{24}	68.1	69.21	9.1	3.30	6.40	79.09	6.21	3.42	42.17	0.65	0.05	0.02	0.15	0.95	0.45	2.55	1372	1281.35	346.00	14.0	1.40	27.6	29.2	26.3
a_{25}	69.5	71.77	1.4	4.45	5.58	80.70	4.89	4.49	48.73	0.98	0.02	0.02	0.18	1.35	0.62	4.49	1409	1361.12	375.00	11.8	1.10	24.9	28.8	28.8

Table 5.9: Performance table for 2018

Action	$g_{1,1}$	$g_{1,2}$	$g_{1,3}$	$g_{1,4}$	$g_{1,5}$	$g_{2,1}$	$g_{2,2}$	$g_{2,3}$	$g_{2,4}$	$g_{2,5}$	$g_{3,1}$	$g_{3,2}$	$g_{3,3}$	$g_{3,4}$	$g_{3,5}$	$g_{3,6}$	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$	$g_{4,4}$	$g_{4,5}$	$g_{5,1}$	$g_{5,2}$	$g_{5,3}$
a_1	76.1	96.00	3.2	1.14	1.80	83.10	7.30	3.96	29.70	0.75	0.02	0.00	0.14	0.46	0.17	0.93	2559	541.65	566.72	10.6	6.80	31.7	33.0	33.0
a_2	95.8	99.20	7.6	1.19	1.83	69.80	6.56	1.52	84.30	0.54	0.00	0.00	0.00	0.22	0.34	1.52	2566	341.12	598.84	14.4	7.30	29.0	26.1	26.1
a_3	83	69.40	0.1	1.63	3.09	70.20	8.38	4.90	45.40	0.99	0.02	0.01	0.08	0.48	0.28	2.97	2063	845.06	526.06	9.3	6.04	29.1	29.9	29.9
a_4	56.2	82.70	0.6	1.06	2.15	88.50	8.18	2.31	32.40	0.74	0.01	0.00	0.00	0.09	0.00	0.27	1759	2543.22	537.76	11.9	6.72	28.7	48.3	53.4
a_5	74.1	62.80	2.8	1.81	3.09	81.80	5.36	3.85	65.00	0.87	0.10	0.00	0.08	1.02	0.99	4.35	2022	691.12	534.50	10.5	8.43	31.9	40.6	41.8
a_6	66.4	82.20	1.1	1.48	2.46	83.10	6.93	2.96	66.50	0.48	0.05	0.00	0.23	0.65	1.35	2.26	2135	525.45	508.70	12.1	5.25	23.5	29.0	28.2
a_7	59	80.90	4.1	1.15	1.65	84.60	6.90	2.65	23.80	0.63	0.00	0.00	0.20	0.21	0.37	2.04	2091	633.31	490.63	13.2	5.86	25.2	28.0	28.0
a_8	83.9	72.70	10.4	1.41	3.16	85.20	9.78	4.13	31.30	0.64	0.00	0.00	0.03	0.65	0.46	0.57	2373	139.59	897.92	11.8	13.91	27.4	28.2	28.2
a_9	60.4	85.90	6.2	0.87	1.35	85.70	6.69	3.50	59.00	0.85	0.04	0.00	0.14	0.36	0.33	0.00	1739	616.93	624.30	12.0	8.48	22.7	22.8	22.8
a_{10}	76.3	68.00	5.1	2.45	4.84	72.90	7.20	3.71	53.10	0.70	0.13	0.00	0.11	0.39	0.45	0.00	2472	862.13	628.96	16.0	2.74	36.7	48.0	48.0
a_{11}	57.1	74.10	1.5	1.09	1.57	79.60	7.98	4.57	43.50	0.60	0.00	0.00	0.07	0.64	0.64	3.22	1474	1200.58	499.27	11.5	5.04	28.5	29.5	29.5
a_{12}	67.6	57.20	8.6	1.88	3.51	81.80	10.50	3.13	33.20	0.54	0.01	0.00	0.15	0.54	0.35	3.21	2702	945.41	827.94	13.7	6.58	28.2	29.6	29.5
a_{13}	80.6	49.50	3.4	2.92	3.52	96.80	5.40	4.05	36.70	1.67	0.12	0.00	0.19	1.09	0.98	3.86	1736	841.26	419.30	11.3	2.43	22.4	28.3	28.3
a_{14}	64.1	70.10	2.6	1.25	2.21	86.20	11.44	2.91	73.50	1.11	0.02	0.01	0.08	0.44	0.29	0.62	1932	696.23	611.23	12.0	4.33	37.7	48.7	48.7
a_{15}	73.2	66.60	4.1	2.03	3.75	79.80	7.09	5.64	12.50	1.38	0.05	0.01	0.26	0.64	0.54	0.90	2318	1019.48	492.76	12.8	7.63	26.6	25.8	25.5
a_{16}	55.7	80.80	1.9	2.78	3.51	84.60	7.44	3.76	71.80	0.96	0.08	0.02	0.18	0.61	0.32	1.99	1617	1108.94	329.66	13.2	2.58	29.4	30.6	30.6
a_{17}	61.5	65.40	3.4	3.56	3.48	76.00	6.07	3.94	16.50	0.44	0.11	0.06	0.18	0.75	1.01	2.43	1872	987.87	625.34	14.4	4.23	34.0	38.8	31.0
a_{18}	76.7	66.10	3.0	1.38	1.73	82.70	4.84	5.53	34.90	0.49	0.03	0.00	0.32	2.01	0.60	2.48	1412	822.24	573.02	15.1	7.26	31.6	51.8	38.0
a_{19}	86.5	51.80	4.4	1.57	2.60	90.20	7.09	4.50	26.80	1.29	0.02	0.01	0.24	0.49	1.17	3.62	1378	874.07	404.06	11.4	5.13	26.3	25.8	25.4
a_{20}	70.2	63.90	6.7	3.98	5.76	80.20	7.05	4.50	51.20	1.35	0.07	0.05	0.24	0.85	0.09	0.70	1878	1210.46	405.98	9.6	3.56	27.5	31.7	31.7
a_{21}	66	65.70	8.0	3.45	5.38	81.10	8.83	4.06	39.20	1.35	0.03	0.00	0.14	0.39	0.14	1.03	1612	151.75	430.98	11.6	0.63	29.9	33.2	33.2
a_{22}	75.1	60.90	5.7	5.08	7.04	83.80	6.54	4.82	35.40	1.30	0.07	0.00	0.21	0.56	0.82	3.27	2019	1216.67	435.95	10.2	1.14	30.9	30.8	30.7
a_{23}	50	74.60	2.3	4.82	7.11	81.40	5.11	3.25	62.70	0.95	0.04	0.03	0.31	0.55	0.18	3.19	1594	1149.94	348.36	10.7	1.96	28.0	27.2	26.7
a_{24}	72.7	79.70	11.3	3.50	5.20	78.40	1.40	2.73	58.30	0.37	0.09	0.00	0.16	0.09	0.41	1.65	1433	1410.01	310.35	11.9	1.45	27.6	29.2	26.3
a_{25}	63.5	68.40	0.5	4.52	5.46	79.80	9.44	4.53	43.80	1.05	0.02	0.01	0.25	1.85	0.69	5.97	1491	1538.55	403.17	14.7	0.97	24.9	28.8	28.8

Chapter 6

Model implementation

Chapter six contains the execution of the previously presented case study. The first task was obtaining the criteria weight using the revised Simos procedure in section 6.1, while the second task consisted in defining model elements in section 6.2, namely categories and thresholds. The third task was the execution of the model using the ELECTRE TRI-nC and ELECTRE TRI-C methods.

6.1 Criteria weighting

The interaction between criteria in ELECTRE methods is modeled through the weights of the interaction coefficients and the modifications in the concordance index [51]. Jean Simos in 1994 originally developed a model to calculate the criteria weight for outranking problems the Simos' deck of cards method. Later in 2002, Roy and Figueira revised the method extending it what allowed to build other ratio and interval scales, the so-called modified Simon Roy Figueira procedure (SRF). The SRF procedure has been applied when using ELECTRE type methods among different real life contexts being the reason for use in our case study [72]. The SRF procedure allows any DM to easily hierarchize the different criteria of a family in a given context and to provide the analyst the information needed to attribute a numerical weight to each of the criteria. Hence, in order to obtain the weights of criteria for this case study, one decided to execute the SRF procedure [72].

The SRF procedure considers two phases: a meeting with the DM to gather all the information needed for the application of the method and afterwards the calculation of the weights of each criterion and subcriterion that can be performed in the DecSpace platform [1]. Regarding this case study the procedure was applied as many times as the number of existing families of criteria and subcriteria, meaning one time for the criteria and five times for the subcriteria. Additionally, the procedure was applied again concerning a sensibility analysis in section 7.3.

For collecting the information with the DM, we followed the presented guidelines for the six times we applied the method:

1. Firstly we provided the DM a set of **n** cards, according to the **n** criteria, containing the criterion's

[1] `http://app.decspacedev.sysresearch.org` (accessed in 15th May 2019)

name previously defined and written on it and we also provided a set of blank cards.

2. Secondly, we asked the DM to rank the cards (or criteria) provided in an ascending order. This resulted in a hierarchy, where the first criterion was the least important (small weight) and the last criterion was the most important (greatest weight). In the case of criteria having the same importance (same weight), they were grouped together. According to the position in the ranking, the cards were attributed into different ranks being the lowest level Rank 1, the second lowest level Rank 2, and so on.

3. Afterwards we asked the DM if there were any consecutive rankings, where the importance between both was bigger. According to the difference between the rankings, the DM added a blank card or more between the rankings. In case no blank card was added it meant the difference of two consecutive levels was one unit, one blank card meant the difference of importance was two units, and so on.

4. In the last step we asked the DM, how many times the criterion/criteria presented in the most important ranking, was/were more important than the criterion/criteria present in the least important ranking. The result was described by numerical value that is called the ratio-z, that is part of the revised SRF procedure [72].

The second phase of the procedure consisted in using DecSpace website, that provides several MCDA methods, to execute the SRF procedure. The first task was creating a DCM-SRF project, that corresponds to the implementation of the revised Simos' procedure. Afterwards, the information that was previously collected with the DM was inserted, including: criteria, ranking of the criteria including the blank cards and the ratio-z. The software allows the user to choose the number of decimal places (one or two) and the weight type (normalized, non-normalized or both displayed), in our case we chose two decimals and both weight types. The result weight calculation of the application of the SRF procedure was represented from table 6.1 to table 6.6. In appendix A, one can consult the DM's ranking choices presented from table A.1 to table A.6, as well as the respective ratio-z.

Table 6.1: Weight attributed by the DM to each criterion.

Criteria	Non-normalized weight	Normalized weight
g_1, Access	7.55	23.60
g_2, Care Appropriateness	9.18	28.69
g_3, Patient Safety	10	31.25
g_4, Efficiency	1	3.12
g_5, Caesarean Appropriateness	4.27	13.34

Table 6.2: Weight attributed by the DM to each Access subcriterion.

Criterion	Subcriterion	Non-normalized weight	Normalized weight
g_1, Access	$g_{1,1}$	2	27.1
	$g_{1,2}$	1.88	25.47
	$g_{1,3}$	1.5	20.33
	$g_{1,4}$	1	13.55
	$g_{1,5}$	1	13.55

Table 6.3: Weight attributed by the DM to each Care Appropriateness subcriterion.

Criterion	Subcriterion	Non-normalized weight	Normalized weight
g_2, Care Appropriateness	$g_{2,1}$	7	26.92
	$g_{2,2}$	10	38.46
	$g_{2,3}$	7	26.92
	$g_{2,4}$	1	3.85
	$g_{2,5}$	1	3.85

Table 6.4: Weight attributed by the DM to each Patient Safety subcriterion.

Criterion	Subcriterion	Non-normalized weight	Normalized weight
g_3, Patient Safety	$g_{3,1}$	5.09	14.69
	$g_{3,2}$	7.55	21.79
	$g_{3,3}$	10	28.87
	$g_{3,4}$	10	28.87
	$g_{3,5}$	1	2.89
	$g_{3,6}$	1	2.89

Table 6.5: Weight attributed by the DM to each Efficiency subcriterion.

Criterion	Subcriterion	Non-normalized weight	Normalized weight
g_4, Efficiency	$g_{4,1}$	7.43	20.72
	$g_{4,2}$	10	27.88
	$g_{4,3}$	10	27.89
	$g_{4,4}$	7.43	20.72
	$g_{4,5}$	1	2.79

Table 6.6: Weight attributed by the DM to each Caesarean Appropriateness subcriterion.

Criterion	Subcriterion	Non-normalized weight	Normalized weight
g_5, Caesarean Appropriateness	$g_{5,1}$	1	20
	$g_{5,2}$	2	40
	$g_{5,3}$	2	40

6.2 Model elements' definition

6.2.1 Definition of categories and reference actions

Hospitals have the objective of providing the best healthcare services to people, they can follow different approaches resulting in different production technology and consume of resources. After the sample reduction in 5.3.1, the result were twenty-five homogeneous entities with similar production technologies, as for that comparable against each other. In line with the DM the entities were classified in an appropriate set of five predefined categories ordered by performance, that describe the performance of the institutions regarding quality:

- C_5, Very Good performance;
- C_4, Good performance;
- C_3, Neutral performance;
- C_2, Poor performance;
- C_1, Very Poor performance;

Later, based on the DM knowledge we defined the reference value of performance for each criterion and subcriterion in a given category. In the case of the criteria the DM was able to establish different reference actions per category, so in this case it was later applied the ELECTRE TRI-nC method. As for the subcriteria, the DM established one reference action per category, since in his opinion the ones defined represent accurately the categories assigned to. Thus, in the case of the subcriteria the method later applied was ELECTRE TRI-C. The performances of the reference actions were described per category in six tables: table 6.7 for the family of criteria and tables from 6.8 to 6.12 for the five different subcriteria families.

Table 6.7: Criteria performances of the reference actions per category.

Category	Performance	Reference Action	Criteria				
			g_1	g_2	g_3	g_4	g_5
C_5	Very Good	b_5^1	5	5	5	5	5
		b_5^2	5	4	5	4	5
		b_5^3	5	4	5	4	4
C_4	Good	b_4^1	4	4	5	4	5
		b_4^2	4	4	5	4	4
		b_4^3	4	4	4	4	4
C_3	Neutral	b_3^1	4	4	4	3	4
C_2	Poor	b_2^1	3	3	4	3	4
		b_2^2	3	3	3	3	3
C_1	Very Poor	b_1^1	3	2	3	2	3
		b_1^2	2	2	2	2	3
		b_1^3	2	2	2	1	3

Table 6.8: Access performances of the reference actions per category.

Category	Performance	Reference Action	Subcriteria				
			$g_{1,1}$	$g_{1,2}$	$g_{1,3}$	$g_{1,4}$	$g_{1,5}$
C_5	Very Good	b_5^1	95.0	95.00	0.0	4.30	6.40
C_4	Good	b_4^1	85.0	85.00	2.0	2.70	4.80
C_3	Neutral	b_3^1	80.0	80.00	5.0	2.10	3.50
C_2	Poor	b_2^1	70.0	75.00	7.0	1.20	2.10
C_1	Very Poor	b_1^1	60.0	70.00	9.0	1.00	1.70

Table 6.9: Care Appropriateness performances of the reference actions per category.

Category	Performance	Reference Action	Subcriteria				
			$g_{2,1}$	$g_{2,2}$	$g_{2,3}$	$g_{2,4}$	$g_{2,5}$
C_5	Very Good	b_5^1	90.00	5.00	2.70	90.00	0.50
C_4	Good	b_4^1	85.00	6.50	3.20	80.00	0.60
C_3	Neutral	b_3^1	80.00	7.40	3.70	50.00	0.90
C_2	Poor	b_2^1	75.00	8.30	4.50	30.00	1.10
C_1	Very Poor	b_1^1	70.00	9.80	5.20	20.00	1.40

Table 6.10: Patient Safety performances of the reference actions per category.

Category	Performance	Reference Action	Subcriteria					
			$g_{3,1}$	$g_{3,2}$	$g_{3,3}$	$g_{3,4}$	$g_{3,5}$	$g_{3,6}$
C_5	Very Good	b_5^1	0.00	0.00	0.00	0.00	0.05	0.15
C_4	Good	b_4^1	0.03	0.02	0.08	0.03	0.16	0.35
C_3	Neutral	b_3^1	0.05	0.04	0.15	0.06	0.33	0.64
C_2	Poor	b_2^1	0.10	0.06	0.21	0.76	0.64	1.00
C_1	Very Poor	b_1^1	0.12	0.09	0.31	1.20	0.81	2.05

Table 6.11: Efficiency performances of the reference actions per category.

Category	Performance	Reference Action	Subcriteria				
			$g_{4,1}$	$g_{4,2}$	$g_{4,3}$	$g_{4,4}$	$g_{4,5}$
C_5	Very Good	b_5^1	1408	537.94	348.12	10.6	1.14
C_4	Good	b_4^1	1536	689.56	407.24	11.6	2.62
C_3	Neutral	b_3^1	1829	847.82	509.85	12.08	5.22
C_2	Poor	b_2^1	2039	1082.11	605.71	13.98	7.29
C_1	Very Poor	b_1^1	2381	1287.73	660.08	14.82	8.51

Table 6.12: Caesarean Appropriateness performances of the reference actions per category.

Category	Performance	Reference Action	Subcriteria		
			$g_{5,1}$	$g_{5,2}$	$g_{5,3}$
C_5	Very Good	b_5^1	15.0	15.0	80.0
C_4	Good	b_4^1	20.0	20.0	85.0
C_3	Neutral	b_3^1	28.4	31.2	90.0
C_2	Poor	b_2^1	30.0	30.0	95.0
C_1	Very Poor	b_1^1	35.0	35.0	100.0

6.2.2 Definition of thresholds

In preference modeling one needs to bear in mind the imperfect knowledge of the considered criteria, which is more frequent when considering multiple criteria methods for obvious reasons.

The definition of each criterion includes some arbitrariness and the data used to build criteria are usually imprecise, ill-determined and uncertain [73]. For example in the definition of the subcriterion availability of doctors, $g_{1,4}$, it was necessary to choose the elements to work with namely the number of standard patients of that institution or the population that the institution serves. The fact that the choice between different options was allowed reflects the presence of arbitrariness. Also, the construction of a criterion usually uses databases that are imprecise and ill-determined. Even though our database was from an official source, there was no precise information on how it was collected and by whom. Thus, to deal with the imperfect knowledge both ELECTRE TRI-nC and ELECTRE TRI-C use thresholds of preference (p_j) and thresholds of indifference (q_j), previously introduced in section 4.2.1. Note that the thresholds defined do not depend on the potential actions considered, but on the performance attributed to these [73].

In this case study the family of criteria was described in ordinal scales of levels, not being possible for an action to be defined by two different levels and as for that no indifference and preference thresholds were applicable. However the veto threshold ,(v_j), could be applied and the DM felt relevant to include it regarding the importance of the Patient Safety and Care Appropriateness criteria assume

when evaluating quality in healthcare.

Table 6.13: Veto thresholds of the family of criteria.

Thresholds	g_1	g_2	g_3	g_4	g_5
v	$\emptyset$	2.0	3.0	$\emptyset$	$\emptyset$

In respect to the groups of subcriteria, all were described in quantitative scales of levels where it is possible that an action is defined by different values that result in a same level of a scale. Hence, in line with the discussion with the DM it resulted in the definition of the thresholds presented in table 6.14.

Table 6.14: Preference, indifference thresholds of the subcriteria.

Thresholds	Subcriteria					
	$g_{1,1}$	$g_{1,2}$	$g_{1,3}$	$g_{1,4}$	$g_{1,5}$	
q	2.0	2.0	2.0	0.4	0.4	
p	5.0	5.0	3.0	0.5	0.5	
	$g_{2,1}$	$g_{2,2}$	$g_{2,3}$	$g_{2,4}$	$g_{2,5}$	
q	3.0	1.0	0.3	3.0	0.2	
p	5.0	2.0	0.5	5.0	0.3	
	$g_{3,1}$	$g_{3,2}$	$g_{3,3}$	$g_{3,4}$	$g_{3,5}$	$g_{3,6}$
q	0.01	0.01	0.01	0.01	0.02	0.02
p	0.01	0.01	0.01	0.01	0.02	0.02
	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$	$g_{4,4}$	$g_{4,5}$	
q	50.0	50.0	25.0	0.5	0.5	
p	100.0	100.0	50.0	1.0	1.0	
	$g_{5,1}$	$g_{5,2}$	$g_{5,3}$			
q	3.0	3.0	1.0			
p	5.0	5.0	3.0			

6.3 Execution of the ELECTRE TRI-nC

The MCDA-ULaval was described in section 4.2.4, since it was the software to be used to execute the ELECTRE TRI-nC and ELECTRE Tri-C methods. The needed inputs to execute a project are: the action set (named alternative in MCDA-ULaval), the criteria set, performance tables and the decision configurations which include the weight of the criterion, the thresholds, the index of credibility λ, the categories and the performance table of the reference actions.

In this dissertation it was created one project per family of subcriteria (five families) and two projects per family of criteria due to the descendant and ascendant viewpoints that were taken, since two different years were analyzed this resulted in fourteen different projects created. The illustration of each of these projects would be too extensive to present, which was why we chose to present only the creation of the creation of one project. The chosen project concerns the descendant viewpoint of the criteria family for the year of 2018 and was illustrated in different steps below.

The first step in the creation of a project concerns the insertion of actions or alternatives in our case healthcare entities. In figure 6.1 the alternative set can be seen, where an action was described by the notation and the full name (optional).

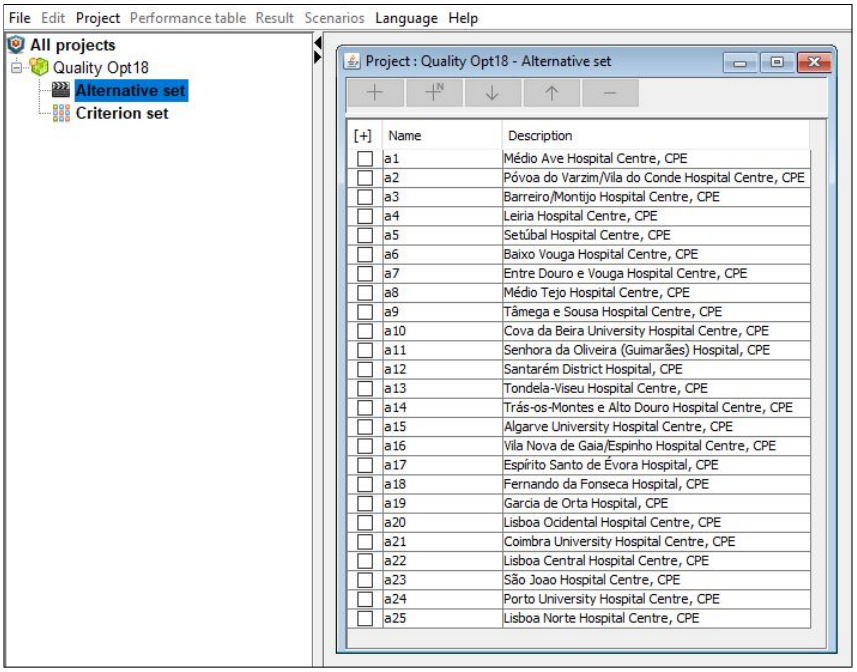


Figure 6.1: Introduction of the action set to evaluate in MCDA-ULaval.

The second step consisted on the insertion of the set of criteria illustrated in figure 6.2. Here it was also necessary to define for each criterion the type of measure (ordinal or cardinal) and the direction (minimize or maximize). In this case all of the criterion were ordinal and to be maximize, where the main concern were the values of the scale and not the distance of the values that do not have any expression respecting its intensity in line what explained in section 4.1.

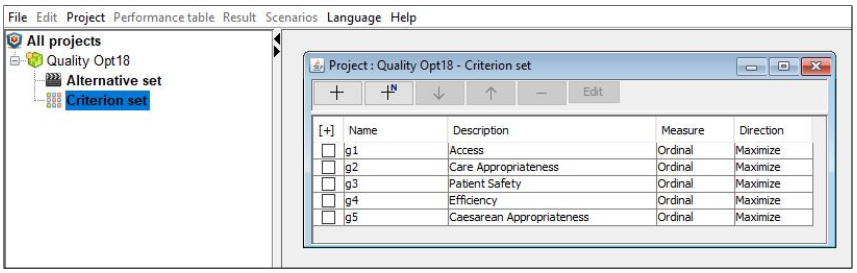
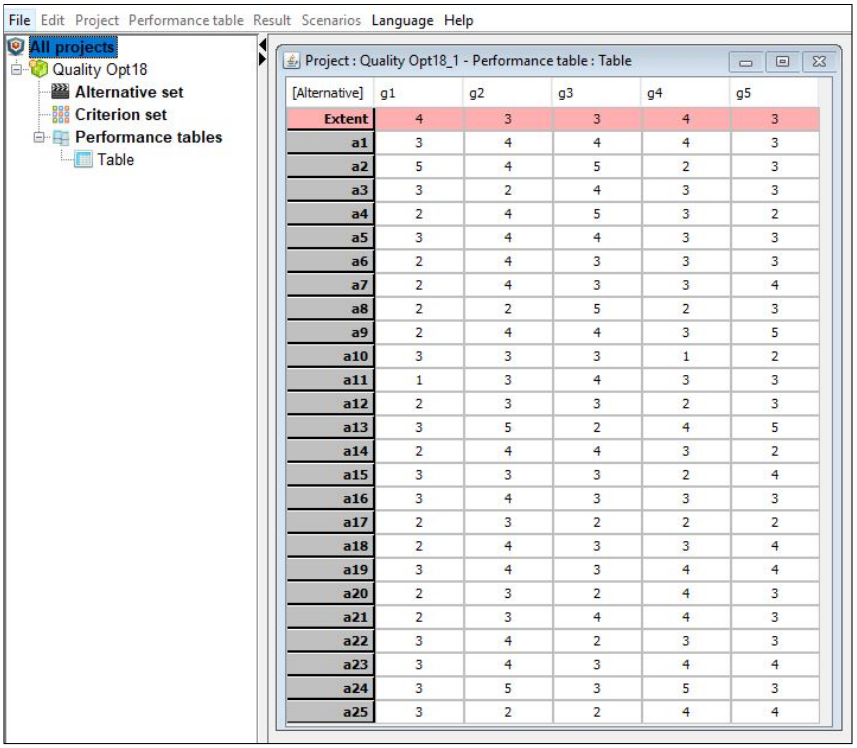


Figure 6.2: Introduction of the criteria set in MCDA-ULaval.

The third step was inserting the performance table in the software as shown in figure 6.3. The table, contains all the actions used and their respective performance in each criterion. Note that this table was first prepared in an excel sheet in a csv format and then imported into the software.

The fourth step was the selection of the method to be applied and the insertion of the decision configuring. In the case of the family of criteria the method selected was the ELECTRE TRI-nC, as shown in figure 6.4, since we defined more than one reference action per category. However, for the groups of subcriteria it was chosen the ELECTRE TRI-C method, since each of the categories only had one reference action per category.

The decision configuration was illustrated from figure 6.5 to 6.7. In figure 6.5 it is shown the weight and the thresholds of each criterion, as well as the credibility level (λ). The weights were obtained



[Alternative]	g1	g2	g3	g4	g5
Extent	4	3	3	4	3
a1	3	4	4	4	3
a2	5	4	5	2	3
a3	3	2	4	3	3
a4	2	4	5	3	2
a5	3	4	4	3	3
a6	2	4	3	3	3
a7	2	4	3	3	4
a8	2	2	5	2	3
a9	2	4	4	3	5
a10	3	3	3	1	2
a11	1	3	4	3	3
a12	2	3	3	2	3
a13	3	5	2	4	5
a14	2	4	4	3	2
a15	3	3	3	2	4
a16	3	4	3	3	3
a17	2	3	2	2	2
a18	2	4	3	3	4
a19	3	4	3	4	4
a20	2	3	2	4	3
a21	2	3	4	4	3
a22	3	4	2	3	3
a23	3	4	3	4	4
a24	3	5	3	5	3
a25	3	2	2	4	4

Figure 6.3: Introduction of the performance table in MCDA-ULaval.

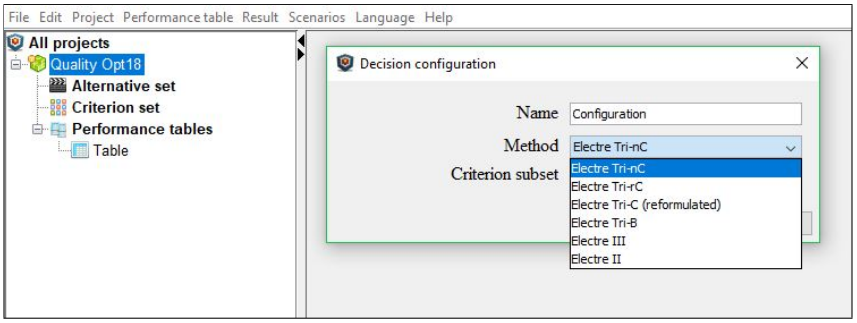


Figure 6.4: Method selection.

through the SRF method presented in section 6.1. As for the thresholds, in this case there was only veto thresholds (v) and no preference (p) or indifference (q) thresholds, as explained in section 6.2.2; however for the groups of subcriteria it happened the opposite, where there is the presence of preference and indifference thresholds but no veto threshold. Regarding the credibility level in the illustrated criteria case it was considered $\lambda = 0.60$, but also the same for the groups of subcriteria.

In figure 6.6, it was illustrated the five categories with the corresponding ordered reference actions below. Note that the top category must be at the top in our case C_5 and the worst at the bottom C_1, the same happens for the reference actions.

In figure 6.7, it is shown the performance values of the reference actions. State that these values can be inserted manually in the table or directly by importing a previously prepared excel sheet in an csv file, which was our case allowing to save time and avoiding typing mistakes.

The last step occurred after all the parameters were inserted, being one finally able to execute the project. In figure 6.8, it is illustrated how to execute the project by pressing *Execute*. Note that in the case

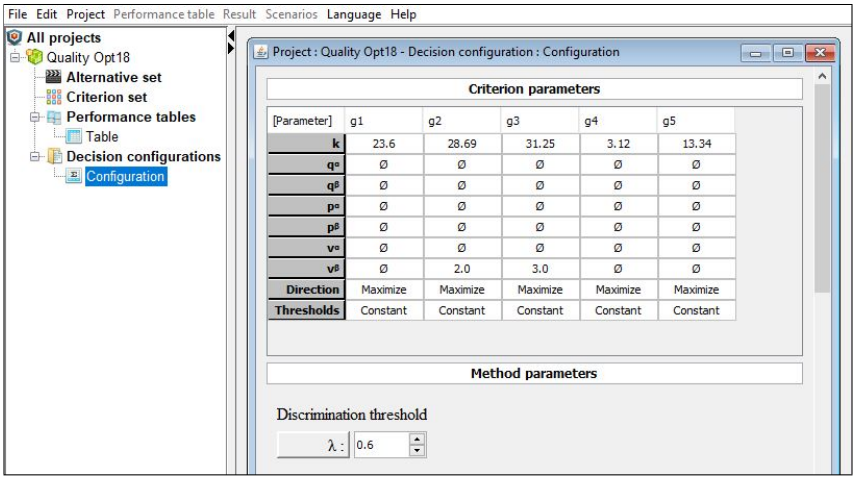


Figure 6.5: Criterion parameters and credibility level.

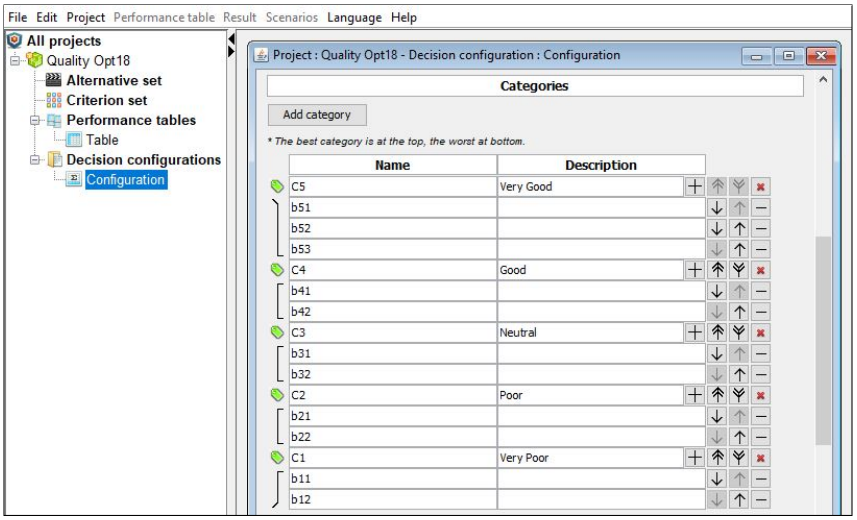


Figure 6.6: Categories and respective reference actions.

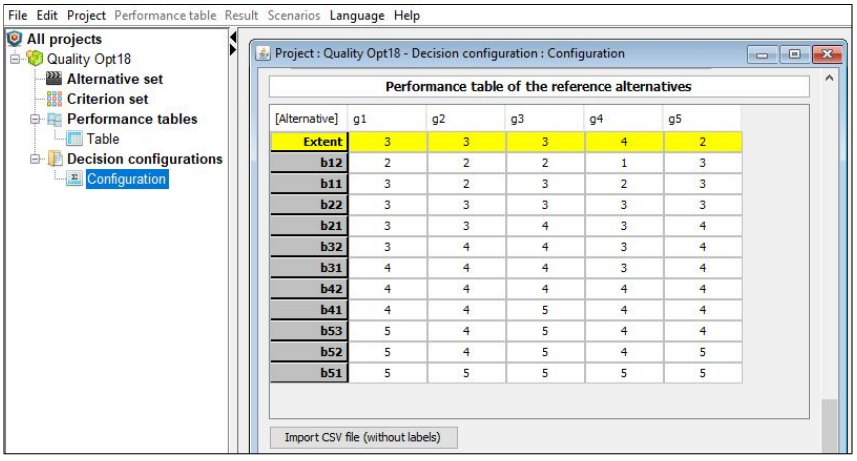


Figure 6.7: Performance table of the reference alternatives.

that any of the parameter inserted is not valid, then the software does not execute and warns the user about a wrong parameter to be changed. The software possesses the button, *Validate Parameter*, that basically checks if all the parameters are valid and in case not it also warns the user of the parameter to

change. As soon as all parameters are valid the MCDA-ULaval will be able to assign each alternative or action to a category or to an interval of categories.

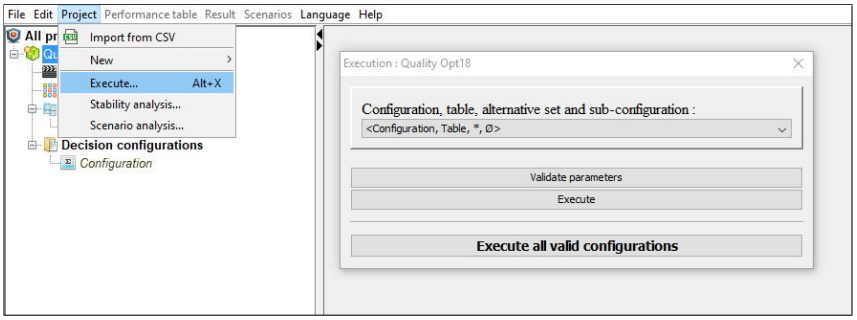


Figure 6.8: Execution menu of MCDA-ULaval.

The results from this project, as well as, the result of the other projects not described in this section were presented and discussed in the next chapter.

6.4 Summary

Once this chapter is over the model is finally implemented. The model began to be built in chapter five by constructing the criteria tree, defining the criteria scales, and the criteria performance tables.

In this chapter the criteria weights were established from the SRF procedure application in the DecSpace software. These weights were determined by performing the SRF procedure with the decision maker know-how and expertise in the sector. The definition of five categories, as well as the reference actions that characterize them, also arrive from interactions with DM. In all the subcriteria family, categories were defined by only one reference action so the method does not differ from ELECTRE TRI-C. As to the criteria family, every category was defined by more than one reference action.

The only input that were still missing were: preference, indifference and the veto thresholds, that exist to tackle imperfect knowledge. The first two, preference and indifference thresholds, were included in all criteria since they were all described in quantitative scales of levels and in line with the DM one decided to include them. As for the veto threshold, it was only included in the criteria Care Appropriateness (g_2) and Patient Safety (g_3).

After defined all model variables, the model was finally implemented in MCDA-ULaval and the results presented in the next chapter.

Chapter 7

Analysis of the model implementation and results

In the previous section the ELECTRE method was executed, as for that, this seventh chapter contains the discussion of the results and recommendations to the model. In first place one presents the construction of an outranking relation, followed by the presentation of the outranking relations and then the assignment procedure. Once the results provided by the software were presented, it is described the performed sensitivity analysis containing two variations of the credibility index combined with three different scenarios of SRF procedures with plus two variations of the ratio-z, which adds variation to our initial project with the objective of analyzing the robustness of the model.

7.1 Construction of an outranking relation

The objective of the execution of this model was to assign the actions to one of the five *a priori* defined categories, this assignment proceeds the establishment of the outranking relations. As stated in section 4.2, the ELECTRE methods allow to build one or more outranking relations that take in consideration the performances of each action on each criterion. These relations enable to state whether an action a, is preferred to an action a', denoted aSa', in case there are enough arguments to decide that a is at least as good as a' according to a criterion g_j. The credibility of these relations is measured by the credibility index, σ, in the ELECTRE Tri-nC named categorical credibility indices [53].

In our case one made use of the MCDA-ULaval to calculate the categorical credibility indices over the potential actions and *vice versa*, the results for the descendant view of 2018 are presented in table 7.1. The software while performing the calculus takes in consideration all the reference actions that compose a category, remember that in this case study all the criteria (from the family of criteria) have more than one reference action. As for that, each of the categories presented in table 7.1 include the set of the reference action characteristic of that category. Note that, the model illustrated in this section, is the descendant viewpoint of the criteria family for the year of 2018, since it would be impossible to represent all the models for space reasons.

Table 7.1: Categorical credibility indices calculated between the potential actions and the set of reference actions of each category for the descendant view of 2018

Actions	$\sigma(a, B_h)$					$\sigma(B_h, a)$				
	C_1	C_2	C_3	C_4	C_5	C_1	C_2	C_3	C_4	C_5
a_1	1.00	1.00	0.87	0.63	0.31	0.00	0.68	0.97	1.00	1.00
a_2	1.00	0.97	0.83	0.84	0.84	0.00	0.08	0.45	0.76	1.00
a_3	1.00	0.71	0.00	0.00	0.00	0.66	1.00	1.00	1.00	1.00
a_4	0.87	0.63	0.63	0.60	0.60	0.00	0.34	0.69	1.00	1.00
a_5	1.00	1.00	0.87	0.60	0.27	0.00	0.71	1.00	1.00	1.00
a_6	1.00	0.76	0.31	0.27	0.13	0.00	0.71	1.00	1.00	1.00
a_7	1.00	0.76	0.45	0.42	0.24	0.00	0.713	1.00	1.00	1.00
a_8	1.00	0.40	0.00	0.00	0.00	0.69	0.69	0.69	1.00	1.00
a_9	1.00	0.76	0.76	0.73	0.42	0.00	0.58	0.87	0.87	1.00
a_{10}	0.87	0.84	0.14	0.00	0.00	0.71	1.00	1.00	1.00	1.00
a_{11}	0.76	0.76	0.26	0.23	0.00	0.29	1.00	1.00	1.00	1.00
a_{12}	1.00	0.73	0.00	0.00	0.00	0.71	1.00	1.00	1.00	1.00
a_{13}	1.00	0.69	0.69	0.27	0.00	0.00	0.00	0.55	0.58	1.00
a_{14}	0.87	0.63	0.63	0.60	0.27	0.00	0.71	1.00	1.00	1.00
a_{15}	1.00	0.97	0.29	0.06	0.03	0.58	1.00	1.00	1.00	1.00
a_{16}	1.00	1.00	0.55	0.27	0.13	0.00	0.71	1.00	1.00	1.00
a_{17}	0.87	0.27	0.00	0.00	0.00	0.71	1.00	1.00	1.00	1.00
a_{18}	1.00	0.76	0.45	0.42	0.24	0.00	0.71	1.00	1.00	1.00
a_{19}	1.00	1.00	0.69	0.45	0.27	0.00	0.68	0.97	1.00	1.00
a_{20}	1.00	0.45	0.01	0.01	0.00	0.68	0.97	0.97	1.00	1.00
a_{21}	1.00	0.76	0.26	0.26	0.01	0.29	0.97	0.97	1.00	1.00
a_{22}	1.00	0.69	0.41	0.13	0.00	0.00	0.71	1.00	1.00	1.00
a_{23}	1.00	1.00	0.69	0.45	0.27	0.00	0.68	0.97	1.00	1.00
a_{24}	1.00	1.00	0.55	0.31	0.16	0.00	0.00	0.68	0.68	1.00
a_{25}	1.00	0.33	0.00	0.00	0.00	0.84	0.97	0.97	1.00	1.00

While observing the table, one can easily notice the presence of outranking relations justified by the presence of categorical credibility indices equal to 1, $\sigma(a, B_h) = 1$ or $\sigma(B_h, a) = 1$. Other important conclusions regarding the categories were described below:

– Most of the potential actions denote a categorical credibility equal or close to one for the case $\sigma(a, B_1)$. In other words the majority of the potential actions demonstrated an outranking relation over B_1, therefore that set of potential actions are at least as good as the B_1 reference action set. This observation sustains the fact that C_1 is the worst category from the existing five.

– The opposite happened for C_5 as expected, where the category demonstrated an outranking relation over all the potential actions, $\sigma(B_5, a) = 1, \forall a$. This sustains the fact that C_5 is the best category from the existing five.

Concerning the level of credibility, as stated in section 4.2.2, it is a value chosen and validated by the DM within the range of $[0.5, 1[$, which describes the minimum value to validate an outranking relation where the action a outranks "a' regarding all the criteria. Moreover is the comparison between the credibility level λ and the categorical credibility indices σ that allows to establish one of the four λ-binary relations described in section 4.2.2: (a)λ-outranking, (b)λ-preference, (c)λ-indifference and (d)λ-incomparability.

Table 7.2: The existing λ-binary relations between the potential actions and the categories for $\lambda = 0.6$

Actions	C_1	C_2	C_3	C_4	C_5
a_1	$>$	I	I	I	$<$
a_2	$>$	$>$	$>$	I	$<$
a_3	I	I	$<$	$<$	$<$
a_4	$>$	$>$	I	$<$	$<$
a_5	$>$	I	I	$<$	$<$
a_6	$>$	I	$<$	$<$	$<$
a_7	$>$	I	$<$	$<$	$<$
a_8	I	$<$	$<$	$<$	$<$
a_9	$>$	$>$	I	I	$<$
a_{10}	I	I	$<$	$<$	$<$
a_{11}	$>$	I	$<$	$<$	$<$
a_{12}	I	I	$<$	$<$	$<$
a_{13}	$>$	$>$	$>$	R	$<$
a_{14}	$>$	I	I	$<$	$<$
a_{15}	$>$	I	$<$	$<$	$<$
a_{16}	$>$	I	$<$	$<$	$<$
a_{17}	I	$<$	$<$	$<$	$<$
a_{18}	$>$	I	$<$	$<$	$<$
a_{19}	$>$	I	I	$<$	$<$
a_{20}	I	$<$	$<$	$<$	$<$
a_{21}	$>$	I	$<$	$<$	$<$
a_{22}	$>$	I	$<$	$<$	$<$
a_{23}	$>$	I	I	$<$	$<$
a_{24}	$>$	$>$	$<$	$<$	$<$
a_{25}	I	$<$	$<$	$<$	$<$

The comparison between an action and the subsets of reference actions of each category, B_h, results in one and only one of the following cases [53]:

– Action a is neither λ-indifferent nor λ-incomparable to $B_h, h = 1, ..., q$.

– Action a is λ-indifferent to at least one subset of reference actions B_h. Furthermore, if B_h is not unique, then the subsets of reference actions, which are λ-indifferent to an action a set of categories consecutive.

– Action a is λ-incomparable to at least one subset of reference actions B_h. Furthermore, if B_h is not unique, then the subsets of reference actions, which are λ-incomparable to action a, define a subset of consecutive categories.

In our case the credibility level chosen was $\lambda = 0.6$ and the results of the λ-binary relations were represented in table 7.2. For the MCDA-ULaval software the **I** represents the λ-indifference relations between the action and the set of reference actions that define a category, the **R** represents the λ-incomparability relations and the inequality symbols $<$ and $>$ denote preference relations, $<$ in case the set of reference actions is preferred to the action and $>$ otherwise.

7.2 Exploitation of an outranking relation

In this step we finally present the pre-defined categories to which the healthcare entities (actions) were assigned to, know as, the assignment procedure. As stated in section 4.2.3, the assignment procedure is done by comparing an action a with the reference actions, bearing in mind the credibility level λ, in our case $\lambda = 0.6$, and applying the two joint rules (the ascending and the descending rules).

The assignment procedure using both rules conjointly selects a lowest and a highest possible categories to an action a, generating a range of possible categories $\Gamma(a)$ that follows the ELECTRE TRI-nC properties [53]:

- Happens when an action a is neither λ-indifferent nor λ-incomparable to B_h, $h = 1, ..., q$: the result is $\Gamma(a)$ being composed of one or two consecutive categories.
- Happens when a is λ-indifferent to at least one subset of reference actions B_h: $\Gamma(a)$ is composed of the subset of consecutive categories defined by such λ-indifference, and, possibly, by including one or two of the adjacent categories to them.
- Happens when a is λ-incomparable to at least one subset of reference actions B_h: $\Gamma(a)$ is composed of the subset of consecutive categories defined by such λ-incomparability, and, possibly, by including one or two of the adjacent categories to them.

As described in section 5.6, we created an innovative approach that used the ELECTRE TRI-C assignment procedure results from the subcriteria families to construct the criteria family scales. However in the assignment procedure some of the actions were assigned to an interval of categories, which originated two viewpoints: the descendant view that considered the best category of the interval assigned to an action and the ascendant view that considered the worst category assigned to an action. Hence, the results of the assignment procedure of the family of criteria include both these viewpoints, which were represented in table 7.3, where one can observe the actions and the correspondent category or interval of categories for the years of 2017 and 2018 and both viewpoints for each of the years.

7.2.1 Comparison between the pessimist and optimist views

After presenting the assignment procedure, where the results were displayed in table 7.3, it is time to analyse them. In table 7.4, it was resumed the number of actions assigned to each interval of categories, as well as the respective percentages for each of the years and viewpoints.

Once observed table 7.4, one noticed variations on the assignment of the actions to the categories regarding the view and also the years.

In the year of 2017 only one interval of categories, $[C_1, C_2]$, maintained the same number of actions assigned for both the views with 5 actions; and also three categories with 0 actions assigned C_3, C_4 and C_5. In the ascendant view the most represented category was the worst category, C_1, with 11 actions and 92% of the actions were assigned to a category equal or lower than C_2. In respect to the highest category assigned it was in the interval of $[C_3, C_4]$ with only one action, a_2. In the descendant view

Table 7.3: Assignment procedure for the years of 2017 and 2018 and respective viewpoints.

Actions	2017				2018			
	Ascendant view		Descendant view		Ascendant view		Descendant view	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
a_1	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_4
a_2	C_3	C_4	C_4	C_5	C_3	C_3	C_4	C_5
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2
a_4	C_2	C_2	C_2	C_2	C_3	C_3	C_3	C_3
a_5	C_2	C_3	C_2	C_4	C_2	C_2	C_2	C_3
a_6	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2
a_7	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_2
a_8	C_1	C_2	C_2	C_2	C_1	C_1	C_1	C_1
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_3	C_4
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2
a_{11}	C_2	C_2	C_2	C_2	C_1	C_1	C_2	C_2
a_{12}	C_1	C_1	C_2	C_2	C_1	C_2	C_1	C_2
a_{13}	C_2	C_2	C_2	C_2	C_2	C_3	C_3	C_4
a_{14}	C_1	C_1	C_2	C_3	C_2	C_3	C_2	C_3
a_{15}	C_1	C_1	C_2	C_2	C_1	C_2	C_2	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2
a_{17}	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2
a_{19}	C_2	C_2	C_2	C_3	C_1	C_2	C_2	C_3
a_{20}	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2
a_{23}	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_3
a_{24}	C_1	C_2	C_1	C_2	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1

Table 7.4: Results of the assignment procedure expressed in number and respective percentage of actions assigned per interval of category.

Interval of category		2017		2018	
Minimum	Maximum	Ascendant view	Descendant view	Ascendant view	Descendant view
C_1	C_1	11 (44%)	4 (16%)	7 (28%)	4 (16%)
C_1	C_2	5 (20%)	5 (20%)	6 (24%)	3 (12%)
C_2	C_2	7 (28%)	10 (40%)	7 (28%)	8 (32%)
C_2	C_3	1 (4%)	3 (12%)	2 (8%)	4 (16%)
C_2	C_4	0 (0%)	2 (8%)	0 (0%)	1 (4%)
C_3	C_3	0 (0%)	0 (0%)	3 (12%)	2 (8%)
C_3	C_4	1 (4%)	0 (0%)	0 (0%)	2 (8%)
C_4	C_4	0 (0%)	0 (0%)	0 (0%)	0 (0%)
C_4	C_5	0 (0%)	1 (4%)	0 (0%)	1 (4%)
C_5	C_5	0 (0%)	0 (0%)	0 (0%)	0 (0%)

the most represented category was C_2 with 10 actions, leaving behind C_1 with 4 actions representing a reduction of 60% comparing to the ascendant view and 76% of the actions were assigned to a category equal or lower than C_2 representing a reduction of 17% comparing to the ascendant view. Furthermore, in the descendant view the highest category assigned to an action was in the interval of $[C_4, C_5]$ with one action assigned, again a_2.

In the year of 2018 only two categories, C_4 and C_5, maintained the same number of actions assigned for both the views with 0 actions. In the ascendant view the most represented category was the worst category, C_1, as well as category C_2 both with 7 actions assigned and 80% of the actions were assigned to a category equal or lower than C_2, in respect to the highest category assigned it was C_3 with 3 actions assigned. In the descendant view the most represented category was C_2 with 8 actions, leaving behind C_1 with 4 actions assigned representing a reduction of 43% comparing to the ascendant view and 60% of the actions were assigned to a category equal or lower than C_2 representing a reduction of 25% comparing to the ascendant view. Furthermore, in the descendant view the highest category assigned to an action was in the interval of $[C_4, C_5]$ with one action assigned ,a_1.

The actions in the ascendant views were assigned to equal or worst categories when comparing to the descendant views, corroborating what was expected in line with the approach created in section 5.6 regarding the scales.

In general there was a maintenance or an improvement of the quality in the healthcare entities between the years of 2017 and 2018, expressed when comparing both ascendant and descendant views.

Concerning all the four assignment procedures, on one hand no actions were assigned to the best category C_5 what allows us to conclude that there was no under evaluation of the reference actions that define that category; on the other hand, regarding the worst category, C_1, there were several actions assigned to it.

In order to provide a better visualization of the assignment procedure one included in figure 7.1 two plots that present the category or interval of categories attributed to an action for the years of 2017 and 2018, one for each viewpoint.

Once again for obvious reasons, it is visible that the descendant view achieved better categories than the ascendant view. Another statement is that the categories attributed to the actions in 2018 tend to be equal or better than in 2017, what is more visible in the descendant viewpoint.

Looking at the actions with better categories assigned, a_2 (Póvoa do Varzim/Vila do Conde Hospital Centre), was considered the best action for both years in the descendant view, the best in the ascendant view in 2017 and together with a_{24} the best in the ascendant view for 2018. These results show that the action a_2 is consistently assigned to the best categories in both viewpoints and years inclusively it achieves an interval of categories $[C_4, C_5]$ which is almost the maximum of the scale. Concerning action a_{24} (Porto University Hospital Centre) together with a_2 it is assigned with the best category for the ascendant view of 2018 with a C_3, having the same evaluation for the descendant view. This suggests that a_{24} is the one presenting better quality healthcare among the largest hospital centres of the NHS. Hospitals a_9 and a_{13} for the year of 2018 in the descendant view were assigned with an interval of categories $[C_3, C_4]$, still far from the results presented by a_2, however amongst the best categories

attributed in this case study.

Although, it is visible that there were actions continuously being assigned to the worst categories C_1 and C_2, where the worst ones were a_{10}, a_3 and a_{17},and from the largest hospital centres a_{25} and a_{20}. Those represent the hospitals with lowest quality healthcare performances according to the case study. In overall there are other hospitals where the categories assigned are not much better than the ones assigned to the previous actions, which suggests that the quality provided by the hospitals of the NHS is low, in the majority of the cases between the categories C_1 and C_2, as it is visible in table 7.4.

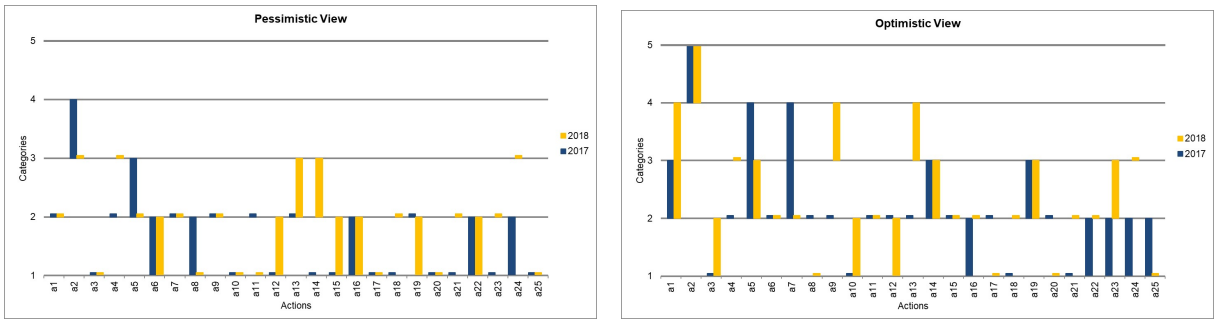


Figure 7.1: Comparison of the assignment procedure between the years of 2017 and 2018 for both viewpoints.

7.3 Sensitivity Analysis

This section evaluates how changes in the inputs of our model influence its outputs. This process of recalculating outcomes under alternative assumptions allows to determine the influence of a parameter in a model, increase the understanding of the relationships between the variables, searching for errors and above all to test the robustness of the presented analysis [55]. For this sensitivity analysis one first tested two different values for the credibility index $\lambda = 0.55$ and $\lambda = 0.65$. In a second analysis we tested three different scenarios that were created at the time the DM established the weights of the family of criteria using the SRF procedure, where we applied changes in the number of blank cards, as well as in the parameter-z. In a last test we varied at the same time the credibility level λ, the scenarios and the parameter-z.

In this dissertation the execution of the model was innovative, as explained before we used the method itself to define the scales of the family of criteria, thus it was crucial to perform an extensive sensitivity analysis to test the robustness of the model and that was why we performed three different tests.

7.3.1 Changing the credibility index λ

The change of the credibility index induces changes assignment procedure, since it directly influences both ascending and descending joint rules:

– In case the credibility index λ increases, the ascending rule as a tendency for increasing the category assigned for an action a, whereas the descending rule as a tendency for decreasing the

category assigned for that same action. In general there is a tendency for both rules to converge in the category to be assigned to an action a, possibly coinciding in a unique category.

– In case the credibility index λ decreases, the ascending rule as a tendency for decreasing the category assigned for an action a, whereas the descending rule as a tendency for increasing the category assigned for that same action. In general there is a tendency for both rules to diverge in the category to be assigned to an action a, possibly generating an interval of categories.

This suggests the existence of a critical λ responsible for assigning the majority of the actions to a unique category [74]. As for that, in this sensitivity analysis the credibility index was varied two times, assuming the values $\lambda = 0.55$ and $\lambda = 0.65$, to be compared to our analysis where $\lambda = 0.60$ with the objective of finding a solution close to the critical value of λ that assigned the majority of the actions to a unique category. In table 7.5, were presented the results of the assignment procedure for $\lambda = 0.55$ and $\lambda = 0.6$ and in table 7.6 were described the results for $\lambda = 0.60$ and $\lambda = 0.65$. Note that in both tables, whenever it was registered a difference between the category or interval of categories assigned when $\lambda = 0.60$ and the two variations of λ, the cell was represented with a grey background for a better visualization.

Taking into account table 7.5, considering the ascendant view of 2017 there were three alterations (12%) where action a_2, was assigned to a unique category (rather than an interval of categories) resulting in a stronger assignment relation comparing to $\lambda = 0.60$, as for actions a_{13} and a_{14} were assigned to a different category (but not an interval of categories). Regarding the descendant view of 2017, there were three alterations (12%) where all the actions were assigned to an interval of categories comparing to $\lambda = 0.60$ resulting in a weaker assignment, note that in the case of actions a_1 and a_{14} both were assigned to a non-consecutive interval of categories. Regarding the ascendant view of 2018, there were four alterations (16%) where the actions were assigned to an interval of categories comparing to $\lambda = 0.60$ resulting in a weaker assignment, note that in the case of actions a_4 and a_{14} both were assigned to a non-consecutive interval of categories. As to the descendant viewpoint of 2018 there were seven alterations (28%), where six of the actions were again assigned to an interval of categories from which only actions a_{15} and a_{16} were assigned to an interval of consecutive categories comparing to $\lambda = 0.60$ resulting in a weaker assignment, the exception was a_{13} that was assigned to a unique category resulting in a stronger assignment. All in all considering the four projects, there were eighteen alterations where fifteen of them (83%) resulted in actions assigned to an interval of categories and only three of them (17%) resulted in actions assigned to a unique category.

In the case where it was used, $\lambda = 0.65$, one notices a reduction in the number of alterations to ten, visible in table 7.6 comparing to the eighteen cases for $\lambda = 0.55$. Considering the ascendant view of 2017 there were four alterations (16%) where two of the actions a_2 and a_{16}, were assigned to a unique category resulting in a stronger assignment relation comparing to $\lambda = 0.60$, the other two actions a_{13} and a_{14} changed from a unique category to another. Regarding the descendant view of 2017, there was only one alteration (4%) assigned to a unique category comparing to $\lambda = 0.60$ resulting in a stronger assignment. In respect to the ascendant view of 2018 there were two alterations (8%), where one of the

Table 7.5: Results of the assignment procedure for $\lambda = 0.55$ and $\lambda = 0.60$.

	$\lambda = 0.55$								$\lambda = 0.60$							
	2017				2018				2017				2018			
	Ascendant view		Descendant view		Ascendant view		Descendant view		Ascendant view		Descendant view		Ascendant view		Descendant view	
Actions	Min	Max	Max	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_4	C_2	C_3	C_2	C_4	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_4
a_2	C_3	C_3	C_4	C_5	C_3	C_3	C_4	C_5	C_3	C_4	C_4	C_5	C_3	C_3	C_4	C_5
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2
a_4	C_2	C_2	C_2	C_2	C_3	C_5	C_3	C_5	C_2	C_2	C_2	C_2	C_3	C_3	C_3	C_3
a_5	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_4	C_2	C_2	C_2	C_3
a_6	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2
a_7	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_2
a_8	C_1	C_2	C_2	C_2	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_1	C_1	C_1	C_1
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_2	C_2	C_2	C_3	C_4
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2
a_{11}	C_2	C_2	C_2	C_2	C_1	C_1	C_2	C_2	C_2	C_2	C_2	C_2	C_1	C_1	C_2	C_2
a_{12}	C_1	C_1	C_2	C_2	C_1	C_2	C_1	C_2	C_1	C_1	C_2	C_2	C_1	C_2	C_1	C_2
a_{13}	C_1	C_1	C_2	C_2	C_2	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_3	C_3	C_4
a_{14}	C_2	C_2	C_2	C_4	C_2	C_4	C_2	C_4	C_1	C_1	C_2	C_3	C_2	C_3	C_2	C_3
a_{15}	C_1	C_1	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_1	C_2	C_2	C_1	C_2	C_2	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_3	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2
a_{17}	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2
a_{19}	C_2	C_2	C_2	C_3	C_1	C_2	C_2	C_3	C_2	C_2	C_2	C_3	C_1	C_2	C_2	C_3
a_{20}	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2
a_{23}	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_3	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_3
a_{24}	C_1	C_2	C_1	C_2	C_3	C_3	C_3	C_3	C_1	C_2	C_1	C_2	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1

Table 7.6: Results of the assignment procedure for $\lambda = 0.60$ and $\lambda = 0.65$.

	$\lambda = 0.60$								$\lambda = 0.65$							
	2017				2018				2017				2018			
	Ascendant view		Descendant view		Ascendant view		Descendant view		Ascendant view		Descendant view		Ascendant view		Descendant view	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_3
a_2	C_3	C_4	C_4	C_5	C_3	C_3	C_4	C_5	C_3	C_3	C_4	C_5	C_3	C_3	C_4	C_5
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2
a_4	C_2	C_2	C_2	C_2	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_3	C_2	C_3
a_5	C_2	C_3	C_2	C_4	C_2	C_2	C_2	C_3	C_2	C_3	C_2	C_4	C_2	C_2	C_2	C_3
a_6	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2	C_1	C_2	C_2	C_2
a_7	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_4	C_2	C_2	C_2	C_2
a_8	C_1	C_2	C_2	C_2	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_1	C_1	C_1	C_1
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_3	C_4	C_2	C_2	C_2	C_2	C_2	C_2	C_3	C_4
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2
a_{11}	C_2	C_2	C_2	C_2	C_1	C_1	C_2	C_2	C_2	C_2	C_2	C_2	C_1	C_1	C_2	C_2
a_{12}	C_1	C_1	C_2	C_2	C_1	C_2	C_1	C_2	C_1	C_1	C_2	C_2	C_1	C_2	C_1	C_2
a_{13}	C_2	C_2	C_2	C_2	C_2	C_3	C_3	C_4	C_1	C_1	C_2	C_2	C_2	C_3	C_3	C_4
a_{14}	C_1	C_1	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_1	C_1	C_2	C_2	C_1	C_2	C_2	C_2	C_1	C_1	C_2	C_2	C_1	C_2	C_2	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2	C_1	C_1	C_1	C_2	C_1	C_2	C_2	C_2
a_{17}	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2
a_{19}	C_2	C_2	C_2	C_3	C_1	C_2	C_2	C_3	C_2	C_2	C_2	C_3	C_1	C_2	C_2	C_3
a_{20}	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_2	C_2
a_{23}	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_3	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_3
a_{24}	C_1	C_2	C_1	C_2	C_3	C_3	C_3	C_3	C_1	C_2	C_1	C_2	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1

actions a_{14} was assigned to a unique category comparing to $\lambda = 0.60$ resulting in a stronger assignment relation, the opposite happened to the action a_4 that was assigned to an interval of categories. As to the descendant viewpoint of 2018 there were three alterations (12%), where only action a_{14} was assigned to a unique category comparing to $\lambda = 0.60$ resulting in a stronger assignment, the actions a_1 and a_4 were assigned to an interval of categories, resulting in a weaker assignment relation. All in all considering the four projects in the ten alterations, three of them (30%) resulted in actions assigned to an interval of categories and five of them (50%) resulted in actions assigned to a unique category, the other two alterations (20%) represent a change of unique category to another.

To conclude, in the case where $\lambda = 0.55$ there was an increase of actions assigned to an interval of categories (weak assignment relations) that suggest that this level of credibility is not close to the critical level. Regarding the case where $\lambda = 0.65$ the balance reflects three more actions assigned to a unique category than for the case where $\lambda = 0.60$, that suggests that the critical level of credibility might be between these two values of λ.

7.3.2 Changing the weight of the criteria

This section tested how variations in the SRF procedure, that was responsible for attributing the weight to the criteria, influenced the results of our project execution. The SRF procedure makes use of the DM knowledge, that is responsible for ranking the criteria, adding the blank cards and choosing the ratio-z, as stated in section 6.1. At the time the DM was ordering the ranking of the family of criteria, when adding blank cards he was not sure wether to add two or three blank cards between the Access criteria and the Caesarean Appropriateness criteria; and also wether to add three or four cards blank cards between the Caesarean Appropriateness criteria and the Efficiency criteria. In the end the DM opted for adding three blank cards between each of the criteria in these cases, however this situation allowed us to create three different scenarios:

- Scenario A: one added two blank cards between the Access criteria and the Caesarean Appropriateness criteria, instead of three cards;
- Scenario E: one added four blank cards between the Caesarean Appropriateness criteria and the Efficiency criteria, instead of three cards;
- Scenario I: one added two blank cards between the Access criteria and the Caesarean Appropriateness criteria, instead of three, and also four blank cards between the Caesarean Appropriateness criteria and the Efficiency criteria, instead of three.

Furthermore, one opted to include in this analysis two variations of the ratio-z, since this ratio influences the weight attributed to each of the criteria. Thus, the variations of the ratio-z were Z=9 and Z=11, to contrast with the value chosen by the DM, Z=10. Note that these variations were only tested for the attribution of weight of the criteria and not to the groups of subcriteria. Due the extensively of the results, they were represented in appendix B, from table B.1 to table B.4 and to resume the number of alterations table 7.7 was created. In the analysis presented in table 7.7, in a universe of 1100 assignments

of categories to the actions, only seven alterations of categories (0.64%) were registered what shows that the results were truly consistent even when using different parameters in the model.

Table 7.7: Number of alterations in the assignment of categories comparing to Scenario DM and ratio-z=10 in each of the projects when varying the scenarios and ratio-z.

	2017 Ascendant view			2017 Descendant view			2018 Ascendant view			2018 Descendant view		
Scenario	Z=9	Z=10	Z=11	Z=9	Z=10	Z=11	Z=9	Z=10	Z=11	Z=9	Z=10	Z=11
DM	0		0	0		2	0		2	0		3
A	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0

7.3.3 Changing the weight of the criteria and the credibility level

In this section, one tested both previous analysis at the same time. The credibility levels were varied two times ($\lambda = 0.55$ and $\lambda = 0.65$), the ratio-z three times (Z=9, Z=10 and Z=11) and the three scenarios (A, E and I) created in the previous section 7.3.2 were tested. The results were represented in appendix B, from table B.5 to table B.12 and to resume the number of alterations resulting from the comparison between the new conditions and the DM scenario with a Z=10 and $\lambda = 0.60$ table 7.8 was created.

As observed in table 7.8, there were 192 alterations in 2400 possible this means 8% of alterations, a small percentage taking into account that in these tests it was changed from one parameter (λ) until three parameters (λ, scenario and ratio-z). There were less alterations for $\lambda = 0.65$, than for $\lambda = 0.55$, what once again is related to the fact that the critical λ is closer to $\lambda = 0.6$ and $\lambda = 0.65$. The maximum number of alterations of category was registered for all the projects of the descendant view of 2018 with $\lambda = 0.55$, with 6 alterations per project and the minimum number of alterations registered was 0 that happened for all the projects of the ascendant view of 2017 with $\lambda = 0.65$.

All in all, this sensitivity analysis with 96 projects, once again, proved that our model is consistent because even though we inserted so many changes in the inputs, the output was nearly the same for all of them.

7.4 Summary

In this chapter, one analyses the results produced by the execution of MCDA-ULaval. There are two models per year, since each of them has a descendant and an ascendant view, resulting in a total of four models. The model illustrated in section 7.1, is the descendant viewpoint of the criteria family for the year of 2018, since it would be impossible to represent all the models for space reasons.

The calculations obtained from U-Laval for the categorical credibility indices σ, allow us to conclude that the better and worst categories present outranking relations with the potential actions. For category C_1, the actions almost always present an outranking relation over B_1, since it is the worst category. For category C_5 the reference actions B_5, denoted an outranking relation over the actions, since it is the best

Table 7.8: Number of alterations in the assignment of categories comparing to Scenario DM and ratio-z=10 per project, when varying the scenarios, ratio-z and the credibility level λ.

	2017 Ascendant view			2017 Descendant view			2018 Ascendant view			2018 Descendant view		
	Z=9	Z=10	Z=11	Z=9	Z=10	Z=11	Z=9	Z=10	Z=11	Z=9	Z=10	Z=11
Scenario	λ=0.55											
DM	1	1	1	3	3	3	4	4	4	6	6	6
A	1	1	1	3	3	3	3	3	3	6	6	6
E	1	1	1	3	3	3	4	3	3	6	6	6
I	1	1	1	3	3	3	3	5	3	6	6	6
Scenario	λ=0.65											
DM	0	0	0	1	1	1	2	2	2	3	3	3
A	0	0	0	1	1	1	2	2	2	3	3	3
E	0	0	0	1	1	1	2	2	2	3	3	3
I	0	0	0	1	1	1	2	2	2	3	3	3

category. However, the same happened almost in all the cases for category C_4 (except to four actions) and category C_3, what suggests that there is a lack of quality in the hospitals.

The credibility level was validated by the DM with the value of $\lambda = 0.60$, and it is through the comparison of this value with the categorical credibility indices that the method establishes outranking relations, that originate the assignment of an action to a category.

Our methodology added two different views, the descendant and ascendant, and the results were consistent. The actions in the ascendant views were assigned to equal or worst categories when comparing to the descendant views, corroborating what was expected.

Concerning all the four assignment procedures, on one hand no actions were assigned to the best category, C_5, what allows us to conclude that there was no under evaluation of the reference actions that define that category; on the other hand, regarding the worst category, C_1, there were several actions assigned to it, once again suggesting the lack of quality of the institutions.

Comparing both years, in general there was a maintenance or an improvement of the quality in the healthcare entities between the years of 2017 and 2018, expressed in both ascendant and descendant views.

Also in this chapter, one performed an extensive sensitivity analysis to test the robustness of the model. This analysis focused on changes in the credibility index and in the weight of the criteria creating three scenarios and inducing changes in the SRF procedure, namely in the cards order and in ratio-z. In total one tested 96 tests, that in 2400 assignments generated only produced 192 alterations, equivalent to 8%, to our original model. This suggests that the model created is robust. Moreover, there were less alterations when considering the credibility level $\lambda = 0.65$, than when considering $\lambda = 0.55$, suggesting that the credibility level validated by the DM is a consistent value.

Chapter 8

Conclusions and future research

8.1 Conclusions

Quality in healthcare is an actual problem of health policy. In Portugal the public health spending has declined in the new millennium, exposing difficulties in public funding of the SNS, which reduce its ability to respond and deliver care to its users. Health system financing tends to increase at rates higher than GDP, due to numerous factors such as demography shifts, an aging population, chronic diseases and the introduction of innovation responsible for generating health gains (however not eliminating costs). To address this problem, policy-makers and healthcare managers are applying measures to improve efficiency, resorting to cost containment measures that tend to decrease the quality of the services delivered. Furthermore, these measures increment barriers to access and compromising infrastructures and equipment. A detailed study is required to assess the status of the public hospitals' quality, the main goal of this dissertation.

To achieve this assessment, there were objectives set in section 1.2. The first one was to contextualize the state of the healthcare sector and how its variables are related. The objective was achieved and was of extreme importance, since it provided a portrait of the health sector in Portugal through the years and the status of the public hospitals, from management to financing, also allowing us to understand the structure of the SNS.

The second objective consisted in defining quality in the healthcare services. This was achieve through an extensive literature review in Chapter 3, that resulted in a multidimensional definition where quality is composed by dimensions such as: safety, effectiveness, person-centeredness, accessibility, efficiency and equity. In this objective it was also contemplated how quality can be measured, what is done resorting to indicators that can measure the process of care or outcomes according to Donabedian [29].

The fact that quality is multidimensional, opened the way for an MCDA approach, towards that our third objective was understanding MCDA methodologies and especially the ELECTRE TRI-nC used to build our model. This work is described in chapter 4 and precedes the creation of our model.

The fourth objective consisted in conceiving and describing our model. Before creating a reliable

model, it is important to create a data set where the source of the data set is also reliable. Therefore, one used the ACSS benchmarking an updated data set following international guidelines and containing indicators related to our literature review. For the selection of the actions/hospitals selected have analogous production technologies to avoid biased results. Afterwards, to create our MCDA model one used the ELECTRE TRI-nC, an ordinal classification and non-compensatory model, which is applicable to health problems where positive performances in a criteria do not compensate wake performances in other especially life-threatening ones [61]. The method uses two joint rules to assign actions to categories. In cooperation with the DM, we defined five categories *a priori*, from the worst C_1 to the best C_5, each of them with more than one reference action, allowing the possibility of considering several appropriate reference actions to characterize a category. The criteria tree arrives from the literature review and from the indicators that one had access (in the ACSS benchmarking), that best judge quality in health care. In the construction of the criteria scales the subcriteria assume a cardinal scale, whereas the criteria family assume an ordinal scale. This arrived from an innovative methodology, that allowed to use the results of the method itself applied to the subcriteria to create scales for the criteria family. The fact that some actions were assigned to an interval of categories in the subcriteria analysis, originated two viewpoint the optimistic and the ascendant. As to the criteria weight, they were defined using the SRF procedure allied to the DM knowledge. To tackle imperfect knowledge, the method enables to insert preference, indifference and veto thresholds that were chosen in cooperation with the DM. The veto threshold was only included in two criteria: Care Appropriateness (g_2) and Patient Safety (g_3), that reinforces the importance of both criteria in a quality assessment and the non-compensatory character of the method.

The results of the model are presented in chapter 7, where the hospitals were finally assigned to a category or an interval of categories. In general, there was a maintenance or an improvement of the quality in the healthcare entities between the years of 2017 and 2018, expressed both in ascendant and optimistic views. However, one can state that no actions were assigned to the best category, C_5, what allows us to conclude that there was no under evaluation of the reference actions that define that category; on the other hand, regarding the worst category, C_1, there were several actions assigned to it. This means that in fact the quality of the Portuguese public hospitals is poor in our models' eyes. A fact also sustained by the results, where actions were continuously being assigned to the worst categories C_1 and C_2. As an example of that considering the year with better results 2018 and the optimistic view, 15 of the 25 hospitals (60%) were assigned to a category or an interval of categories equal or less than the poor performance category, C_2, the ones presenting less quality. Whereas, only 3 hospitals (%12) were assigned to a category higher than the neutral performance category C_3, the best performance categories. These facts point out that there is a lack of quality present in the Portuguese public hospitals. Nonetheless, a_2 (Póvoa do Varzim/Vila do Conde Hospital Center), was considered the best action in both years and views, inclusively being assigned to the highest categories $[C_4, C_5]$ two times. This suggests the possibility of using this entity as a benchmarking. Also action a_{24} (Porto University Hospital Center) together is assigned with the best category for the ascendant view of 2018 with a C_3, having the same evaluation for the optimistic view. This suggests that a_{24} is presenting better quality healthcare

among the largest hospital centers of the SNS, adding on the fact that this entity saw the assigned category improve from a $[C_1, C_2]$ in 2017, to a C_3 in 2018 what suggests that good practices are being followed resulting in an improvement of quality.

In order to assure that the model developed was producing reliable results and because our model had an innovation methodology never tested, it was crucial to perform an extensive sensitivity analysis. Thus, the model was tested with changes in the credibility index and also different scenarios with changes in the weight of the criteria. All in all, were created 96 projects, where the results presented 192 alterations in 2400 possible, meaning only 8% of the categories assigned changed. This suggests a construction of a robust model confirmed by the sensitivity analysis, so the fourth objective was achieved.

The fifth objective concerned about the future studies, where this dissertation could generate major impact and is present in the last section 8.3.

All the goals proposed for the development of this dissertation were successfully achieved. Finally, the application of an MCDA approach to assess the quality of the Portuguese public hospitals was fulfilled , validating this model ,and consequently dissertation.

8.2 Limitations

Models are developed to represent real situations, they are not perfect, neither our model. Thereby the major limitations are hereby presented.

In the case study, it was used the data present in the ACSS benchmarking, as it includes clinical quality indicators that were significant and reliable. Even though the benchmarking presents several quality indicators, according to the literature review there are more indicators, than the ones we had access to. Therefore, to increase the robustness of our criteria tree and consequently our model, it would be needed more data gathered and provided by the benchmark. Information centered in the outcomes, such as patient satisfaction, which is of difficult access, or about the infrastructures would be interesting to apply on this method.

The results of this dissertation highly depend on the weights (attributed by the SRF procedure), thresholds and scales attribute to the criteria, a task that it is developed conjointly between the analyst and the DM. Once we only had one DM to collaborate with us, we were deprived of generating more results from our model that would allow us to compare attributions and different perspectives regarding weights and scales. Having access to other DMs to test our model, would provide information about the model's adaptability to other opinions and scenarios. Another limitation was defining more than one reference action for the subcriteria families, what was surpassed with the use of ELECTRE TRI-C instead of ELECTRE TRI-nC. Nonetheless, the DM provided much of his time and knowledge that made this dissertation possible.

To finish, the literature regarding definitions of levels from a subcriterion composed by several indicators, to a criterion, only presented not-feasible approaches for our case study. This made us opt for an innovative approach, where one used the results of the ELECTRE TRI-C applied to the family of subcriteria, to define levels for the criteria set. Therefore, two viewpoints were generated, optimistic and

ascendant, in an ideal situation each hospital would have only one category or an interval of categories to define its quality.

8.3 Future research

At the day I am writing this section one of the most prestigious medical journals in the world, The Lancet, published an editorial about the SNS. The publication concluded that the NHS no longer meets the needs of the population [2]. Portugal is one of four countries (of 33 analysed) where the public heath expenditure was reduced between 2000 and 2017. As a result of that, the hospitals were not renovated and the medical equipment became obsolete. Moreover, the public care has been losing space to the private care, who hire public medical workforce from public care taking advantage from their poor work conditions and demotivation.

The application of a multicriteria approach to perform a quality assessment of the Portuguese public hospitals proved to be a reliable tool. If there is a need of reformulating and investing in the SNS, quality must be considered to assure the needs and safety of patients, workforce and the health institutions. In other words, it would be an honour if the results of this dissertation could contribute to future studies among several areas in the healthcare field. Furthermore, new scenarios would need to be tested, where efficiency would assume a major weight (this is being developed with the DM). Furthermore, at a time that public-private-partnership are so criticized, the application of the model concerning data of these hospitals would be interesting, towards proving data to assess these partnerships and their existence.

For now, efforts are being made to write a paper in an international scientific journal.

If there is a need of reformulating and investing in the SNS, quality must be considered to assure the needs and safety of patients, workforce and the health institutions. In future, this model could work as a guideline to create in-depth assessing from hospital funding, to physicians' evaluations. Furthermore, at a time that public-private-partnership are so criticized, the application of the model concerning data of these hospitals would be interesting, towards proving data to assess these partnerships and their existence.

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Appendix A

Ranking of projects - SRF procedure

In this chapter of the appendix, the following tables illustrate the rankings composed by the decision-maker following the SRF procedure. In case of existence, blank cards were numerically represented between two consecutive ranking levels. Note that the ranks were numerically ordered, where R1 represents the least important ranking.

Table A.1: Ranking of the family of criteria

Ranks and blank cards	
R5	g_3
	0
R4	g_2
	1
R3	g_1
	3
R2	g_5
	3
R1	g_4
Ratio-z	10

Table A.2: Ranking of the Access of subcriteria

Ranks and blank cards	
R4	$g_{1,1}$
	0
R3	$g_{1,2}$
	2
R2	$g_{1,3}$
	3
R1	$g_{1,4}$, $g_{1,5}$
Ratio-z	2

Table A.3: Ranking of the Care Appropriateness subcriteria

Ranks and blank cards	
R3	$g_{2,2}$
	1
R2	$g_{2,1}, g_{2,3}$
	3
R1	$g_{2,4}, g_{2,5}$
Ratio-z	10

Table A.4: Ranking of the Patient Safety subcriteria

Ranks and blank cards	
R4	$g_{3,3}, g_{3,4}$
	2
R3	$g_{3,2}$
	2
R2	$g_{3,1}$
	4
R1	$g_{3,5}, g_{3,6}$
Ratio-z	10

Table A.5: Ranking of the Efficiency subcriteria

Ranks and blank cards	
R3	$g_{4,2}, g_{4,3}$
	2
R2	$g_{4,1}, g_{4,4}$
	4
R1	$g_{4,5}$
Ratio-z	10

Table A.6: Ranking of the Caesarean Appropriateness subcriteria

Ranks and blank cards	
R2	$g_{5,2}, g_{5,3}$
	1
R1	$g_{5,1}$
Ratio-z	10

Appendix B

Sensitivity Analysis Data-sheets

In this appendix B, one can find the assignment procedure results used for the sensitivity analysis for the two years studied and both descendant and ascendant views. The cells in grey background represent the cases where there was an alteration of category assignment relatively to the DM scenario, ratio-z=10 and $\lambda = 0.60$.

Table B.1: Assignment procedure for the ascendant view of 2017 with variations of ratio-z and blank cards.

	$\lambda = 0.60$																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_2	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_6	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{13}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{14}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{16}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{24}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.2: Assignment procedure for the descendant view of 2017 with variations of ratio-z and blank cards.

	$\lambda = 0.60$																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_3	C_2	C_3
a_2	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_6	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_7	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_8	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{13}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{14}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_3	C_2	C_3
a_{15}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{20}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{24}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{25}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2

Table B.3: Assignment procedure for the ascendant view of 2018 with variations of ratio-z and blank cards.

	$\lambda = 0.60$																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_2	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_5	C_3	C_3	C_3	C_3	C_3	C_3
a_5	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_6	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{12}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{13}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{14}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_3	C_2	C_3
a_{15}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{24}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.4: Assignment procedure for the descendant view of 2018 with variations of ratio-z and blank cards.

	$\lambda = 0.60$																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_2	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5
a_3	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_5	C_3	C_3	C_3	C_3	C_3	C_3
a_5	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_3	C_2	C_3
a_6	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_9	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4
a_{10}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{13}	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4
a_{14}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_4	C_2	C_3	C_2	C_3	C_2	C_3
a_{15}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{16}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{22}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{23}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{24}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.5: Assignment procedure for the ascendant view of 2017 with variations of ratio-z, blank cards and λ=0.55

	$\lambda = 0.55$																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_2	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_6	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{13}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{14}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{24}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.6: Assignment procedure for the descendant view of 2017 with variations of ratio-z, blank cards and $\lambda = 0.55$

	λ=0.55																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_2	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_6	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_7	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_8	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{13}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{14}	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_{15}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{20}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{24}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{25}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2

Table B.7: Assignment procedure for the ascendant view of 2018 with variations of ratio-z, blank cards and $\lambda = 0.55$

	λ=0.55																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_2	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5
a_5	C_2	C_3	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_3	C_2	C_2	C_2	C_2	C_2	C_2
a_6	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{12}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{13}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{14}	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_{15}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{24}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.8: Assignment procedure for the descendant view of 2018 with variations of ratio-z, blank cards and $\lambda = 0.55$

	λ=0.55																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_2	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5
a_3	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_4	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5	C_3	C_5
a_5	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_6	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_9	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_{10}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{13}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{14}	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_{15}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{16}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{22}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{23}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{24}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.9: Assignment procedure for the ascendant view of 2017 with variations of ratio-z, blank cards and $\lambda = 0.65$

	λ=0.65																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_2	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_6	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{13}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{14}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{16}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{24}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.10: Assignment procedure for the descendant view of 2017 with variations of ratio-z, blank cards and $\lambda = 0.65$

	λ=0.65																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_2	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_6	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_7	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4	C_2	C_4
a_8	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{13}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{14}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{20}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{24}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{25}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2

Table B.11: Assignment procedure for the ascendant view of 2018 with variations of ratio-z, blank cards and $\lambda = 0.65$

	λ=0.65																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_2	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_5	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_6	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_9	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{11}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{12}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{13}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{14}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{16}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{22}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{23}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{24}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1

Table B.12: Assignment procedure for the descendant view of 2018 with variations of ratio-z, blank cards and $\lambda = 0.65$

	λ=0.65																							
	Z=9								Z=10								Z=11							
	Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I		Scenario DM		Scenario A		Scenario E		Scenario I	
Actions	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
a_1	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_2	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5	C_4	C_5
a_3	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_4	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_5	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_6	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_7	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_9	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4
a_{10}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{11}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{12}	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
a_{13}	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4	C_3	C_4
a_{14}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{16}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{22}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{23}	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3	C_2	C_3
a_{24}	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1