TÉCNICO LISBOA

Developing simulation and optimization approaches to support the planning of mental health care services: predicting demand and designing a network of services

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Thesis to obtain the Master of Science Degree in

Biomedical Engineering

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October 2016

Acknowledgments

First and foremost, I would like to thank my supervisor Prof. Teresa Grilo for her constant support, availability and shared knowledge throughout the work towards this thesis. I want to express my gratitude to Dr. Maria João Heitor for her explanations on mental health care provision in Portugal and also for her suggestions for this work. I am also grateful to Prof. Mónica Oliveira and Prof. Teresa Grilo for giving me the opportunity to present this work in the Operational Research Applied to Health Services (ORAHS) Conference.

I would like to thank my family and my closest friends, with whom I shared my thoughts on the project, for their encouragement and patience. Special thanks to my mother, father and brother for their unconditional support and for keeping my spirits up in the most stressful moments. I also want to thank my grandmother and father for all the prayers they did for me. Manuel, I have not enough words to thank you. Your presence, patience and love made this achievement come true.

Abstract

Mental health care problems currently represent one of the leading causes of disability and morbidity in many European countries. As a result, an increasing demand for mental health care is predicted for coming years across these countries. Still, the current supply of mental health services is far from being enough to satisfy this growing demand for care, and the current economic crisis can seriously hinder the development of such supply. Within this context, planning mental health care networks currently represents a health policy priority across European countries. In fact, mathematical programming models have been developed to support health care planning in general. Nevertheless, specific applications in mental health are still scarce.

This study aims to develop a mathematical programming model – MHC model – to aid health planners in the management, design and planning of networks of mental health services. The model provides information for planning, both in terms of services' location, capacity planning and allocation of patients to services, while ensuring the attainment of multiple objectives relevant in the mental health care sector, namely the minimization of costs and the maximization of several equity dimensions. The proposed model integrates estimates on future demand for mental health care based on the characteristics of the population with potential need of such care, predicted within the scope of this study. The applicability of the model is shown through its application to the mental health care sector in the Great Lisbon region in Portugal under different planning contexts.

Keywords: Mental health care, Estimates on future demand, Mathematical Programming Models, Network Planning

Resumo

Os problemas de saúde mental constituem hoje uma das principais causas de incapacidade e morbilidade em muitos países europeus, incluindo Portugal, prevendo-se um aumento significativo na procura de cuidados de saúde mental. No entanto, estes cuidados em Portugal não estão dimensionados para responder a este desafio, uma vez que a oferta disponível é escassa e atualmente existem fortes constrangimentos financeiros, o que condiciona o seu desenvolvimento. Todo este contexto, faz da saúde mental uma prioridade para a política de saúde em Portugal, sendo essencial o planeamento da oferta destes cuidados tendo em vista dar respostas adequadas às necessidades das populações. Para isto, têm sido desenvolvidos modelos de programação matemática para apoiar o planeamento de redes em saúde, no entanto existem ainda poucas aplicações na área da saúde mental.

Neste estudo é apresentado um modelo de programação matemática – modelo MHC – para apoiar os responsáveis pela gestão e política de saúde no planeamento do sector da saúde mental. O modelo fornece informação útil para planeamento, em termos de localização de serviços, planeamento de capacidade e alocação de doentes aos serviços, considerando múltiplos objetivos relevantes neste setor, nomeadamente a minimização de custos e a maximização de vários tipos de equidade. O modelo integra previsões das estimativas das necessidades de cuidados de saúde mental baseadas nas características da população com potencial necessidade de vir a precisar deste tipo de cuidados – previstas no âmbito deste estudo. O modelo é aplicado no sector da saúde mental em Portugal na região da Grande Lisboa sob diferentes contextos de planeamento.

Palavras-chave: Cuidados de saúde mental, Estimativas de necessidades futuras, Modelos de Programação Matemática, Planeamento de Redes

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List of Abbreviations

AC Ambulatory care

ALOS Average length of stay

DALY Disability-adjusted life years

DGH Directorate-General of Health

DM Decision Maker

EA Equity of access

EDU Equity of disease-specific utilization

ESU Equity of service-specific utilization

GAMS General Algebraic Modelling System

GE Geographical equity

GP General practitioner

HBC Home-based care

IC Institutional care

ICD-10 International Statistical Classification of Diseases and Related Health Problems 10th Revision

IP Integer programming

IPSS Private institutions for social solidarity (Instituições particulares de solidariedade social)

LOS Length of stay

LP Linear programming

LVT Lisbon and Tagus Valley

MACBETH Measuring Attractiveness by a Category-Based Evaluation Technique

MILP Mixed integer linear programming

NGOs Non-governmental organizations

NHS National Health Service

NLP Non-linear programming

OECD Organisation for Economic Co-operation and Development

OU Occupational unit

PHCCs Primary health care centers

PNSM National Plan for Mental Health (Plano Nacional de Saúde Mental)

RHA Regional Health Administration

RU Residential unit

WHO World Health Organization

WMHSI World Mental Health Survey Initiative

YLD Years lived with disability

Chapter 1

Introduction

European countries are currently facing demographic, social and economic changes affecting the well-being of the population and the provision of quality care [1]. The ageing phenomenon and the increase in the prevalence of mental disorders lead to an increase in the demand for mental health care. Mental health problems affect a large part of the population [2] and have a strong impact on the economy, affecting also the rest of the population [3].

Mental health is described by the World Health Organization (WHO) as “a state of well-being in which an individual realizes his or her abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to his or her community” [4]. Among the European countries, several mental health care provision paradigms can be found. Mental health care includes treatment, rehabilitation and promotional and preventive activities, delivered in primary health care centers (PHCCs), general hospitals, psychiatric hospitals and through services in the community [5]. The most recent mental health policy developed by the WHO focuses on rehabilitation and social integration. For this purpose, the WHO recommends that countries should replace large psychiatric hospitals by community services through a deinstitutionalization process.

Over the past years, the provision of mental health care in Portugal has undergone restructuring in order to transit from a hospital-based therapy to a model of continued and family-oriented. One of the measures taken to accomplish this was the implementation of a national plan developed in accordance to WHO recommendations. Persisting problems related to difficulties in accessing mental health care and the high prevalence of mental disorders are still being addressed. Nevertheless, great improvements in mental health care provision have already been achieved, namely, the development of community services, the setup of the basis for launching continuous care and the beginning of the deinstitutionalization process followed by the closure and restructuring of some psychiatric hospitals.

The Portuguese mental health care network operates within the scope of the Ministry of Health and the Ministry of Labour and Social Solidarity, providing different typologies of health and social care services delivered by multidisciplinary teams [6]. The health services include institutional care, ambulatory care and home-based care. Regarding the social services, these correspond mainly to rehabilitation services.

However, despite the evidence of improvements in mental health care provision, there is still a large proportion of the population that does not receive care [1, 7]. This situation has a strong impact on the economy and in the sustainability of health systems. Besides this, the current economic crisis imposes severe budget cuts along with a pressure to reduce public health care spending, which can seriously hinder the development of mental health care supply. Consequently, there has been a worldwide awareness on this matter, leading to huge challenges and pressures concerning the development and improvement of mental health care provision in Portugal and many other European countries [1].

Within this context, there is a need to invest wisely in mental health and to make good resource allocation choices [3]. Thus, a suitable planning of mental health care networks currently represents a health policy priority across European countries. The development of mathematical programming models have been widely used to support health care planning in general and have potential to be used to assist policy makers and health planners in the organization of networks of mental health care.

Over the last decade, several studies proposing mathematical programming models to aid health care planners to support location-allocation decisions in the health care sector have been developed [8]. Particularly, different types of mathematical programming models have been proposed in the area, namely: single and multi-service models (Mestre et al. [9] presents an example of a multiple service approach); single and multi-objective model (see, for instance Mitropoulos et al. [10]); and deterministic [11] and stochastic models [12]. Regarding the case of the mental health sector, there is still little research on models considering its specificities. Moreover, most of the mathematical programming models have been developed to support the planning of mental health care services in the US context. Thus, there is evidence on the need to plan mental health care networks operating in the context of National Health Service (NHS) systems. Furthermore, predicting future demand for health care services is crucial in order to be integrated in mathematical programming models for planning purposes. Different approaches have been used to predict future demand for health, namely: using the information from current levels of service utilization and considering the characteristics of the population in need [13].

The aim of this thesis is to predict the demand for mental health care services and develop a mathematical programming model - MHC model - to aid health care planners in the management, design and planning of networks of mental health care services, both at a strategical and tactical level, in the medium-term. The estimates on future mental health demand are to be integrated in the MHC model. The proposed model provides information for planning, both in terms of services' location, capacity planning and allocation of patients to services, while ensuring the attainment of multiple planning objectives relevant in the mental health care sector, namely the minimization of costs and the maximization of multiple dimensions of equity. These multiple objectives may be jointly considered depending on the planning circumstances.

In particular, the model provides detailed information on:

- When and where to open/close mental health services;
- How much capacity in terms of beds and human resources should be available in each service and location;
- How to geographically distribute this capacity across services and patient/disease groups;
- How should mental health patients be allocated to existing services;
- Which changes to the mental health care network are needed over time;
- Which funding is required to implement these changes;
- Which is the impact on cost and equity-related objectives.

Moreover, the model can be used to explore: (i) how to reorganize the mental health care network under different circumstances, such as when full demand satisfaction is required or when specific equity targets should be attained, and at what cost; (ii) which equity improvements can be obtained under these circumstances and (iii) the existing trade-off between cost and multiple equity dimensions. Therefore, the model can support the planning of mental health care networks under different contexts with potential interest for health planners in the mental health care sector.

The MHC model, implemented in the General Algebraic Modelling System (GAMS), is thus an innovative multi-objective mathematical programming model that gives support to health planners on how to re(organize) a multi-service network of mental health care through an adequate planning, in the context of NHS-based countries in the medium-term.

To contribute to the health care planning literature, this study (i) predicts future demand for mental health care services to be integrated with planning models; and (ii) proposes a mathematical programming approach to support planning decisions, both in terms of location of services, capacity planning and allocation of patients to services in the mental health care sector. The model considers the specificities of the mental health care sector, namely: the multiple mental health care services (institutional care, ambulatory care, home-based care and rehabilitation services) and the multiple equity dimensions relevant for planning in NHS-based systems.

This thesis is organized as follows. Chapter 2 presents background information on mental health care and future prospects on the area, as well as the main goal of this thesis. In Chapter 3, a literature review on existing methods to plan the delivery of health care services, including (i) approaches to predict demand for health care services in order to be integrated in mathematical programming models and (ii) mathematical programming models for support health care planning in general, and mental health care in particular, are presented. This review identifies the need to develop methods to support planning decisions in the health care sector and especially in the mental health sector, where applications are still scarce. Chapter 4 presents the process used to predict the demand for mental health care services and the mathematical programming model developed - MHC model - to assist planners on how to design a mental health care network. A case study applied to the Portuguese context is presented in Chapter 5, which includes an overview of the dataset used for predicting the demand for mental health care and for application of the model to support the reorganization of the mental health care network in the Great Lisbon region throughout the 2016-2019 period. This chapter includes a detailed analysis on how to use the model under three different planning contexts with potential interest for a real decision maker (DM) in the mental health care sector in Portugal. Finally, the main conclusions and final remarks, as well as the future work are described in Chapter 6.

Chapter 2

Background

This chapter presents relevant background information about mental health care within the context of countries with a NHS, such as Portugal. It describes the evolution of mental health care over time; presents the different types of mental health services, as well as their organization and provision; depicts the global impact of mental disorders and presents the main challenges and policy objectives in this sector. The chapter is organized in three sections: overview of mental health care in European Union countries (section 2.1) with emphasis on the Portuguese case (section 2.2) and motivation and objectives of this thesis (section 2.3).

2.1 Mental health care

2.1.1 Mental health care in Europe

Mental health problems currently represent one of the leading causes of disability and morbidity in many European countries [14]. The WHO describes mental health as “a state of well-being in which an individual realizes his or her abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to his or her community” [4]. By contrast, mental ill health includes “mental health problems and strain, impaired functioning associated with distress, symptoms, and diagnosable mental disorders” [15] classified according to the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) [16]. Mental disorders can be measured by prevalence, burden of disease and disability [1] and are divided into five major groups: common mental disorders, as depression; severe mental disorders, such as schizophrenia; eating disorders, as anorexia nervosa; personality disorders and dementias, including Alzheimer [2].

In the Organisation for Economic Co-operation and Development (OECD) countries, about 5% of the working-age population has a severe mental health condition and 15% is affected by a more common mental disorder [3]. In the European Union, it is estimated that more than one third of the population (38%) have mental health problems at one time, the most common being depression and anxiety [2]. Furthermore, along with the ageing population comes an increase in the prevalence of dementia, typically 5% in people over 65 and 20% in those over 80 [1].

Mental health problems not only affect a large part of the population - as they do in a very severe way. People with mental disorders have life expectancy shorter than that of the general population, often dying more than 20 years younger [3]. One reason is the high suicide rate, but the main factor is the high prevalence of comorbidities, especially chronic diseases such as cardiovascular diseases, cancer and diabetes. In fact, people diagnosed with chronic conditions suffer from very high rates of depression that often remain undiagnosed [16]. According to the disability-adjusted life years (DALY) indicator, that measures the disease burden expressed in number of years lost due to ill health, disability or early death, mental disorders are the second leading cause of loss of DALYs in Europe, corresponding to 19% of the total loss [2].

Besides the direct effect on patients, mental health problems also have a strong impact on the economy, affecting the rest of the population. Mental health problems admit direct and indirect costs that may exceed 4% of Gross Domestic Product in OECD countries [3]. Direct costs include medical expenditure and social costs associated with long term care, while indirect costs refer to the productivity lost due to illness and premature death, including also informal care provided by family members [3, 17]. To make things worse, there is a vicious cycle between mental illness and unemployment: unemployment can lead to mental illness and people with mental health disorders are often unable to work [3]. As a matter of fact, a high percentage of people who receive social welfare benefits or pensions because of disability have, as their primary condition, a mental disorder. These factors contribute to the increase of the financial burden of mental health problems on many countries [1].

In order to pursuit financial sustainability of health systems, several strategies of mental health prevention have been developed by many European and international organizations. In 2005, the European Comission published the “Green Paper: Improving the mental health of the population” [15], endorsed by the Portuguese Government. Following this action, the European Union organized a conference in 2008, which resulted in the “European Pact for Mental Health and Well-being” [18], which admits as a priority five areas of action on mental health, namely: prevention of depression and suicide; mental health in youth and education; mental health in workplace settings; mental health of older people and combating stigma and social exclusion. These international initiatives led to the development of the “Mental Health Action Plan 2013- 2020” [16] by the WHO, which recognizes the essential role of mental health for the well-being of all the population, and whose objective is to achieve equity through universal health coverage, with emphasis on the role of mental health, also advocating the need of prevention [16]. Besides this, the importance of promoting mental health is reinforced by the OECD, whose activities in 2014 included the publication of a report which highlighted the social and economic impact of neglecting mental health care [3].

2.1.2 Mental health care provision in Europe

A variety of mental health care provision paradigms can be found across Europe. In particular, mental health care is provided in primary care centers, general hospitals, mental/psychiatric hospitals and through services in the community [5]. Figure 2.1 presents the different components of mental health services found across Europe. Primary care services include treatment and promotional and preventive activities delivered by primary care professionals, while services offered by general hospitals include external consultations, partial (day/night) hospital programmes and acute inpatient care provided by specialist mental health professionals, such as psychiatrists and psychologists [5]. Community mental health services can be divided into: (i) formal services provided by mental health professionals, such as rehabilitation services (community mental health centres, day care centers, support groups and employment workshops) and supervised residential services, and (ii) informal services, usually provided by family members or friends of the patient [5]. The specialist institutional mental health services include acute and high-security units, specialist units for children and elderly people and other specialized services such as forensic psychiatry units. Dedicated mental hospitals provide mainly long-stay institutionalizations [5].

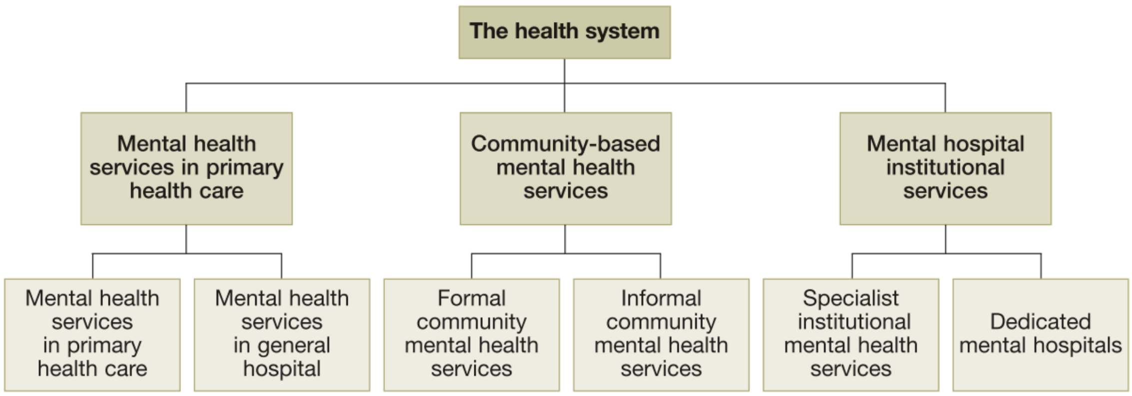

Figure 2.1: Components of mental health services [5]

In terms of expenditure, the mental health provision has been rising in OECD countries, representing between 5% and 18% of total health expenditure [3]. However, despite the evidence of effective treatments for many mental disorders, a large proportion of the population does not receive care due to poor accessibility (treatment gap) or experiences long delays [1].

To improve this situation, the WHO recommended that mental health care should be provided mostly through general health services and community services. Therefore, there is a need to replace large and centralized psychiatric institutions by other services (deinstitutionalization) [19]. In some European countries, such as United Kingdom and Italy, the deinstitutionalization process started over 50 years ago [3]. Presently, the capacity and quality of services and workforce vary across the European countries: some provide a comprehensive network of community-based services, while other still rely on the use of large psychiatric hospitals. [1].

2.2 Mental health care in Portugal

2.2.1 Evolution of mental health care

The history of mental health care in Portugal starts in 1964, when mental primary care centres were created in the different districts and in the largest cities: Lisbon, Coimbra and Oporto, after the principles of mental health care provision were approved. In 1984, the Directorate-General for Primary Health Care was created with a Division of Mental Health Services, in order to integrate mental health services in the general system of health care provision, and in 1992 the mental primary care centres were integrated into general hospitals [20] .

Despite being a great improvement over the previous situation, this organization needed to be changed, due to the recommendations of the United Nations and the WHO with respect to the emphasis on community services and focus on rehabilitation and social integration [19]. The need to move from a hospital-based therapy to a model of continued and family-oriented mental health care was obvious, so an update to the Mental Health Law in force since 1963 was made. The present Mental Health Law, published in 1998, defines the principles of mental health policy and creates a clear referral system as well as a community care network [21].

The progress was not limited to a reorganization of mental health care provision. In fact, a cooperation between the health sector and the social security was established within the scope of the Ministry of Health and the Ministry of Labour and Social Solidarity [22]. This law created various social typologies of response for mental health patients in situations of dependency [22]. In 2010, continuous integrated multidisciplinary services oriented towards people with serious mental disorders in dependent situations were created to replace the responses within the scope of 'Despacho Conjunto 407/98'. Specifically, the government decided to constitute a network with responses adapted to mental health patients linked to the National Network of Long-Term Care, created in 2006 to ensure the provision of health and social care services for individuals in dependency situations [23]. However, the beginning of the proposed network has faced several challenges and its implementation has been repeatedly delayed since 2011 until now [7].

Nevertheless, some progress was made, as the Ministry of Health nominated a specialized commission in 2006 with the objective of studying the existing situation with respect to the provision of mental health care at a national level and proposing an action plan to restructure and develop mental health care services. The commission was able to identify several constraints related to access, equity and quality in mental health care. Specifically, it was realized that (i) only a small percentage of people suffering from mental disorders had real access to health care; (ii) an excessive concentration of mental health care resources was allocated to the city areas of Lisbon, Oporto and Coimbra, together with an asymmetric distribution of human resources, and (iii) quality patterns were below reasonable standards [24]. Moreover, the mental health care services supply was inadequate according to the WHO standards, as depicted in Figure 2.2.

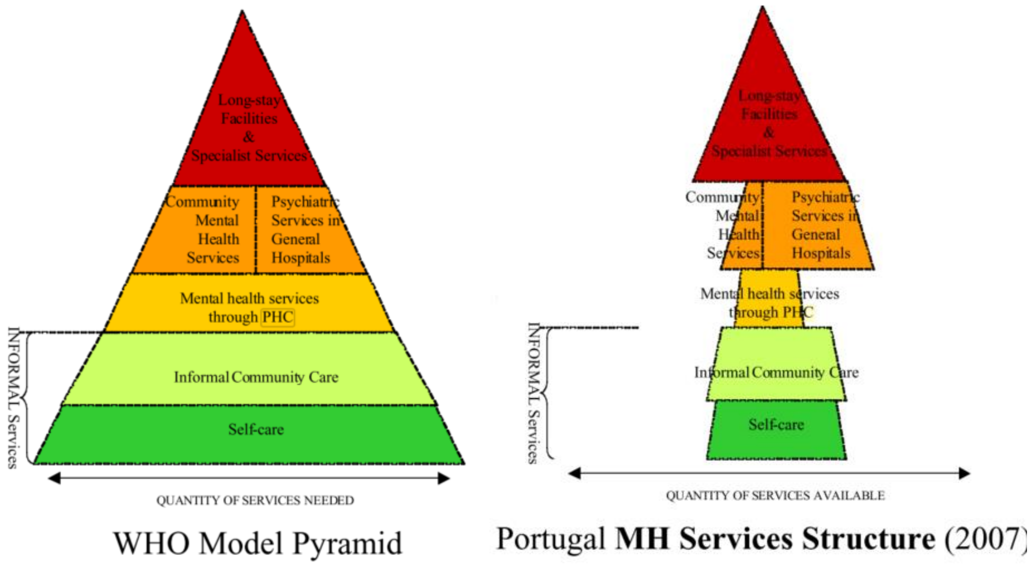

Figure 2.2: Comparison between the mental health care services structure proposed by the WHO and the one existent in Portugal (2007) [25]. Legend: WHO - World Health Organization; MH - mental health

In an attempt to overcome these difficulties, by 2007, the commission published the National Plan for Mental Health (Plano Nacional de Saúde Mental, PNSM) for the period 2007–2016, that highlights the advantages of a model of continued and family-oriented mental health care when compared to hospital-based therapy. The policy of mental health care presently in force in Portugal is based on this plan, whose implementation was primarily attributed to the National Coordination for Mental Health [17]. The PNSM core values are: mental health as part of the general health care; protection of human rights of people suffering from mental disorders, including the right of access to adequate care, housing and employment as well as protection against discrimination; promotion of community care and coordination and integration of care, to facilitate health care continuity [14].

In 2012, some years after the implementation of the PNSM, an assessment was undertaken by the Directorate-General of Health (DGH), showing that the main mental health problematics were related to the high prevalence of disorders and the difficulty in accessing mental health care, especially rehabilitation services. In this context, it was considered appropriate to evaluate the objectives attained up to that moment as well as to make a review of the main constraints concerning the implementation of the PNSM, ultimately fostering the feasibility of a better mental health care in Portugal. Particularly, it was concluded that the goals achieved up to that moment were related to the development of new services and community programs as well as the setup of the basis for launching continuous care services, following the closure and restructuring of psychiatric hospitals associated with the deinstitutionalization process [26].

Nevertheless, there were still some problems that needed to be addressed. In particular, the fact that the PNSM is very focused in chronic patients with high levels of disability, ignoring sometimes patients with less severe mental health problems. For this reason, these patients do not have access to specialized care, thereby overloading the primary health care system. Also, the assessment emphasizes the insufficient administrative and financial autonomy of the National Coordination of Mental Health. This entity was discontinued due to the new regulation defined by the Health Ministry and six National Health Priority Programs were developed by the DGH for the following groups of diseases: brain and cardiovascular, oncological, respiratory, diabetes, HIV/AIDS and mental disorders [27]. The National Program for Mental Health [26], presented in 2012, is one of these National Health Priority Programs. It consists in an update of the PNSM, adapted to the new reality and challenges, and is still being implemented.

2.2.2 Mental health care organization and provision

2.2.2.1 Health and social care components of mental health care

The mental health care system in Portugal consists of a network of public and private non-profit-making care providers. This system is composed by a health and a social component as represented in Figure 2.3. The health component is delivered by the NHS, incorporating PHCCs, general hospitals and psychiatric hospitals; and by the social health sector, constituted by private institutions for social solidarity (Instituições particulares de solidariedade social, IPSS) that have partnerships with the NHS. The social component is delivered by IPSS and non-governmental organizations (NGOs) [6].

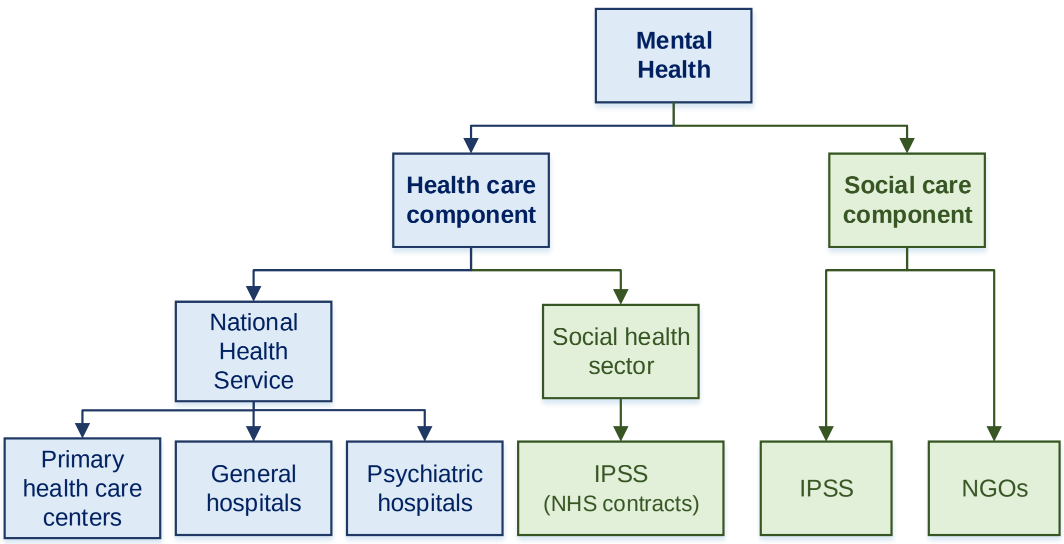

Figure 2.3: Organigram of the mental health care system in Portugal

Accordingly, the mental health system ensures the delivery of a wide range of health and social care services (Figure 2.4). The health services include institutional care (IC), ambulatory care (AC) and home-based care (HBC); and the social services, that are focused on psychosocial rehabilitation, include occupational unit (OU) and residential unit (RU) ensured within the scope of the Ministry of Health and the Ministry of Labour and Social Solidarity. These services are delivered by multidisciplinary teams which include physicians, nurses, social assistants, and occupational therapists, among others.

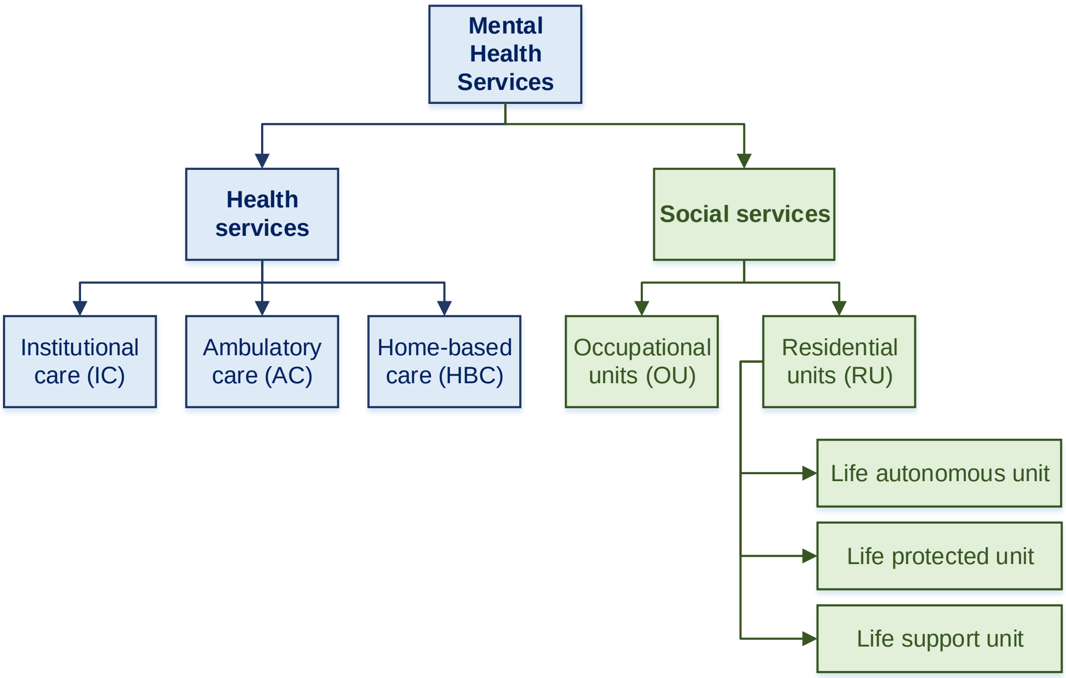

Figure 2.4: Mental health care services provided in Portugal

IC comprises services delivered to acute patients located in general hospitals, psychiatric hospitals and IPSS, and to chronic patients in psychiatric hospitals and IPSS. The public sector delivers this service mainly to acute patients, while the social sector is mainly focused on chronic patients. However, the social sector also has capacity for acute patients [6]. Considering the number of beds as an indicator of the installed capacity, it turns out that from the 4.562 existing beds in Portugal in 2013, 32% belonged to the public sector and 68% to the social sector [6]. AC, provided in general hospitals, psychiatric hospitals and IPSS, includes external consultations and partial institutionalizations (day hospital/day center). HBC is based in PHCCs and is provided within the scope of the primary care network, but is also delivered by general and psychiatric hospital teams. The health services are provided within the scope of the Portuguese NHS, available to all citizens that according to their social and economic background benefit from an approximately free-of-charge service, tax financed system of coverage [17].

Regarding the psychosocial rehabilitation services, these include the following typologies of social support units: OU and three types of RU - life autonomous unit, life protected unit and life support unit - delivered in psychiatric hospitals, IPSS and NGOs. These responses, carried out in conjunction with the health state sector, social security and employment departments, are aimed at people with severe mental disorders resulting in temporary or permanent psychosocial disability that are in a situation of physical, psychological or social dependence [22]. For these services a contribution is charged based on the financial capability of the beneficiary [28].

The OU, the only unit that does not involve the residence of the patient, is a response aimed at patients with moderate and low degree of psychosocial disability that present dysfunctions in the relational, occupational and social integration areas. The unit promotes social and familiar reinsertion and integration in professional training programs (normal or protected employment) [28]. The different types of RU provide accommodation for clinically stabilized patients that have no family or adequate social support. They vary according to the extent of patient dependence, being classified as [28]:

- Life autonomous unit: unit located in the community designated for patients with low degree of psychosocial disability. This unit ensures individualization and stability of patients at a social and professional level;
- Life protected unit: unit designated for patients with moderate degree of psychosocial disability. The objective of this unit is to promote strategies of personal, social and relational autonomy, as well as social and occupational integration and a close interaction with the community;
- Life support unit: Response aimed at patients with high degree of psychosocial disability that need support for activities of daily living (ADL), but do not require frequent medical intervention [7]. This unit promotes psychosocial rehabilitation and/or occupational programs and the maintenance of family relationships.

Figure 2.5 summarizes the mental health care services supply of each public and social provider of mental health care in Portugal, represented in blue and green, respectively.

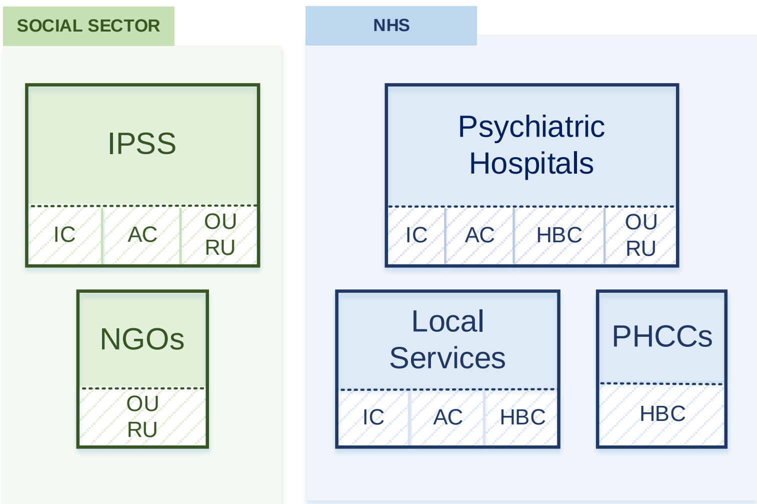

Figure 2.5: Mental health care services supply of public and social providers in Portugal. Legend: IPSS - private institutions for social solidarity; NGOs - non-governmental organizations; IC - institutional care; AC - ambulatory care; HBC - home-based care; RU - residential unit; OU - occupational unit

2.2.2.2 Organization of mental health care

The organization of the mental health care services in Portugal is based on a referral model of community care described in Law nr. 36/98 (Mental Health Law) and executed by Decree-Law nr. 35/99. This organization is based on the following scheme:

- The mental health care services are organized by level (local and regional) and are interconnected with one another via the Referral Network of Psychiatry and Mental Health, which also uses a “catchment area” model to ensure links with the PHCCs [25];

- The PHCCs in the patient region of residence are the first point of contact within the mental health system. In theory, patients do not have direct access to specialized care and have to be referred by their general practitioner (GP). However, many people bypass their GP and go directly to the emergency department, and are referred if they need specialized care. Patients that are being followed in another medical speciality are also immediately referred [17]. The two Referral Networks of Psychiatry and Mental Health (one for Adult Psychiatry and other for Child and Adolescent Psychiatry) describe the patients flows inside the mental health system [29]. The need to create two separate networks arises because mental health care delivered in Portugal is different for adults and child and adolescents - in this work, the focus is on psychiatric and mental health for adults. The networks architecture was published in 2004 by the DGH and is still in force. Nevertheless, there is an ongoing project in order to adapt these networks to the objectives of the National Program for Mental Health [30];

- The local mental health care services are the basis of the mental health care system. Their function is to ensure unity and continuity in the provision of IC, AC and HBC to a population of a given geographical area through a network of programs and services. Local services are organized as departments or services in general NHS hospitals, according to their respective influence area as defined in the National Program for Mental Health, and work in conjunction with the PHCCs in the same geographical area. They are expected to constitute competence centers with their own budget and action plans within the applicable law [31], and are organized regionally when they cannot be established at a local level;

- Regional mental health care services deliver specialized care, such as forensic psychiatry, and are provided by psychiatric hospitals. Psychiatric hospitals are also responsible to ensure the provision of mental health care in geographical areas under their jurisdiction where local services have not been created yet. Their function is to support the local health teams, to provide specialized and inpatient care for patients with long evolution periods, and to provide residential services for patients without any family or social support system. They are also expected to improve humanization and quality of life as well as to develop rehabilitation programs specifically adapted to the requirements of patients, supporting their reinsertion in the community [31]. In fact, psychiatric hospitals have a mixed function, as they deliver both regional and local services but with different geographical coverages.

2.2.2.3 Funding of mental health care

In Portugal, 5.2% of the health budget is allocated to mental health care, which is mainly financed through general taxation [32]. The Ministry of Health receives a global budget for the NHS from the Ministry of Finance, which is then allocated to the many institutions within the NHS (hospitals; health regions, which then allocate funds to primary care centres; and special programmes) [17]. The financing formula used in mental health is identical to the one used for other specialities and does not consider community-based care, whose financing is thus not conveniently defined. For this reason, the existing model tends to privilege a centred hospital–based care model, promoting asymmetries in the allocation of resources [7].

2.2.2.4 Current provision of mental health care

Currently, there are 44 establishments from the NHS that provide mental health care, including 3 psychiatric hospitals (Hospital Magalhães Lemos, Hospital Sobral Cid and Centro Hospitalar Psiquiátrico de Lisboa) and psychiatric departments/services integrated in general hospitals (Table 2.1) [6]. This supply is mostly located in the North (36%) and Lisbon and Tagus Valley (LVT) (30%) Regional Health Administration (RHA). The mental health care offer of the social sector, also summarized in Table 2.1, includes 12 IPSS with partnerships with the NHS and 26 NGOs [6], mainly located in the North, Centre and LVT RHAs. This information corroborates the high concentration of mental health care resources in the city areas of Lisbon, Oporto and Coimbra, denoting the need to plan the mental health care sector, in order to ensure equal access to all citizens.

Table 2.1: Number of mental health care establishments, by RHA [7]

RHA	Local services	Psychiatric Hospitals	IPSS	NGOs
North	16	1	4	4
Centre	10	1	2	5
LVT	13	1	5	13
Alentejo	3	0	1	1
Algarve	2	0	0	3
Total	44	3	12	26

According to an evaluation carried out in 2011 by the WHO to the PNSM, the labour force ratio in mental health in Portugal was below the recommended range, according to the European standards. The standard ratios of human resources in mental health used as a reference in Portugal are defined as the desired number of health professionals per unit population. They were established by the DGH in 1995 for psychiatrists, clinical psychologists, nurses, social assistants and occupational therapists, indicating the need for multidisciplinary teams in this health area [29]. Table 2.2 presents the effective and standard ratios in public hospitals for psychiatrists (per 75.000 population) and the other human resources (per 50.000 population), by RHA. In all RHAs, the effective ratio is below the standard for psychiatrists, social assistants and occupational therapists, and is approximately verified for clinical psychologists. For nurses, the human resource that must be available in greater numbers to the population with mental health problems, the standard ratio is only respected in the Centre RHA. This shows a significant asymmetry in the distribution of human resources across the RHAs, that causes inequalities and access limitations [7].

Table 2.2: Ratios of effective health professionals in psychiatry, by RHA [7]

RHA	Psychiatrists	Nurses	Clinical Psychologist	Social Assistant	Occupational Therapist
North	2,33	2,7	1,4	0,6	0,3
Centre	3,26	6,1	0,9	0,6	0,3
LVT	2,8	4,3	1,7	0,6	0,5
Alentejo	1,81	2,8	1,0	0,6	0,4
Algarve	1,51	4,2	1,0	0,2	0,3
Standard ratio	**4**	**6**	**1**	**1**	**1**

The WHO evaluation demonstrated that Portugal had a low supply of mental health services, regarding the number of psychiatric beds and services in the community [33]. Currently, the national reality in technical resources, in terms of bed capacity, is presented in Table 2.3 [6]. The standard ratio defined by the DGH for acute inpatient units is 10 beds/100.000 population. Despite across all RHAs the effective ratio is equal to the standard ratio, it is only verified in Centre, LVT and Algarve RHAs, which shows that there is an asymmetric distribution of resources.

Table 2.3: Number of acute beds in psychiatric units, in the public sector, by RHA [7]

RHA	Number of acute beds	Acute beds/100.000 population
North	320	9
Centre	268	15
LVT	374	10
Alentejo	34	7
Algarve	46	10
Total	1.042	10

Regarding the integration of people with mental disorders in the community, the Economist Intelligence Unit has developed the “mental health integration index”, that measures the support and degree of commitment of European governments in this subject. From a global evaluation of this index, Portugal is ranked in the 27th position within thirty countries. Portugal has got the worst classification in the “access” category, being ranked in position 28th, and the best classification was obtained in the “favourable familiar environment” category, ranked in the 21st position (Figure 2.6).

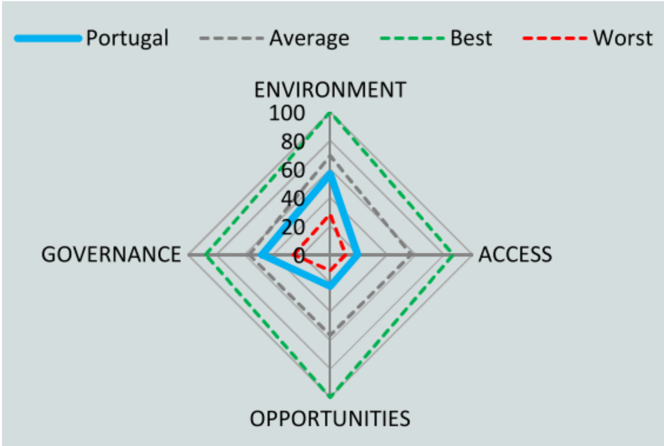

Figure 2.6: Relative position of Portugal's mental health integration index [34]

Summing up, the current supply of mental health care services in Portugal is not enough to satisfy the increasing demand for care. Thus, there is evidence on the need to reorganize the existing network, which can be accomplished through an adequate planning of the mental health care sector in Portugal.

2.2.3 Morbidity and overall impact of mental disorders

The first morbidity study was conducted in 2006-2008 to evaluate the prevalence of mental disorders in the Portuguese adult population and determine the degree of disability associated with these disorders [35]. This project was part of an international initiative, the World Mental Health Survey Initiative (WMHSI), coordinated by the Harvard University and the WHO. The study covered the most prevalent mental disorders in the adult population (anxiety, depressive, impulse control and substance use disorders) [35]. The group of severe mental disorders, such as schizophrenia, were excluded because they require large samples and more complex methodologies that were not available [36].

According to this study, in Portugal, the prevalence of mental disorders in 2013 reached 22.9% of the total population, the most significant contributors being the anxiety and depressive disorders, which affected 16.5% and 7.9% of the Portuguese population that year, respectively [35]. Portugal presented the highest total prevalence rate of the eight European countries integrated in the study. Despite the high prevalence of mental health problems observed in Portugal, about 65% of patients diagnosed with moderate psychiatric disorder did not use mental health care in the 12 months preceding the interview held under the WMHSI [35]. However, the treatment gap in Portugal was lower than in countries like Germany, France or Italy (Wang et al., 2011).

The measure of global burden of disease as an indicator of the impact on populations has been gaining preponderance in the last years, complementing other more common epidemiological indicators as incidence and prevalence rates. In 2010, 45.16% of the estimates of global burden of disease in Portugal, measured by DALY indicator, corresponded to the six National Health Priority Programs: brain and cardiovascular diseases achieved the most significant weight (13.74%), mental disorders accounted for

11.75%, followed by oncological diseases (10.38%), respiratory diseases (3,99%), diabetes (3,59%) and HIV/AIDS (1.71%) [27]. Regarding the morbidity burden, quantified by the years lived with disability (YLD) indicator, 33,65% were attributed to the National Health Priority Programs. Mental disorders were responsible for a morbidity weight of 22,55%, that is higher than the sum of the morbidity attributed to all the others programs [27], clearly demonstrating the status of mental disorders as chronic diseases. These data fully justify the need for maintaining mental health as a top priority from the point of view of continuous improvement of care and further implementation of the National Program for Mental Health.

2.2.4 Challenges and policy objectives in the mental health care sector

Portugal, as most European countries, is currently facing many challenges in the mental health sector, affecting the well-being of the population and the provision of quality care [1, 32]. The existing supply is far from being enough to satisfy the demand for care, as international estimates suggest that the treatment gap is 32.2% for schizophrenia, 56.3% for depression and 57.5% for anxiety disorders [3]. A recent report [7] states that, in Portugal, this low supply leads to an inadequate utilization of alternative services by mental health patients, which results in higher costs for the health system. Besides this, an increasing demand for mental health care is predicted for the coming years across these countries, due to the ageing phenomenon and the increase in the prevalence of mental disorders [18, 35].

Moreover, in the current European context of severe budget cuts imposed by the economic crisis, there is a high pressure to control and reduce public spending in health care. For this reason, NHS-based countries, such as Portugal, are encouraged to minimize mental health delivery costs, which can seriously hinder the development of the supply. According to the Joint Action on Mental Health and Well-being [32], the present economic situation of Portugal requires the adoption of more cost-effective strategies. However, OECD [3] argues that expenditure on mental health is too low, given its large overall economic and social burden, and so there is a need to invest wisely in mental health in terms of resource allocation. Within this setting, planning mental health care networks represents a health policy priority across European countries.

The mental health care network in Portugal ensures the provision of health and social care services, operating within the context of the NHS. The NHS is available to all Portuguese citizens in an approximately free-of-charge service through a tax financed system, which is designed to cover all integrated health care, including mental health care [17]. Within this context, the mental health care network aims to guarantee universal coverage of demand (with nearly free access access at the point of use), to promote equal access to health care for all citizens (irrespective of their economic condition and geographical location) and to ensure equity in the distribution of resources and use of health services [17].

Particularly, the mental health policy currently in force in Portugal is based on the National Program for Mental Health, that reinforces the policy objectives pursued by the NHS and defines specific objectives for the mental health sector [14]:

(i) ensure equal access to quality mental health care for all people with mental disorders, including the vulnerable groups (homeless people, members of households living in poverty, victims of domestic violence, people with chronic health conditions, children exposed to maltreatment and neglect, etc);

(ii) promote and protect the human rights of people with mental health problems;

(iii) reduce the impact of mental disorders and promote the mental health of the population;

(iv) promote the decentralization of mental health care services, in order to allow a provision of care closer to the patients and facilitate a larger participation of the families and communities;

(v) promote the integration of mental health care in the general health system at the primary care level, general hospitals and long-term care, in order to facilitate the access and reduce institutionalization.

2.3 Goal

As shown, a proper mental health planning is being increasingly recognized as a health policy priority across European countries. Therefore, this thesis aims to: (ii) build estimates on future demand for mental health care services; and (i) develop a mathematical programming model - the MHC model - that can potentially aid mental health planners in the management, designing and planning of networks of mental health care services, both at strategical and tactical level, within the context of NHS-based countries. The estimates on future demand for mental health care are built based on the characteristics of the population with potential need of such care, and are to be integrated in the MHC model for planning purposes. The MHC model aims to support planning in terms of location of services, capacity planning and allocation of patients to services in the mental health care sector, considering the entire range of mental health services (IC, AC, HBC, RU and OU). For this purpose, the model accounts for multiple planning objectives considered the key policy objectives in the mental health care sector: the minimization of cost and the maximization of several equity dimensions. Particularly, in terms of equity objectives, the model accounts for: equity of access, geographical equity, equity of service-specific utilization and equity of disease-specific utilization. These multiple objectives may be jointly considered depending on the planning context, and thus the model can support mental health planning under different circumstances. In particular, the model can be used to explore (i) how to reorganize the mental health care network under circumstances, such as when full demand satisfaction is required or when specific equity targets should be attained, and at what cost; (ii) which equity improvements can be obtained under these circumstances; and (ii) the existing trade-offs between cost and multiple equity dimensions. The usefulness and applicability of the MHC model is shown through its application to the mental health care sector in the Great Lisbon region in Portugal under different planning contexts.

Chapter 3

State of the art

This chapter provides a revision on the methods used to support network health care planning, with emphasis on mental health planning. Approaches for predicting demand for health care services are also reviewed. The little research on methods to support the delivery of mental health care services provides evidence on the need to plan this sector and proves that there is scope for developing methods to aid mental health care planning.

The databases consulted in this search were mainly *PubMed*, *Science Direct* and *Google Scholar* with different combinations of the following keywords: “health care”, “mental health care”, “services”, “network”, “strategic”, “tactical”, “planning”, “mathematical programming models”, “optimization”, “location-allocation models”, “methods”, “modelling”, “estimates”, “predict”, “forecast” and “demand”.

This chapter is organized as follows. First, an overview on the methods used for network planning in the health care sector is presented (section 3.1). Then, particular emphasis is provided on mathematical programming methods (section 3.2), particularly, on models for planning health care in general and mental health care in particular, presented in sections 3.2.1 and 3.2.2, respectively. Then, approaches used for building estimates on future demand for health are described in section 3.3. At last, the contribution of this thesis to the health care literature is discussed in section 3.4.

3.1 Methods for planning health care networks

Before discussing methods for executing a network plan it is crucial to understand which are the different planning levels that should be considered [37]: operational, tactical and strategic. These, in the referred order, can be thought of as stepping-stones to goal achievement. Starting with the higher most, strategic planning considers structural decision making, taking into account an organization as a whole, and looks to define an organization’s mission or strategy. Generally, this type of planning accounts for long periods of time and is based on aggregated data. These plans serve as an outline for lower-level planning. Examples of strategic planning include determining of facility’s location, dimensioning resource capacities and deciding on the service and case mix. Tactical planning supports strategic planning by translating these into specific plans for a specific area of an organization. These plans then present the guidelines for operational planning decisions. Examples of tactical planning are staff-shifting scheduling and surgical block schedule that allocates operating time capacity to patient groups. Operational planning consists of short-term decision making focused on precise procedures and processes that occur within the lowest levels of the organization, with a high level of detail. This type of planning can be divided into offline and online operational planning. Offline subtype accounts for advanced planning while online operational planning controls the process and resolves unplanned issues [37]. Examples of offline operational planning include patient-to-appointment assignment, staff-to-shift assignment and surgical case scheduling. Real-time dynamic re(scheduling) of elective patients when an emergency patient requires immediate attention is an example of online operational planning. Within this setting, this thesis aims to develop a method to support strategic and tactical planning decisions in the mental health care sector, particularly, decisions related to services location, capacity planning and allocation of patients to services. And in what concerns strategical and tactical planning decisions, different methods have been proposed such as computer simulation, Markov processes, heuristics and mathematical programming.

Computer simulation aims at imitating the operation of real-world system over time by developing a "simulation model". It is usually based on assumptions regarding the operation in the form of mathematical or logical relations between the objects of interest in the system [38, 39]. This technique has been widely used as a planning tool in the health care sector, and an example is the study proposed by Harper and Shahani [40] to plan and manage bed capacities based on simple deterministic spreadsheet calculations. The simulation model developed considers various types of patient flows, presenting bed needs over time. Simulation models are very useful for what-iff analysis, which explores the best course of action in different circumstances. However, these methodologies are not adequate to determine the best solution for the configuration of a health network for planning purposes, as they do not allow to calculate optimal solutions.

Markov models are mathematical models used to study the random evolution of a system, respecting the Markov property: given the present (state of stochastic process), the future (evolution of the process) is independent of the past [41]. These methods allow to divide the population into discrete states of health and evaluate the transition between these states over time, according to pre-defined transition probabilities. For instance, Leff et al. [42] developed a deterministic first order Markov simulation model for mental health planning. The model allow planners to assign service packages to functional level groups, that describe the states through which patient pass in the course of mental illness. Markov models are simulation models that do not guarantee that an optimal solution is found, and thus are not the most appropriate methodologies for the study proposed in this thesis.

Heuristics methods are systematic methods used to optimize a problem by improving presented solutions when exact approaches take too much computation time. Although useful for quick resolutions, they do not guarantee that an optimal solution is found [43] [39]. An example of this method is presented by Utley et al. [44]. They proposed an approach to analyse circumstances under which the introduction of a new class of health service providers (treatment centres) improve the efficiency of service delivery in terms of overall capacity requirements.

Ultimately, mathematical programming consists of optimization models that maximize or minimize an objective function, respecting a set of constraints that circumscribe the decisions variables [45]. Thus, mathematical programming models can represent real world interactions through mathematical relationships (such as equations, inequalities and logical dependencies), mostly independent of the data in the model. These models can be classified as linear programming (LP) models, non-linear programming (NLP) models and integer programming (IP) models [46]. Within LP there is a particular class of models, the so-called mixed integer linear programming (MILP) models capable of modelling several types of problems and characterized by linear mathematical expressions containing both continuous (real) and discrete (integer) variables. Mathematical programming approaches have been increasingly used to support location selection and capacity planning decisions in the health care sector [8], and so have potential to be used within the context of this thesis. The following section thus presents the main features considered relevant for health care planning and provides examples of studies using mathematical programming models for planning the delivery of health care services.

3.2 Mathematical programming models for health care planning

3.2.1 Health care

As noted in Brailsford and Vissers [8], mathematical programming models have been widely used in the health care planning literature. And within this area of research, existing models differ in several aspects, namely: in the planning purpose; in the number and types of services accounted for; in the number and types of objectives pursued; and in the consideration or not of uncertainty aspects. However, an adequate planning of health care networks must take into consideration: (i) the multi-service nature of health care systems; (ii) the joint effect of multiple objectives relevant in the health care sector; and (iii) the impact of uncertainty on planning decisions.

3.2.1.1 Single and multi-service models

Most of existing models in the health care planning literature account for one single service (for instance Oliveira and Bevan [47] and Ben Abdelaziz and Masmoudi [12]). The multi-service nature of health service delivery has been explored in the past years, but there is still little research on these. Examples of multi-service models are presented below:

- Teshebaeva and Jain [48] developed a mathematical model for optimization of health facility locations. The model determines new potential locations of various public services while minimizing the distance between demands points and facilities;

- Santibáñez et al. [49] presented a mathematical model to plan the inpatient hospital network for Fraser Health in Canada, in particular the location selection of 34 clinical services (such as general medicine, ophthalmology and cardiac surgery) across hospitals and distribution of bed capacity;
- Mestre et al. [9] proposed a mathematical programming model that considers the multi-service structure of hospital production, including inpatient care, emergency care and external consultations. This study aims to inform decision on the location and supply of hospital services;
- Cardoso et al. [50] developed a multi-service mathematical programming model to aid health care planners on how to plan the delivery of a multiplicity of long-term care services, namely, institutional, home-based and ambulatory care services.

3.2.1.2 Single and multi-objective models

Modeling single and multiple objectives

The planning of health care services delivery usually depends on several conflicting objectives [51]. The management of these objectives is very challenging, and for that reason most of the existing studies on health care propose single-objective models [52]. Nevertheless, there has been an increasing interest in the development of multi-objectives approaches. Within the health care literature, equity, efficiency, costs and health gains are the most commonly used objectives. Examples of multi-objective models accounting for these objectives are described below.

Equity is a key objective pursued in NHS based-systems [53, 54], and for that reason is one of the objectives most widely used in the literature. However, there is no single definition of equity that can be used to plan the delivery of health care services and there is little consensus on how equity should be measured [55]. Different equity concepts have been used, for instance equity of access [9], geographical equity [56], equity of utilization [47] and socioeconomic equity [57].

Mestre et al. [9] developed a model that provides information on the location and structure of hospital supply, while improving geographical access - measured as the total travel time for patient to access hospital services. Cardoso et al. [56] explored the joint analysis of multiple equity objectives, by proposing a multi-objective model to support planning decision in the long-term care sector that accounts for three equity-related objectives (equity of access, geographical equity and socioeconomic equity). The geographical equity objective considered by Cardoso et al. [56] was operationalized in the following measure: minimization of the level of unmet need for the geographical area(s) with the highest level of unmet need. The structure of this objective is similar to the minimax objective presented by Eiselt and Laporte [58], with the distance being replaced by the proportion of unmet need. Oliveira and Bevan [47] analysed the redistribution of hospital supply by comparing alternative models using different objective functions and assumptions about the utilization behaviour of patients. The different objective functions represent alternative definitions of equity of utilization. For example, one of the models aims to equalize utilization by small area, by minimizing differences between predicted and normative utilization (according to need) by small area. Drezner and Drezner [57] proposes an equity model between groups of demand points (for instance, rich and poor neighbourhoods - socioeconomic equity - or urban and rural neighborhoods). The goal is to provide equal service to the different groups by minimizing the deviation from equality among groups. Thus, the objective function - to be minimized - is the sum of squares of differences between all pairs of service distances between demand points in different groups.

Efficiency and equity objectives have been frequently combined in the health care literature. Mitropoulos et al. [10] proposed a bi-objective model for locating hospitals and PHCCs in Achaia (Greece) considering (1) the minimization of the travel distance between patients and assigned facilities; and (2) an equitable distribution of facilities among citizens. Similarly, efficiency and equity objectives were also accounted by the mathematical model proposed by Smith et al. [59] to aid DMs planning the location of new facilities.

In the health care literature, cost minimization has also been commonly addressed. Syam and Côté [11] developed a model for the location and allocation of specialized heath care services for the Department of Veterans Affairs (VA), including two criteria: (1) the VA's cost of providing service, including the fixed and variable treatment costs and lost patient cost (cost per patient not treated); and (2) the service rate provided to VA's patients, defined as the proportion of eligible patients served by the VA for a given geographical area. This model explored the existing trade-off between the cost of providing service and the need to provide such service at some specified minimum service level. The minimization of costs has also been considered in the study presented by Sun et al. [60], in order to optimize the patient allocation during an influenza pandemic outbreak. In particular, two objectives related to patients' cost of access to health care services were considered: (1) minimization of the total travel distance by patients to hospitals; and (2) minimization of the maximum distance a patient travels to a hospital.

Stummer et al. [51] used a multi-objective approach to determine the location and size of medical departments within a network of hospitals, considering four objectives: (1) minimize the total travel costs incurred by the patients; (2) minimize the total costs associated with location-allocation in the hospital plan (the total number of beds were considered as an indicator); (3) minimize the number of patients rejected as a consequence of low service capacities (shortage of beds); and (4) minimize the number of unit moves required to restructure the current allocation.

Furthermore, the maximization of population's health was considered in the mathematical model proposed by Koyuncu and Erol [61] for optimal resource allocation decisions in countries where a risk of pandemic influenza may exist. These resources include monetary budget for antivirals and preventive vaccinations, Intensive Care Unit beds, ventilators and non-Intensive Care Unit beds. The model considers three objectives: (1) minimization of the number of deaths; (2) minimization of the number of cases; and (3) minimization of total morbidity days during a pandemic influenza. Cardoso et al. [62] combined the maximization of expected health gains and the minimization of expected costs using a multi-objective stochastic mathematical programming approach to support the planning of a network of long-term care.

Approaches for dealing with multiple objectives

To deal with multiple objectives, different approaches have been employed within the health context: (i) the multiple objectives can be written as a single objective function, using for example the weighting or goal programming methods; and (ii) a Pareto frontier can be built, by identifying compromise solutions (Pareto optimal solutions), which represent “solutions that cannot be improved in one objective function without deteriorating their performance in at least on of the rest” [63].

The weighting method consists in attributing weighting coefficients to the multiple objectives of the objective function. This method is one of the most widely approach used to deal with multiple objectives, not only within the health sector, but also for planning a wide range of sectors. However, in most cases the weights used to solve the multi-objective models are not subjected to a detailed analysis (no discussion on their meaning). Instead, arbitrary values considered reasonable are chosen and a sensitivity analysis is performed to evaluate the impact of the weights on planning decisions. Still, some studies are now considering alternatives so as to deal with these objectives. Cardoso et al. [56] is an example of such study. Cardoso et al. [56] uses the weighting method to deal with the multiple equity objectives referred above. The weights are built with preference information of the DM, using the Measuring Attractiveness by a Category-Based Evaluation Technique (MACBETH). MACBETH is a decision-aid approach that follows a constructive view by asking DMs for qualitative judgements of difference in attractiveness between options, generating weights for each criteria [64]. This procedure allows to explain clearly how the weights should be interpreted, and thus helps DMs to understand the substantive meaning of the weights.

The goal programming approach is used to transform a multi-objective linear program into a linear program by fixing target values for some or all objectives (also called goals). Specifically, the objective functions are transformed into constraints and then the difference between the objective functions values and these goals is minimized [65]. This approach has been extensively applied in health care settings. One example is the model proposed by Oddoye et al. [66], that uses the goal programming method to allocate resources in a medical assessment unit. The objectives modelled are: (1) the minimization of the patients’ delay time; and (2) the minimization of the amount of extra resources needed (doctors’ and nurses’ time and beds).

Mitropoulos et al. [10] used the constraint method to derive the Pareto optimal solutions, between the conflicting objectives of the bi-criterion problem presented above. The constraint method consists in optimizing one objective while the others are constrained to values that vary through a range of feasible values [67].

Summing up, the choice of the approach to be used to deal with multiple objectives depends on the circumstances: if there is possibility to work with DMs in the area, it makes sense to gather information useful to the construction of weights or goals, and thus use the weighting or the goal programming methods; on the contrary, if there is not access to DMs, the construction of the Pareto frontier is useful to guide the planning.

3.2.1.3 Deterministic and stochastic models

The mathematical programming models can also be divided in deterministic and stochastic. Deterministic models are based on initial conditions and parameters with no uncertainty associated. Stochastic programming models arise when some of the data in the model are uncertain but can be specified by a probability distribution [46]. Within the health care area, the main studies developed consist in deterministic approaches (see for instance Syam and Côté [11] and Cardoso et al. [56]). Nevertheless, some examples exist proposing stochastic models for health care planning. For instance, models developed for strategic and tactical planning of health care services are proposed by Ben Abdelaziz and Masmoudi [12], Mestre et al. [68] and Cardoso et al. [62].

Ben Abdelaziz and Masmoudi [12] propose a multi-objective stochastic program model to assign beds to hospital departments when the demand for beds is random. For handling uncertainty associated with the demand, the multi-objective stochastic model is transformed into an equivalent mathematical program based on a mixture between the chance constraint method, the recourse approach and the goal programming approach (to deal with the three objective functions). Mestre et al. [68] developed two stochastic location–allocation models to assist hospital network planning under uncertain conditions. The study focuses on uncertainty associated to the demand for hospital services (more specifically, the impact of demand changes from populations that are aging and experiencing increases in life expectancy), modelled through a set of discrete scenarios that illustrate future possible realizations of the uncertain parameters. The multi-objective stochastic mathematical programming approach proposed by Cardoso et al. [62] to support the planning of a long-term care network, accounted for uncertainty in the demand and delivery of care. In particular, regarding uncertainty two parameters were estimated: (i) the number of individuals in need for all types of long-term care services; and (ii) the length of stay (ALOS) associated with each type of institutional service. To describe the combinations of these uncertain parameters, a scenario tree with 81 scenarios was built.

An alternative approach to deal with uncertainty in mathematical programming models is to develop sensitivity analysis. Sensitivity analysis has been the simplest approach used to address uncertainty [69], and it is simply applied by varying the values of the most uncertain parameters and evaluating whether those variations have impact or not on planning decisions. Examples of the use of sensitivity analysis within the health context can be found in Mestre et al. [9] and Cardoso et al. [56]. Mestre et al. [9] performed a sensitivity analysis on the following parameters: (i) transfer rates between district hospitals (DH) and central hospitals (CH); (ii) average length of stay (ALOS); and (iii) demand for hospital services. Cardoso et al. [56] employed sensitivity analysis on: (i) the demand for institutional long-term care; and (ii) length of stay (LOS). Nevertheless, in what concerns methods for planning the delivery of health care services in an uncertain environment, simulation has been the most used method (for example, Harper et al. [70]) since there is still little research considering stochastic approaches.

3.2.2 Mental health care

Planning the delivery of mental health services, and particularly the planning of deinstitutionalization has generated increasingly complex problems in the past years [71]. The current trend toward transferring patients from psychiatric hospitals to community-based health centres (deinstitutionalization) has required planning for the effective (re)distribution of services and resources. Several researchers developed mathematical programming models to aid planners with the deinstitutionalization process (for instance Wolpert and Wolpert [72] and Muraco et al. [73]).

Wolpert and Wolpert [72] developed an assignment model in order to realocate released patients from mental hospitals to residential communities. The model attempts to maximize favorable treatment outcomes for patients by evaluating the distribution of patients across treatment modalities and reassigning them, when necessary, in order to achieve a more favourable therapeutic outcome. Muraco et al. [73] proposed an allocation model applied to the Lucas County (Ohio) mental health delivery system, in order to analyze the impact of decentralized and centralized strategies when demand is geographically concentrated. The objective considered was the minimization of patients travel distance subjected to service constraints.

Also, Leff et al. [74] proposed a multi-period mathematical programming model for resource planning and policy evaluation to aid health planners making resource allocation decisions in the mental health care sector. The model developed optimizes the decisions of allocating resources to programs and assigning programs to patients. In particular, the model assigns service packages to patients in each period of the planning horizon by optimizing a measure of system performance. Several measures/objectives are proposed, but they are analysed individually because the proposed model accounts only for a single objective. Examples of the measures include the maximization of the total improvement in patients' functional levels and minimization of the number of patients with minimum functional level at the end of the planning horizon. These functional levels were defined to categorize the mental health population based on services' needs and a Markov property was applied to patients transitions between these levels.

At this point, problems were encountered when applying mathematical programming in the mental health research area - few models exist (according to the literature review developed, the only studies that were found are the two studies described above), and these few models only account for one single objective and no uncertainty analysis was performed. This is problematic for several reasons. First, the use of single objective models do not represent adequately the existing trade-offs and conflicts underlying the delivery of mental health care. Second, models not accounting for uncertainty aspects do not represent correctly the reality, since mental health planners operate in a very uncertain environment [71]. Third, the multi-service nature of mental health care needs to be considered, since mental health patients require multiple responses, and so multiple services should be planned.

To overcome this, models relying in multiple objectives, accounting for multiple services and considering uncertainty have been developed. Franz et al. [71] suggested a chance-constrained goal programming approach to plan the delivery of mental health services in Region V of the State of Nebraska. A chance-constraint model allows the transformation of a stochastic problem into an equivalent nonlinear deterministic model. The objective function was defined to minimize deviations from the mental health system goals according to previously assigned priorities and/or weights. The goals used in developing the planning model are the following: (i) do not exceed the Region V budget; (ii) achieve phase 1 of deinstitutionalization; (iii) meet the overall projected demand for mental health services; (iv) satisfy the mental health service patient demand for psychiatric time; (v) provide mental health education to school children in the region; (vi) provide necessary professional staff and (vii) increase the number of citizens reached by community based education services.

Another example is the model proposed by Specht [75], that presented a goal programming approach to be used as a tool in planning mental health care services delivery, illustrated through a case study from a Midwestern US mental health services programme. The mental health delivery system consists of a regional centre (RC), that provides specialized inpatient care, and three community mental health centres (CMHC), providing outpatient, partial care and limited inpatient services. The delivery of mental health care services involve several social, political and economic objectives, some of which are in conflict. In particular, the specific objectives considered are similar to the ones proposed by Franz et al. [71]: (i) do not exceed patient care and counselling budget; (ii) achieve additional deinstitutionalization by reducing patients receiving care in the regional centre by 30 per cent; (iii) meet projected demand increase of 10 per cent for all mental health services; (iv) provide psychiatric care to all patients who require it; (v) provide mental health education to all primary and secondary school children in the area served by the CMHC; (vi) provide necessary professional staff care to all patients and (vii) double the number of citizens reached by mental health education service of CMHC.

These two studies presented solutions to the existing challenges in the mental health care sector. However, there is still a lack of studies to support mental health planning in the context of NHS-systems considering the impact of multiple equity objectives - key objectives pursued in NHS-based countries.

The main features considered relevant for planning the delivery of health care services in general, and of mental health care services in particular are presented in Table 3.1. It can be observed that there is little research on studies applied to the mental health sector, despite the relevance of a proper planning of mental health care networks being increasingly recognized in the literature. Most of the mathematical programming models developed have been used to support the planning of mental health care networks in the US context. In fact, no study was found for planning mental health care networks in the context of NHS-systems. It is thus clear that there is need for developing research in this area applied to the European context, in particular NHS-based systems.

Table 3.1: Features of studies using mathematical programming models for planning the delivery of health care services in general, and of mental health care services in particular. Legend: IC - institutional care; AC - ambulatory care; HBC - home-based care; RC - rehabilitation care; NHS - National Health Service

Studies	Multiple services				Multiple objectives		Planning under uncertainty	Mental health care sector applications	NHS system
	IC	AC	HBC	RC	Cost	Equity			
[49]	X				X				
[68]	X	X			X	X	X		X
[56]						X			X
[10]						X			X
[59]						X			
[50]	X	X	X				X		X
[60]					X	X			
[62]	X	X	X		X		X		X
[12]					X		X		
[72]								X	
[73]								X	
[74]							X	X	
[71]	X	X	X		X		X	X	
[75]	X	X	X		X			X	
MHC	X	X	X	X	X	X	X	X	X

Although it is known that mental health planners operate in a very uncertain environment, uncertainty has been rarely addressed in the context of mental health planning. Moreover, most studies do not consider the joint effect of cost and equity objectives. Also, few studies have explored the multi-service nature of mental health services delivery. In particular, rehabilitation services have not been considered so far. Within this context, it can be observed that no study has accounted for these features altogether. For this reason, MHC model proposed in this thesis contributes to fill this gap in literature.

Summing up, this thesis' major focus is on the development of a mathematical programming model to support the planning of a multi-service mental health care network in NHS-based countries. Since these models have already shown evidence to be successful for aiding the planning in other health sectors, they show great promise for being applied to plan the mental health care sector.

3.3 Building estimates on future demand for health

So as to ensure an adequate planning of health care services, the previously reviewed methods should depart from information on current and future demand for care. Nevertheless, this type of information is often not available, and so there is need to develop methods to predict this. However, very little research has been done on this subject. Studies on health forecasting are often focused on very specific conditions, such as diabetes [76], ischaemic heart disease [77] or aggregate health situations, as for instance emergency department visits [78, 79]. To be able to accurately predict the demand for health, reliable data and appropriate analytical tools are required [80].

When it comes to estimating and predicting future demand for health care services, in order to be integrated in mathematical programming models for health care planning, different approaches have been followed. Some studies have proposed methods to predict future demand for health based on information from current level of service utilization. However, if the current supply of services is not enough to meet all the demand, this approach will result in an underestimation of needs. For this reason, in this situation any approach that uses current utilization of services is considered inadequate to predict the demand for health services [81]. Another approach consists in predicting future demand based on the characteristics of the potential population in need for health care services. For instance, Cardoso et al. [13] developed a simulation model to predict the annual number of individuals in need of each type of long-term care service, considering the population needs, by accounting for several health and socio-economic-related characteristics.

In the mental health care planning literature, studies constructing future demand estimates in order to be integrated into mathematical programming models to support planning of mental health care networks were not identified. Within this context, along with the fact that the current supply of mental health care services is far from being enough to meet all the demand, it is essential to build estimates on future demand for mental health care based on the characteristics of the population with potential need of such care.

3.4 Contribution of the thesis

This study contributes to the health care planning literature by (i) building estimates on future demand for mental health care services (in order to be integrated in mathematical programming models to support the planning of mental health care networks) and (ii) proposing a mathematical programming approach to support planning decisions, in terms of location of services, capacity planning and allocation of patients to services, in the mental health care sector (a health sector not widely studied in the literature), within the context of NHS-based countries.

Regarding the mathematical programming model, it not only contributes by considering the specificities of the mental health care sector, but also by: (i) considering the multi-service nature of mental health care; (ii) accounting for multiple objectives relevant in this sector, namely costs and several equity dimensions (equity of access, geographical equity, equity of service-specific utilization and equity of disease-specific utilization); and (iii) exploring the impact of uncertainty on planning decisions through sensitivity analysis.

Chapter 4

Methodology

This chapter begins with an overview of the methodology used in this study (section 4.1), followed by the explanation of the approach used for predicting the demand for mental health care services (section 4.2) and the description of the mathematical programming model developed to support the planning of mental health care networks (section 4.3).

4.1 Global overview of the methodology

The methodology used in this study is illustrated in Figure 4.1. First, the future demand for mental health care was estimated (represented in green). Then, a mathematical programming model was developed to aid mental health planning (represented in blue), with the predicted demand being a key input of the model.

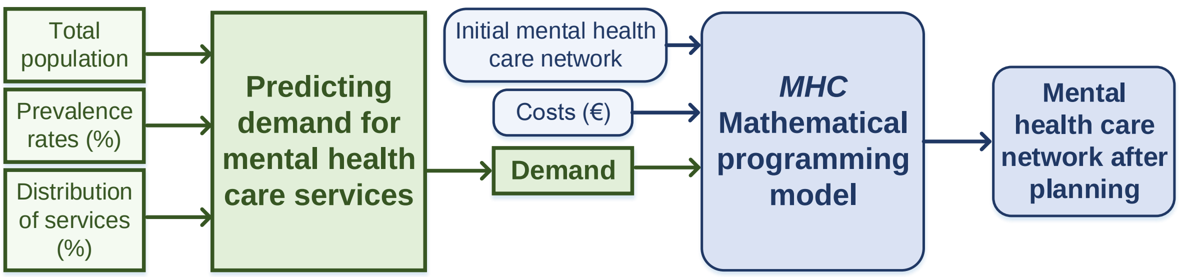

Figure 4.1: Representation of the methodology used in this study

4.2 Predicting demand for mental health care

This section explains the approach used to predict one the most important inputs of the model: the demand for mental health care disaggregated by municipality, age group, patient/disease group, service and year. A schematic representation of the followed methodology is presented in Figure 4.2. First, the prevalence rates are applied in order to determine the population with mental disorders. Different prevalence rates are employed for different types of mental disorders. And then, information on the distribution of services is used and multiplied by the population per municipality, age group, patient/disease group and year, resulting in the demand for each mental health care service.

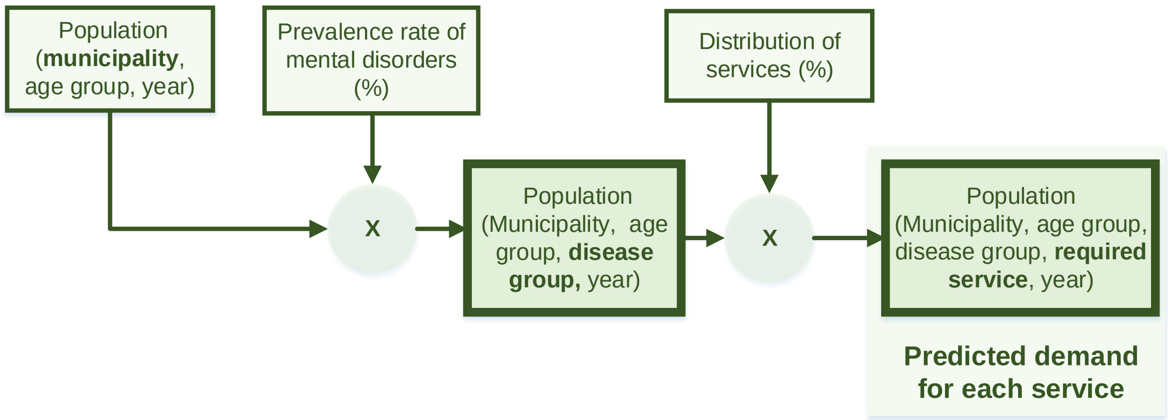

Figure 4.2: Representation of the methodology used to predict the demand for mental health care

4.2.1 Notation

The notation adopted to formulate the steps of the approach followed to predict the demand for mental health care services is presented in Table 4.1.

Table 4.1: Notation adopted to predict future demand for mental health care

Notation	Description
Indices	
m	Municipalities
a	Age groups
d	Mental disorders/Disease groups
s	Mental health care services
y	Years
Parameters	
Pop_{may}	Population from municipality m and age group a in year y
$Prev_d$	Prevalence of mental disorders d (in %)
$Distrib_s$	Distribution of mental health care services s (in %)
Variables	
PMD_{mady}	Population from municipality m and age group a with mental disorder d in year y
$PMHC_{madsy}$	Population from municipality m and age group a with mental disorder d requiring mental health care service s in year y

4.2.2 Predicting the number of individuals with mental disorders

The first step was the determination of the population with mental disorders. For that purpose, the multiplication of the population per municipality, age group and year (Pop_{may}) by the prevalence rate of different mental disorders ($Prev_d$) is computed (Eq. 4.1), resulting in the disaggregation of the data by disease group (PMD_{mady}). The results thus obtained are expected to be overestimated, due to the existence of comorbidities that are not taken into consideration, i.e., people that have more than one mental disorder are counted multiple times.

$$PMD_{mady} = Pop_{may} \times Prev_d \tag{4.1}$$

4.2.3 Predicting the number of individuals requiring mental health care

The next step consisted in finding out how many people with the different mental disorders are in need of each mental health care service (IC, AC, HCB, RU and OU). To do so, the population per municipality, age group, disease group and year (PMD_{mady}) is multiplied by the distribution of mental health care services (%), as shown in Eq. 4.2, resulting in the disaggregation of the data by required service ($PMHC_{madsy}$).

$$PMHC_{madsy} = PMD_{mady} \times Distrib_s \tag{4.2}$$

4.3 Designing a network of mental health services

An adequate design of mental health care networks must address different planning issues. Particularly: (i) the location and capacity of multiple services should be planned; (ii) patients requiring mental health care should be allocated to existing services; and (iii) the attainment of multiple planning objectives relevant in the mental health care sector should also be ensured.

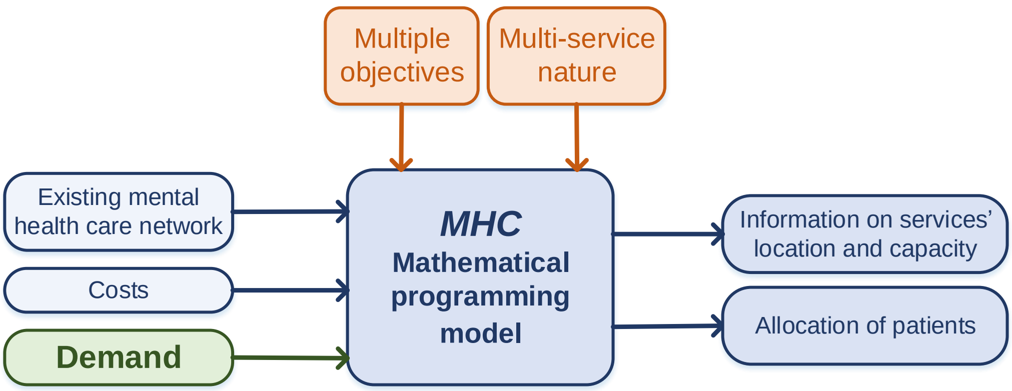

Figure 4.3: Representation of the key features of the MHC model

Mathematical programming models have been widely used to support health care planning in general, in terms of location-allocation decisions, and have potential to be used to ensure this planning. This work proposes a multi-objective mathematical programming model - the MHC model (with MHC standing for Mental Health Care) - to support the planning of a multi-service network of mental health care services in the context of NHS-based countries in the medium-term when multiple policy objectives need to be pursued. Figure 4.3 summarizes the key features of the MHC model, with special relevance given to the demand for mental health care services predicted in order to be integrated in the MHC model for mental health planning. The MHC model takes into account the multi-service nature of mental health care as well as the multiple objectives relevant in this sector.

4.3.1 Overview of the mathematical programming model

MHC is a MILP model that provides information for planning, both in terms of services' location and capacity, while ensuring the attainment of multiple objectives, namely, the minimization of cost and the maximization of multiple dimensions of equity. Particularly, in terms of equity, the model accounts for four equity dimensions – equity of access, geographical equity, equity of service-specific utilization and equity of disease-specific utilization, explained in detail in section 4.3.2.2. Based on literature review presented earlier, these are the key policy objectives in the mental health care sector.

The present model assists health care planners to reorganize and design this network, by providing key information over time related to: (i) the opening and closure of mental health care services; (ii) the capacity (beds and human resources) needed in each service and location; (iii) the geographical distribution of the capacity across services and patient/disease groups; and (iv) the impact of the changes in the mental health care network on equity and cost-related objectives.

Figure 4.4 summarizes the features of the MHC model. Departing from an initial network of mental health care that ensures the provision of IC, AC, HBC, RU and OU delivered by public (PHCCs, general and psychiatric hospitals) and social care providers (IPSS and NGOs) one should consider:

- Opening/closing of services - the opened services are identified with the respective coloured box with a black border (e.g., one RU and one OU service opened in the IPSS and NGO, respectively) and the closed services are identified with the respective faded coloured box (the RU service in the IPSS);

- Assigning patients to the required service - solid arrows represent patients receiving the care they need in the respective service [for IC, AC, RU and OU], and dashed arrows depict the provision of mental health care at patients' homes [for HBC]). Note that the different colours of the patients correspond to the colours of the services they require;

- Capacity needed per service - how many beds and human resources (physicians and nurses) are needed per service over time;

- Addition/reallocation of beds - the dotted arrow pointing to IC service represents the addition of new beds to this service (identified with a plus sign), while the other dotted arrow represents the reallocation of beds from the closed RU service to the new opened RU service situated in a different location.

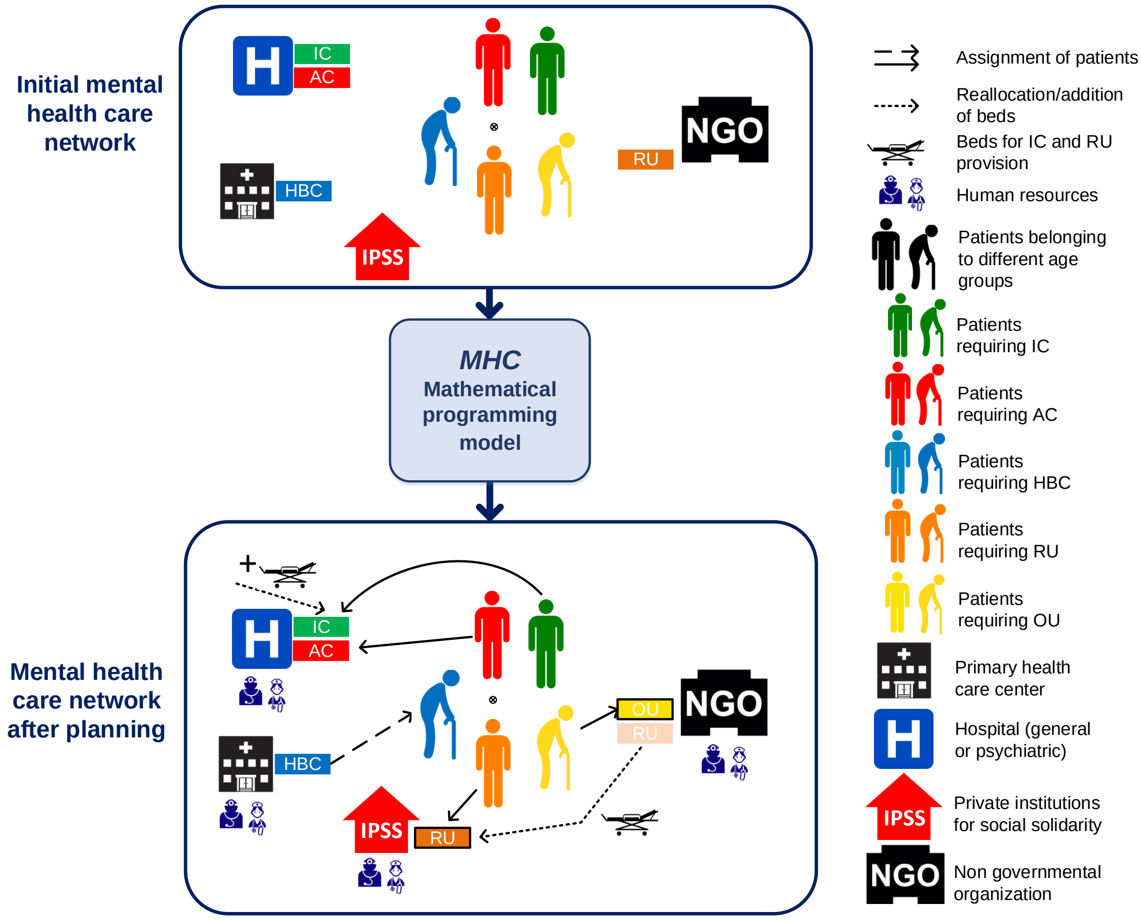

Figure 4.4: Representation of how the MHC model plan changes in the existing mental health care network. Legend: IC- institutional care; AC - ambulatory care; HBC - home-based care; RU - residential until; OU - occupational unit

4.3.2 Building the mathematical programming model

This section presents the mathematical details of the MHC model. First, the notation used for the mathematical formulation of the model, organized into indices, sets, parameters and variables is listed in Tables 4.2-4.5. Then, the objectives considered and the method used to deal with the multi-objective function, as well as the constraints are presented. The model proposed in this section departs from the model proposed by Cardoso et al. [50], since several common characteristics can be found between the mental health care network and the long-term care network considered in this study. Nevertheless, several adaptations were made to the model proposed by these authors, with all those changes being carefully explained throughout this section.

4.3.2.1 Notation

Table 4.2: List of indices

Indices	Description
t, t'	Time periods
d	Demand points
s, s'	Mental health care services
l, l'	Location for services
p	Patient groups
a	Age groups
h	Human resources
j, j'	Type of mental health care provider

Table 4.3: List of sets

Sets	Description
T	Set of time periods
D	Set of demand points
$S = S^1 \cup S^2 \cup S^3 \cup S^4 \cup S^5$	Set of mental health care services divided into subsets S^1 (subset of IC services, $s, s' \in S^1 \subseteq S$), S^2 (subset of AC services, $s, s' \in S^2 \subseteq S$), S^3 (subset of HBC services, $s, s' \in S^3 \subseteq S$), S^4 (subset of RU services, $s, s' \in S^4 \subseteq S$) and S^5 (subset of OU services, $s, s' \in S^5 \subseteq S$)
$L = L^1 \cup L^2 \cup L^3 \cup L^4$	Set of location for services divided into subsets L^1 (subset of locations for IC services, $l, l' \in L^1 \subseteq L$), L^2 (subset of locations for AC services, $l, l' \in L^2 \subseteq L$), L^3 (subset of locations for HBC services, $l, l' \in L^3 \subseteq L$) and L^4 (subset of locations for RU and OU services, $l, l' \in L^4 \subseteq L$)
P	Set of patient groups
A	Set of age groups
H	Set of human resources
J	Set of mental health care providers
$M = \{(s, l) : s \in S, l \in L\}$	Set of services s that can be provided in locations l
$V = \{(s, l) : s \in S, l \in L\}$	Set of services s provided in locations l at the beginning of the planning horizon
$\bar{V} = \{(s, l) : s \in S, l \in L\}$	Set of services s not provided in locations l at the beginning of the planning horizon
$C = \{(l, j) : l \in L, j \in J\}$	Set of locations l of services delivered by provider j
$F = \{(d, l) : d \in D, l \in L\}$	Set of demand points d that can receive care in locations l
$R = \{(s, h) : s \in S, h \in H\}$	Set of services s provided by human resources h

The sets M, V, $\bar{V}$, C, F and R are subsets of all ordered pairs from two given sets. They capture the specificities of the mental health care networks, and are used to restrict the domain of the equations used to formulate the model. Set M defines for each service s the set of locations l where s can be provided, e.g., IC can only be delivered in psychiatric hospitals, general hospitals and IPSS, while OU can also be provided in NGOs. The matrix presented below illustrates the previous example, with the rows representing the services (from top to bottom: IC and RU) and the columns the locations (from left to right: psychiatric hospitals, general hospitals IPSS and NGOs). The locations where IC and/or OU services are delivered correspond to entries with the number 1, and 0 otherwise.

$$M(s,l) = \begin{pmatrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{pmatrix}$$

The current geographical distribution of services is captured by sets V and $\bar{V}$, representing the set of services s that are, and are not provided in locations l at the beginning of the planning horizon, respectively. These sets are used to define the opening and closure of services, as will be shown later. As mentioned before, mental health care is delivered by public and social providers. Set C establishes the set of locations l belonging to each type of provider j, i.e., PHCCs, general hospitals and psychiatric hospitals belong to the public sector, and IPSS and NGOs to the social sector. The following matrix depicts the previous example, with the rows corresponding to the services location (from top to bottom: PHCCs, general hospitals, psychiatric hospitals, IPSS and NGOs) and the columns to the type of provider (from left to right: public and social sector). Thus, the entries with the number 1 in the first and second columns correspond to service locations belonging to the public and social sectors, respectively.

$$C(l,j) = \begin{pmatrix} 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{pmatrix}$$

Set F defines for each demand point d the locations l of services where people can receive care, which is important to take into account for the assignment of patients. For example, patients can only receive HBC delivered by teams that are based in the PHCCs on their area of residence. Set R designate the set of services s provided by each type of human resource h, e.g., nurses provide mainly IC, AC and HBC services, while social assistants provide rehabilitation services as RU and OU.

Table 4.4: List of parameters

Parameters	Description
ni_{dpast}	Number of individuals from demand point d, patient group p and age group a requiring service s at t
niD_{dt}	Number of individuals from demand point d requiring care at t
niS_{st}	Number of individuals requiring service s at t
niP_{pt}	Number of individuals from patient group p requiring care at t
ni_s^{min} / ni_s^{max}	Minimum/maximum number of individuals allowed per AC, HBC and OU service $s\,(s \in (S^2 \cup S^3 \cup S^5) \subseteq S)$
nb_{sl}	Number of beds available in IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ located in $l\,(l \in (L^1 \cup L^4) \subseteq L)$ at t=0
LOS_s	Average length of stay, measured by the number of days in IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$
nb_s^{min} / nb_s^{max}	Minimum/maximum bed capacity allowed per IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$
nh_{hsl}	Number of hours of care provided by human resources h in service s located in l at t=0
rh_{hs}	Recommendation for the hours of care to be provided by human resource h for each individual requiring service s
oc_{st}	Operational cost per service s per period t (in €)
ic_{st}	Investment cost per new bed installed in IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ at t (in €)
rc_{st}^{diff}	Cost of reallocating a bed to IC and RU service $s\,(s \in (S^1 \cup S^4 \subseteq S)$ from a service delivered in a different location at t (in €)
rc_{st}^{same}	Cost of reallocating a bed to IC and RU service $s\,(s \in (S^1 \cup S^4 \subseteq S)$ from a service delivered in the same location at t (in €)
τ_{dl}	Travel time between demand point d and service location l (in minutes)
τ^{max}	Maximum travel time allowed for patients to access services (in minutes)
τ_t^{tot}	Maximum total travel time at t (in minutes)
ε_s	Efficiency factor associated with the provision of service s
β_{st}	Minimum level of satisfied demand per service s at t
α	Number of days per time period
Φ	High value auxiliary parameter
$T^{EA}, T^{GE}, T^{ESU}, T^{EDU}$	Equity targets set by the DM at the end of the planning horizon (corresponding to the desired levels of achievement)

The parameters listed above are the inputs of the model, except the ni_{dpast} parameter that had to be estimated. Further information can be found in section 4.2.

Table 4.5: List of variables

Variables	Description
Binary variables	
X_{sljt}	Equal to 1 if service s is located in l delivered by provider j at t; 0 otherwise
Y_{sljt}	Equal to 1 if there is need to invest in new beds for IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ located in $l\,(l \in (L^1 \cup L^4 \subseteq L)$ delivered by provider j at t; 0 otherwise
W_{sljt}	Equal to 1 if at least one bed is reallocated to IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ located in $l\,(l \in (L^1 \cup L^4) \subseteq L)$ delivered by provider j at t; 0 otherwise
Integer variables	
$Q_{dpasljt}$	Proportion of individuals from demand point d, patient group p and age group a receiving service s in location l delivered by provider j at t
ID_{dt}	Number of individuals from demand point d receiving care at t
IS_{st}	Number of individuals receiving service s at t
IP_{pt}	Number of individuals from patient group p receiving care at t
$NB_{dpasljt}$	Number of beds to be made available for individuals from demand point d, patient group p and age group a receiving IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ located in $l\,(l \in (L^1 \cup L^4) \subseteq L)$ delivered by provider j at t
NAB_{sljt}	Number of additional beds to invest in for IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ located in $l\,(l \in (L^1 \cup L^4) \subseteq L)$ delivered by provider j at t
$NRB^{in}_{sljs'l'j't}$/ $NRB^{out}_{sljs'l'j't}$	Number of beds reallocated to/from IC and RU service $s\,(s \in (S^1 \cup S^4) \subseteq S)$ located in $l\,(l \in (L^1 \cup L^4 \subseteq L)$ delivered by provider j from/to IC and RU service $s'(s' \in (S^1 \cup S^4) \subseteq S)$ located in $l'\,(l' \in (L^1 \cup L^4) \subseteq L)$ delivered by provider j' at t
Positive variables	
$NH_{hdpasljt}$	Number of hours of care provided by human resource h for individuals from demand point d, patient group p and age group a receiving service s located in l delivered by provider j at t
NAH_{hsljt}	Number of additional hours of care that need to be provided by human resource h in service s located in l delivered by provider j at t
NEH_{hsljt}	Number of hours of care provided by human resource h that are no longer required in service s located in l delivered by provider j at t
TT_t	Total travel time (in minutes) at t
TO_t/TI_t	Total operational/investment cost at t
$f^{EA}, f^{GE}, f^{ESU}, f^{EDU}$	Multiple equity objectives (EA, GE, ESU and EDU)
f^C	Cost objective
E^{EA}_t, E^{GE}_{dt}, $E^{ESU}_{st}, E^{EDU}_{pt}$	Equity measure defined for each equity objective at t (and for demand point d for GE, service s for ESU, patient/disease group p for EDU)

4.3.2.2 Defining the multiple objective function

The model accounts for multiple equity objectives - equity of access (EA), geographical equity (GE), equity of service-specific utilization (ESU) and equity of disease-specific utilization (EDU) - pursued in any NHS-based system, as well as in the mental health care sector; and a cost objective, that is relevant in the current context of severe budget cuts and limited public health care spending. The objective of the model is thus to minimize cost and/or maximize several equity dimensions, as represented in the organigram presented in Figure 4.5. These multiple objectives may be jointly considered for planning, or only part of it may be worth pursuing, depending on the planning circumstances.

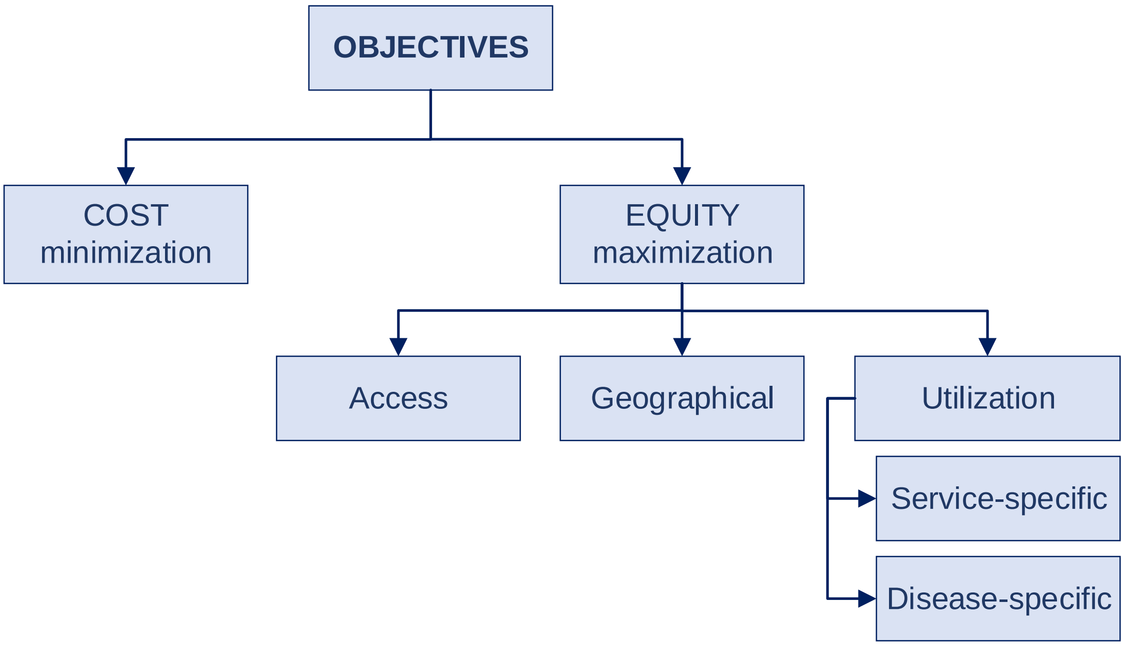

Figure 4.5: Objectives relevant in the mental health care sector

According to the selected measures for the equity-related objectives, presented below, higher levels of equity correspond to a higher total travel time, for EA, and higher levels of unsatisfied demand (unmet need) for GE, ESU and EDU. For this reason, equity maximization is achieved through the minimization of its value. In order to operationalize the objectives, the following measures are considered:

- EA - $Minf^{EA}$: Minimization of the total travel time (TT_t) for patients accessing mental health care services throughout the planning horizon (Eqs. 4.3-4.4). This objective ensures that patients receive the care they need as close as possible to their place of residence. The maximum total travel time (τ_t^{tot}), defined in Eq. 4.5, corresponds to the situation of all patients that require mental health care having to incur the maximum travel time (τ^{max}). The division of the total travel time (TT_t) by the maximum total travel time (τ_t^{tot}) allows to represent this EA measure in a common [0,1] scale;

$$Minf^{EA} = \frac{\sum\limits_{t \in T} TT_t}{\sum\limits_{t \in T} \tau_t^{tot}} \tag{4.3}$$

$$TT_t = \sum_{d \in D} \sum_{p \in P} \sum_{a \in A} \sum_{s \in S} \sum_{\substack{l \in L \\ l:(s,l) \in M \\ l:(d,l) \in F}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} Q_{dpasljt} \times ni_{dpast} \times \tau_{dl} \quad \forall t \in T \tag{4.4}$$

$$\tau_t^{tot} = \sum_{d \in D} \sum_{p \in P} \sum_{a \in A} \sum_{s \in S} ni_{dpast} \times \tau^{max} \quad \forall t \in T \tag{4.5}$$

- GE - $Minf^{GE}$: Minimization of unmet need for the geographical area(s) with the highest level of unmet need throughout the planning horizon (Eqs. 4.6-4.7), avoiding a total lack of provision in some regions. GE is measured as the percentage of patients in the worst-off geographical area that do not receive care and is built to be represented in a common [0,1] scale. For example, a 0.4 value means that care is not provided to 40% of patients in need belonging to the geographical area with the lowest provision of mental health care. Thus, this objective ensures the maximum provision of care in the geographical area(s) with the lowest level provision.

$$Minf^{GE} = \max_d \left(1 - \frac{\sum_{t \in T} ID_{dt}}{\sum_{t \in T} niD_{dt}} \right) \tag{4.6}$$

$$ID_{dt} = \sum_{p \in P} \sum_{a \in A} \sum_{s \in S} \sum_{\substack{l \in L \\ l:(s,l) \in M \\ l:(d,l) \in F}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} Q_{dpasljt} \times ni_{dpast} \quad \forall d \in D, t \in T \tag{4.7}$$

- ESU - $Minf^{ESU}$: Minimization of unmet need for the service with the lowest level of provision throughout the planning horizon (Eqs. 4.8-4.9), avoiding a total lack of provision of a particular service (usually the most expensive services or the ones with the highest LOS). ESU is represented in a common [0,1] scale. For instance, a 0.2 value corresponds to care not being provided to 20% of the patients in need for the service with the lowest level of provision. Hence, this objective ensures the maximum provision of the service with the lowest level of provision. Neglecting this objective can result in high variations in the utilization across different types of mental health care services.

$$Minf^{ESU} = \max_s \left(1 - \frac{\sum_{t \in T} IS_{st}}{\sum_{t \in T} niS_{st}} \right) \tag{4.8}$$

$$IS_{st} = \sum_{d \in D} \sum_{p \in P} \sum_{a \in A} \sum_{\substack{l \in L \\ l:(s,l) \in M \\ l:(d,l) \in F}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} Q_{dpasljt} \times ni_{dpast} \quad \forall s \in S, t \in T \tag{4.9}$$

- EDU - $Minf^{EDU}$: Minimization of unmet need for the patient/disease group with the highest level of unmet need throughout the planning horizon (Eqs. 4.10 - 4.11), preventing a total lack of provision for a particular patient/disease group. EDU is represented in a common [0,1] scale, with a 0.5 value meaning that care is not provided to 50% of patients belonging to the patient/disease group with the lowest level of provision. Therefore, this objective ensures the maximum provision of care for the patient/disease group with the lowest level of provision.

$$Minf^{EDU} = \max_{p} \left(1 - \frac{\sum\limits_{t \in T} IP_{pt}}{\sum\limits_{t \in T} niP_{pt}} \right) \tag{4.10}$$

$$IP_{pt} = \sum_{d \in D} \sum_{a \in A} \sum_{s \in S} \sum_{\substack{l \in L \\ l:(s,l) \in M \\ l:(d,l) \in F}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} Q_{dpasljt} \times ni_{dpast} \quad \forall p \in P, t \in T \tag{4.11}$$

- Cost - $Minf^{C}$: Minimization of total cost (operational and investment costs) associated with the mental health care provision throughout the planning horizon (Eqs. 4.12-4.14). Operational costs are defined by Eq. 4.13 and include costs associated to the operation of beds in IC and RU services (first term) and to the provision of AC, HBC and OU services (second term). Investment costs are defined by Eq. 4.14 and include the investment in new beds (first term), reallocation of beds between services in different locations (second term) and in the same location (third term). All the cost parameters need to be adjusted by inflation effects.

$$Minf^{C} = \sum_{t \in T} (TO_t + TI_t) \tag{4.12}$$

$$\begin{aligned} TO_t = \sum_{d \in D} \sum_{p \in P} \sum_{a \in A} \Bigg(& \sum_{s \in (S^1 \cup S^4)} \sum_{\substack{l \in (L^1 \cup L^4) \\ l:(s,l) \in M \\ l:(d,l) \in F}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} NB_{dpasljt} \times oc_{st} \\ & + \sum_{s \in (S^2 \cup S^3 \cup S^5)} \sum_{\substack{l \in (L^2 \cup L^3 \cup L^4) \\ l:(s,l) \in M \\ l:(d,l) \in F}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} Q_{dpasljt} \times ni_{dpast} \times oc_{st} \Bigg) \quad \forall t \in T \end{aligned} \tag{4.13}$$

$$\begin{aligned} TI_t = \sum_{s \in (S^1 \cup S^4)} \sum_{\substack{l \in (L^1 \cup L^4) \\ l:(s,l) \in M}} \sum_{\substack{j \in J \\ j:(l,j) \in C}} \Bigg(& NAB_{sljt} \times ic_{st} + \sum_{s' \in (S^1 \cup S^4)} \sum_{\substack{l' \in (L^1 \cup L^4) \\ l':(s',l') \in M \\ l' \neq l}} \\ & \sum_{\substack{j' \in J \\ j':(l',j') \in C}} NRB_{sljs'l'j't} \times rc^{diff}_{st} + \sum_{\substack{s' \in (S^1 \cup S^4) \\ s':(s',l) \in M}} NRB_{sljs'l'j't} \times rc^{same}_{st} \Bigg) \quad \forall t \in T \end{aligned} \tag{4.14}$$

The equity of access and geographical equity objectives (EA and GE) are based on the model proposed by Cardoso et al. [56]. According to the author, the defined EA objective encapsulates two equity objectives: (i) ensures that patients receive the care they need at the closest available service (Eq. 4.5) and (ii) ensures that services will be provided to as many patients in need as possible, through the definition of a penalty, which assumes that patients not receiving care incur the maximum travel time. In the present model, the EA objective was adapted so that this penalty is not considered. Instead, a minimum level of demand satisfaction was imposed as a constraint, as will be detailed further. Another adaptation to the original model is as follows: while Cardoso et al. [56] defined EA objective only for institutional services, the model proposed in this thesis considers the multi-service nature of mental health care, and so EA is defined so as to include the entire range of mental health care services (IC, AC, HBC, RU and OU). By contrast, GE objective is in line with the equity objective proposed by Cardoso et al. [56], without changes. Furthermore, the structure of the ESU was based on the satisficing equity level defined for EU presented by Cardoso et al. [50]. The denomination 'service-specific' was used to allow the distinction between the two types of equity of utilization considered in this study. The cost objective was adapted from Cardoso et al. [50], taking into account all the mental health care services.

An additional objective of equity of utilization, the EDU, is first introduced in the model proposed in this thesis due to its relevance to the mental health care network planning (namely, the high variation in the utilization of mental health care services across patient/disease groups). The structure of the EDU objective is similar to the presented for the ESU objective.

Dealing with the multi-objective function

As shown in the literature review, when pursuing multiple objectives, in general, there is no single optimal solution that simultaneously optimizes all the objectives [63]. Instead, the set of the Pareto optimal solutions (also called Pareto set) can be identified. The augmented ε-constraint method proposed by Mavrotas [63] provides a subset of the Pareto set. This method is a novel version of the conventional ε-constraint method that solves its well-known pitfalls: (i) the calculation of the range of each objective function over the efficient set, (ii) the guarantee of efficiency of the obtained solution and (iii) the increased solution time for problems with more than two objective functions [63]. In the augmented ε-constraint method one of the objective functions is optimized using the other objectives functions as constraints.

In case multiple objectives need to be considered in a given planning context, the proposed model allows dealing with these multiple objectives through this method. The augmented ε-constraint method is applied by minimizing costs, whereas the equity-related objectives are imposed as constraints. The objective function is given by Eq.4.15 and the equity-related constraints are given by Eqs. 4.16-4.19.

$$Min(f_C - eps \times (s_{EA} + s_{GE} + s_{ESU} + s_{EDU})) \tag{4.15}$$

$$f_{EA} - s_{EA} = e_{EA} \tag{4.16}$$

$$f_{GE} - s_{GE} = e_{GE} \tag{4.17}$$

$$f_{ESU} - s_{ESU} = e_{ESU} \tag{4.18}$$

$$f_{EDU} - s_{EDU} = e_{EDU} \tag{4.19}$$

where eps is a small number (usually between 10^{-3} and 10^{-6}), s_i represent slack or surplus variables and e_i depend on the minimum and maximum values of each objective and on the number of grids points choose for building the Pareto Frontier.

4.3.2.3 Constraints

After building the objective function, several constraints typically used in the health care planning literature were defined: assignment of patients's, opening and closure of services, capacity, resources' requirements, resources allocation and service level, as well as the variable domains. Departing from these constraints formulated in the model published by Cardoso et al. [50], adaptations were made according to the specificities of the mental health care network, such as the existence of a wide variety of services (not only IC, AC and HBC, but also RU and OU). Also, to take into account the distinction between public and social providers, a new resource reallocation constraint was introduced (Constraint 4.34) so as to model the reallocation of beds between different providers.

Assignment of patients'

Constraints 4.20-4.22 define the conditions for the assignment of patients. Obviously, patients are only assigned to services s in locations l where they are available ($X_{sljt} = 1$), as stated by Constraint 4.20.

$$Q_{dpasljt} \leq X_{sljt} \quad \forall p \in P, a \in A, s \in S, l \in L : (s,l) \in M, (l,j) \in C, (d,l) \in F, t \in T \tag{4.20}$$

According to NHS-based systems, services should be provided as close as possible to where demand is located [17], which is ensured by Constraint 4.21. If location l is closer than another location l' to demand point d and provides the service s ($X_{sljt} = 1$), Constraint 4.21 imposes that patients from d should not receive the required service at l' ($Q_{dpasl'jt} = 0$). However, it should be noted that these patients may not receive the mental health care they need at the closest available service located at l, as there may not be enough resources to meet their needs. Furthermore, Constraint 4.22 ensures that patients cannot receive care in locations that are situated beyond the maximum travel time (τ^{max}).

$$X_{sljt} + Q_{dpasl'jt} \leq 1 \quad \forall p \in P, a \in A, s \in S, (l,l') \in L : (s,l) \in M, (s,l') \in M, (l,j) \in C, (l',j) \in C,$$
$$(d,l) \in F, t \in T, \tau_{dl} < \tau_{dl'}, l \neq l' \tag{4.21}$$

$$Q_{dpasljt} = 0 \quad \forall p \in P, a \in A, s \in S, l \in L : (s,l) \in M, (l,j) \in C, (d,l) \in F, t \in T, \tau_{dl} > \tau^{max} \tag{4.22}$$

The model proposed by Cardoso et al. [50] considers these constraints valid only to IC services, because in the context of an NHS-based country, the long-term AC and HBC services are provided within the primary health care network, whose network is already established. Accordingly, in such circumstances, patients requiring AC and HBC within the long-term care network can only receive it in PHCCs belonging to their area of residence, and so no assignment is required for these services. But in the mental health care sector this does not apply. In fact, mental health AC and HBC services are based in PHCCs, but they are also delivered by other providers, and so there is need to assign patients to the closest ones. Moreover, there are rehabilitation services (RU and OU) to be considered. For these reasons, the assignment of patients' constraints were adapted from Cardoso et al. [50] to be applied to all mental health care services while respecting set F.

Opening and closure of services

Constraints 4.23 and 4.24 model the opening/closure of IC, RU and OU services. If a service is opened/closed it is not allowed to close/open that service in a future time period, in order to ensure the stability of the mental health care network and also because these procedures involve high costs. For instance, if a service s is provided in location l at the beginning of the planning horizon, i.e. the service is open $X_{slj(t=0)}$ =1, and is decided to be closed in the next time period ($X_{slj(t=1)}$=0), according to Constraint 4.23 that service is forced to remain closed until the end of the planning horizon. Constraint 4.24 ensures the opposite situation, i.e., it does not allow to close a service that was opened in a previous time period.

$$X_{sljt'} \leq X_{sljt} \quad \forall s \in (S^1 \cup S^4 \cup S^5), l \in (L^1 \cup L^4) : (s,l) \in (M \cap V), (l,j) \in C, (t,t') \in T, t' > t \quad (4.23)$$

$$X_{sljt'} \geq X_{sljt} \quad \forall s \in (S^1 \cup S^4 \cup S^5), l \in (L^1 \cup L^4) : (s,l) \in (M \cap \bar{V}), (l,j) \in C, (t,t') \in T, t' > t \quad (4.24)$$

Openings and closures are not applied for AC and HBC services, as stated by Constraint 4.25, because these services are partially provided within the scope of the primary care network, already established in the context of an NHS-based country.

$$X_{sljt} = 1 \quad \forall s \in (S^2 \cup S^3), l \in (L^2 \cup L^3) : (s,l) \in M, (l,j) \in C, t \in T \quad (4.25)$$

Capacity

Constraints 4.26 and 4.27 establish the minimum and maximum capacity for mental health care services. For IC and RU, this is measured by the bed capacity per service (Constraint 4.26). These services can only be opened if they have at least nb_s^{min} beds and cannot exceed nb_s^{max}. Regarding AC, HBC and OU services, the capacity refers to the minimum and maximum number of patients that can be assigned per service (Constraint 4.27).

$$nb_s^{min} \times X_{sljt} \leq \sum_{d:(d,l) \in F} \sum_{p \in P} \sum_{a \in A} NB_{dpasljt} \leq nb_s^{max} \times X_{sljt} \quad \forall s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C, t \in T \quad (4.26)$$

$$ni_s^{min} \times X_{sljt} \leq \sum_{d:(d,l)\in F} \sum_{p\in P} \sum_{a\in A} Q_{dpasljt} \times ni_{dpast} \leq ni_s^{max} \times X_{sljt} \quad \forall s \in (S^2 \cup S^3 \cup S^5), l \in (L^2 \cup L^3 \cup L^4) : (s,l) \in M, (l,j) \in C, t \in T \tag{4.27}$$

Resources requirements

Constraint 4.28 calculates the number of beds that should be available at t for IC and RU service s located in l delivered by provider j for individuals from demand point d, patient group g and age group a. The length of stay (LOS_s) included in the constraint, measured by the number of days in IC and RU services, captures the amount of services required by mental health patients. An efficiency factor (ε_s) associated with the provision of service s is also included, given that in the health care sector a full occupancy of services is not expected.

$$NB_{dpasljt} = \frac{LOS_s}{\alpha} \times Q_{dpasljt} \times ni_{dpast} \times \frac{1}{\varepsilon_s} \quad \forall p \in P, a \in A, s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) :\in M, (l,j) \in C, (d,l) \in F, t \in T \tag{4.28}$$

Constraint 4.29 states that the total bed capacity that needs to be available in each service and location must be equal to the capacity required in each time period, defined by a balance between new beds (first term), reallocated beds (second term) and existing beds (third term). For t=1, the existing beds are the beds that are available at the beginning of the planning horizon (nb_{sl}) and for $t \geq 1$ they correspond to the number of beds in place in the previous time period.

$$\sum_{d:(d,l)\in F} \sum_{p\in P} \sum_{a\in A} NB_{dpasljt} = NAB_{sljt} + \sum_{\substack{l' \in (L^1 \cup L^4) \\ l':(s',l')\in M}} \sum_{\substack{j' \in J \\ l':(l',j')\in C}} NRB^{in}_{sljs'l'j't} - NRB^{out}_{sljs'l'j't} + \\ + \begin{cases} nb_{sl}\,, & t=1 \\ \sum\limits_{d:(d,l)\in F} \sum\limits_{p\in P} \sum\limits_{a\in A} NB_{dpaslj(t-1)}\,, & t \geq 1 \end{cases} \quad \forall s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C \tag{4.29}$$

Similarly, Constraint 4.30 calculates the number of hours of care that should be provided by human resource h for individuals from demand point d, patient group p and age group a requiring service s located in l and delivered by provider j at t. Constraint 4.31 establishes a balance between the additional hours of care that need to be provided (first term), hours of care that are no longer required (second term) and hours of care provided by existing human resources (third term), for each type of human resource h.

$$NH_{hdpasljt} = Q_{dpasljt} \times ni_{dpast} \times \frac{rh_{rs}}{\varepsilon_s} \quad \forall p \in P, a \in A, (d,l) \in F, (s,l) \in M, (l,j) \in C, (s,h) \in R, t \in T \tag{4.30}$$

$$\sum_{d:(d,l)\in F}\sum_{p\in P}\sum_{a\in A} NH_{hdpasljt} = NAH_{hsljt} - NEH_{hsljt} + \begin{cases} nh_{hsl}\,, & t=1 \\ \sum_{d:(d,l)\in F}\sum_{p\in P}\sum_{a\in A} NH_{hdpaslj(t-1)}\,, & t\geq 1 \end{cases}$$
$$\forall (s,l)\in M, (l,j)\in C, (s,h)\in R \tag{4.31}$$

Resources reallocation

The reallocation of beds within the network of IC and RU services follow a set of conditions that are captured by Constraints 4.32-4.35. Constraint 4.32 ensures that the number of beds reallocated to service s located in l delivered by provider j from service s' located in l' delivered by provider j' is equal to the number of beds removed from service s' located in l' to service s located in l.

$$NRB^{in}_{sljs'l'j't} = NRB^{out}_{s'l'j'sljt} \quad \forall (s,s')\in (S^1\cup S^4), (l,l')\in (L^1\cup L^4) : (s,l)\in M, (s',l')\in M, (l,j)\in C, (l',j')\in C, t\in T \tag{4.32}$$

The reallocations of beds can occur between two IC services, two RU services or between an IC and an RU service. However, the reallocation of beds between services provided in different locations is only allowed in the first time period (Constraint 4.33), while between services in the same location is always allowed. This constraint contribute to the stabilization of the mental health care network after the first period of time. Also, the possibility to reallocate beds across services in different locations at t=0 is key to reorganize an existing network of services that is far from the most adequate one.

$$NRB^{in}_{sljs'l'j't} = 0 \quad \forall (s,s')\in (S^1\cup S^4), (l,l')\in (L^1\cup L^4) : (s,l)\in M, (s',l')\in M, (l,j)\in C, (l',j')\in C, l\neq l', t>1 \tag{4.33}$$

Furthermore, within this network it is only possible to reallocate beds between services delivered by the same provider. For this reason, Constraint 4.34 was introduced to prohibit the reallocation of beds from a service delivered by the social sector to a service belonging to the public sector, and vice versa.

$$NRB^{in}_{sljs'l'j't} = 0 \quad \forall (s,s')\in (S^1\cup S^4), (l,l')\in (L^1\cup L^4) : (s,l)\in M, (s',l')\in M, (l,j)\in C, (l',j)\in C, j\neq j', t\in T \tag{4.34}$$

Constraints 4.35 defines the maximum number of beds that can be reallocated from a service s, by establishing that the number of beds reallocated from service s in location l at t must be less than the number of existing beds in that service in the previous time period. In particular, for t=1 the existing beds correspond to the number of beds available at the beginning of the planning horizon (nb_{sl}). This constraint is necessary to prevent the reallocation of all existing beds in one particular service, which would only make sense if that service is to be closed.

$$\sum_{s' \in (S^1 \cup S^4)} \sum_{\substack{l' \in (L^1 \cup L^4) \\ l':(s',l) \in M}} \sum_{\substack{j' \in J \\ l':(l',j') \in C}} NRB^{out}_{sljs'l'j't} \leq \begin{cases} nb_{sl}\,, & t = 1 \\ \sum_{d:(d,l) \in F} \sum_{p \in P} \sum_{a \in A} NB_{dpaslj(t-1)}\,, & t > 1 \end{cases} \tag{4.35}$$

$$\forall s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C,$$

Minimum service level

Constraint 4.36 imposes a minimum level of satisfied demand per service s (represented by β_{st}) to be achieved per time period t.

$$\frac{IS_{s(t=|T|)}}{niS_{s(t=|T|)}} \geq \beta_{st} \quad \forall s \in S, t \in T \tag{4.36}$$

Variable domains

The variables domains are given by the following set of Constraints:

$$X_{sljt} \in [0,1] \quad \forall s \in S, l \in L : (s,l) \in M, (l,j) \in C, t \in T \tag{4.37}$$

$$Y_{sljt} \in [0,1] \quad \forall s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C, t \in T \tag{4.38}$$

$$W_{sljt} \in [0,1] \quad \forall s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C, t \in T \tag{4.39}$$

$$Q_{dpasljt} \geq 0 \quad \forall p \in P, a \in A, s \in S, l \in L : (s,l) \in M, (l,j) \in C, (d,l) \in F, t \in T \tag{4.40}$$

$$ID_{dt} \in Z \quad \forall d \in D, t \in T \tag{4.41}$$

$$IS_{st} \in Z \quad \forall s \in S, t \in T \tag{4.42}$$

$$IP_{pt} \in Z \quad \forall p \in P, t \in T \tag{4.43}$$

$$NB_{dpasljt} \in Z \quad \forall p \in P, a \in A, s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C, (d,l) \in F, t \in T \tag{4.44}$$

$$NAB_{sljt} \in Z \quad \forall s \in (S^1 \cup S^4), l \in (L^1 \cup L^4) : (s,l) \in M, (l,j) \in C, t \in T \tag{4.45}$$

$$NRB^{in}_{sljs'l'j't} \in Z \quad \forall (s,s') \in (S^1 \cup S^4), (l,l') \in (L^1 \cup L^4) : (s,l) \in M, (s',l') \in M, (l,j) \in C, (l',j') \in C, t \in T \tag{4.46}$$

$$NRB^{out}_{sljs'l'j't} \in Z \quad \forall (s,s') \in (S^1 \cup S^4), (l,l') \in (L^1 \cup L^4) : (s,l) \in M, (s',l') \in M, (l,j) \in C, (l',j') \in C, t \in T \tag{4.47}$$

$$NH_{hdpasljt} \geq 0 \quad \forall s \in S, l \in L : (s,l) \in M, (l,j) \in C, (d,l) \in F, (s,h) \in R, t \in T \tag{4.48}$$

$$NAH_{hsljt} \geq 0 \quad \forall s \in S, l \in L : (s,l) \in M, (l,j) \in C, (s,h) \in R, t \in T \tag{4.49}$$

$$NEH_{hsljt} \geq 0 \quad \forall s \in S, l \in L : (s,l) \in M, (l,j) \in C, (s,h) \in R, t \in T \tag{4.50}$$

$$TT_t \geq 0 \quad \forall t \in T \tag{4.51}$$

$$TO_t, TI_t \geq 0 \quad \forall t \in T \tag{4.52}$$

Chapter 5

Case study

This chapter presents the applicability of the MHC model through the resolution of a case study. The proposed MHC model was implemented in GAMS and applied to the county level in the Great Lisbon region in Portugal over the 2016-2019 period to illustrate how it can support planning decisions in the mental health care sector. This chapter is organized in the following sections: Dataset used and assumptions, Planning Contexts and Results.

The first section starts by presenting an overview of the dataset used for predicting the demand for mental health care services and for the model application. Then, a detailed description of the planning contexts relevant to DMs operating in the mental health sector are presented. Particularly, the model can be used to explore (i) how to reorganize the mental health care network under different circumstances, such as when full demand satisfaction is required or when specific equity targets should be attained, and at what cost; (ii) which equity improvements can be obtained under these circumstances; and (ii) the existing trade-offs between cost and multiple equity dimensions. Finally, the results obtained for each planning context are analysed and the potential of the model is demonstrated. These results were obtained by solving the MHC model with CPLEX 12 on a Two Intel Xeon E5-2660, 2.60 GHz computer with 64 GB RAM.

5.1 Dataset used and assumptions

5.1.1 Dataset used for predicting demand

The present work focuses on the Great Lisbon region, which contains a population of 2,026,834 inhabitants and is included in the LVT RHA. The Great Lisbon region is divided into 9 smaller area population units (*"Concelhos"*). This section presents the data gathered from literature (summarized in Table 5.1) to predict mental health care demand for all types of services (IC, AC, HBC, RU and OU) in each county in the Great Lisbon region between 2016 and 2019, disaggregated by age and patient/disease groups. The assumptions made in this process are also listed. As mentioned before, the future mental health demand for services was predicted using the approach presented in section 4.2. The use of estimated data was required since there was no data available for the Portuguese context.

Table 5.1: Data gathered from literature to predict the future demand for mental health care with a brief explanation and the sources

Data	Details	Source
Annual projections of total population	Total population disaggregated by age groups from the central projection scenario for the period 2016-2019	[82]
Population per municipality (%)	Population per municipality (%) disaggregated by age groups	[83]
Prevalence rates of mental disorders	Portuguese prevalence rates for anxiety, depressive, impulse control and substance use disorders. Schizophrenia international prevalence rate	[35, 36]
Distribution of mental health care services	Distribution of services based on their utilization in 2013	[6]

In summary, to predict the demand for mental health care, the following assumptions were made:

- The central projection scenario accurately predicts the total population per age group and year;
- The prevalence rates of mental disorders are independent of municipality and age group and constant over time;
- Comorbidities do not have a significant impact in predicting mental health care;
- Missing data from the public sector is assumed analogous to the social sector;
- The distribution of services is independent of the patient/disease group and constant over time.

5.1.2 Dataset used for applying the MHC model

This section provides a description of the dataset used (parameters defined in section 4.3.2.1) to run the model and assist the planning of the mental health care network in the Great Lisbon region. These data comprise a wide range of information, summarized in Table 5.2, as well as a brief explanation on the data and its sources.

Figure 5.1 displays the mental health care network currently operating in the Great Lisbon region, which is composed of 1 psychiatric hospital, 6 general hospitals, 5 IPSS and 10 NGOs. The PHCCs based in the primary health care network already established are not represented in the figure. Also, for simplification purposes, institutions in each county are *Sintra (1), Sintra (2)* and *Sintra (3)*.

Table 5.2: Data gathered from literature to apply the MHC model with a brief explanation and the sources

Data	**Details**	**Source**
Demand per service	Mental health care demand for all types of services (IC, AC, HBC, RU and OU) in each county, disaggregated by age and patient/disease groups	Predicted by approach detailed in section 4.2
Current geographical distribution of services	Location of IC, AC, HBC, RU and OU services at the beginning of 2016	[6]
Number of beds per service	Number of beds available in each IC and RU service location at the beginning of 2016	[6]
Length of stay (LOS)	LOS (in days) for IC and RU services	[7]
Number of hours to be provided by human resources per service	Recommendation for the hours of care to be provided by physicians and nurses per individual requiring each mental health service	[84]
Operational and investment costs (€)	Operational and investment costs per mental health service	[85]
Reallocation costs (€)	Cost of reallocating beds to/from IC and RU services	[17]
Distance between services and demand points	Travel time (in minutes) between each county and each mental health service	Calculated using Google Maps
Maximum distance travelled by patients	Maximum travel time allowed per patient accessing mental health services (in minutes)	[7]
Efficiency factor	Efficiency factor associated with the provision of mental health care services	[23]
Equity targets	The desired levels of equity to be achieved in 2019 defined by the DM	Head of the Department of Psychiatry and Mental Health of the *Hospital Beatriz Ângelo*

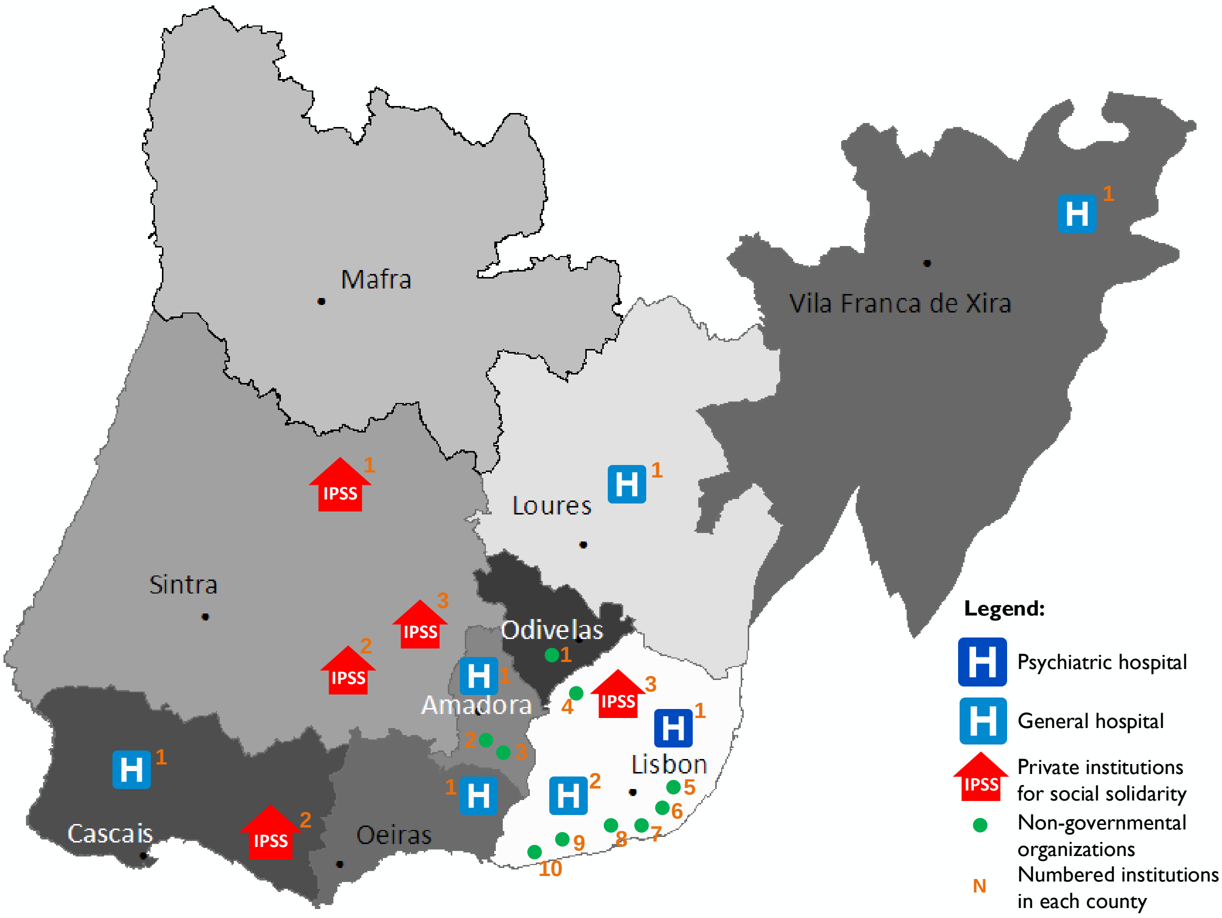

Figure 5.1: Current location of mental health care providers in the Great Lisbon region in Portugal

5.2 Predictions of future demand

To remind, the approach used to predict the demand for mental health care included two steps: (i) application of the prevalence rates in order to determine the population with mental disorders; and (ii) utilization of the information of distribution of services to calculate the demand for each mental health care service.

The future demand for mental health care was estimated for five different types of mental disorders: anxiety, depressive, impulse control, substance use and schizophrenia. The prevalence rates of these diseases are represented in Figure 5.2. The results obtained for the population with mental disorders from Lisbon county for the period 2017-2019, disaggregated by the two considered age groups: 15-64 and +65 are presented in Table 5.3.

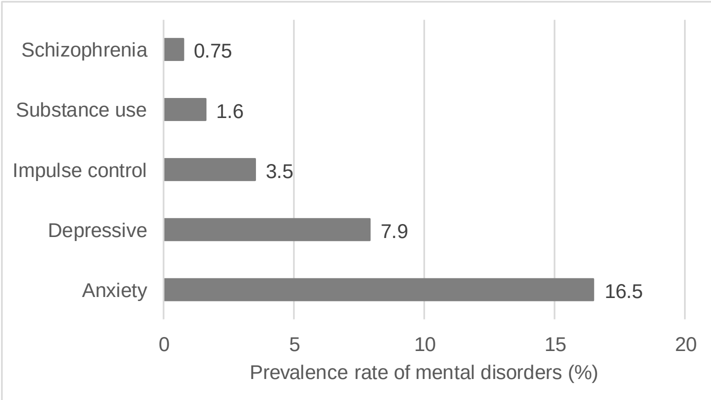

Figure 5.2: Prevalence rates of the mental disorders considered in this study [35, 36]

Table 5.3: Population with mental disorders from Lisbon county, disaggregated by age groups

Mental	2017		2018		2019	
disorders	15-64	+65	15-64	+65	15-64	+65
Anxiety	51,101	29,949	51,090	30,512	51,093	31,045
Depressive	24,467	14,339	24,461	14,609	24,463	14,864
Impulse control	10,840	6,353	10,837	6,472	10,838	6,585
Substance use	4,955	2,904	4,954	2,959	4,955	3,010
Schizophrenia	2,323	1,361	2,322	1,387	2,322	1,411

The distribution of mental health care services is presented in Figure 5.3. AC has the most significant weight (89.19%), followed by IC (8.59%) and HBC (1.57%). The rehabilitation services RU and OU accounted for 0.34% and 0.31%, respectively. The predicted demand for AC of Lisbon county disaggregated by type of mental disorder and age group in 2019 is represented in Figure 5.4.

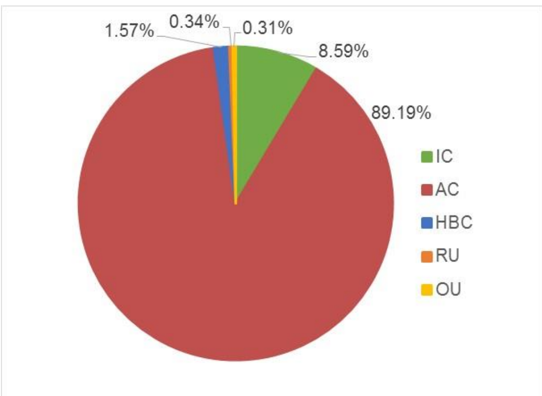

Figure 5.3: Distribution of mental health care services based on their utilization in 2013 [6]

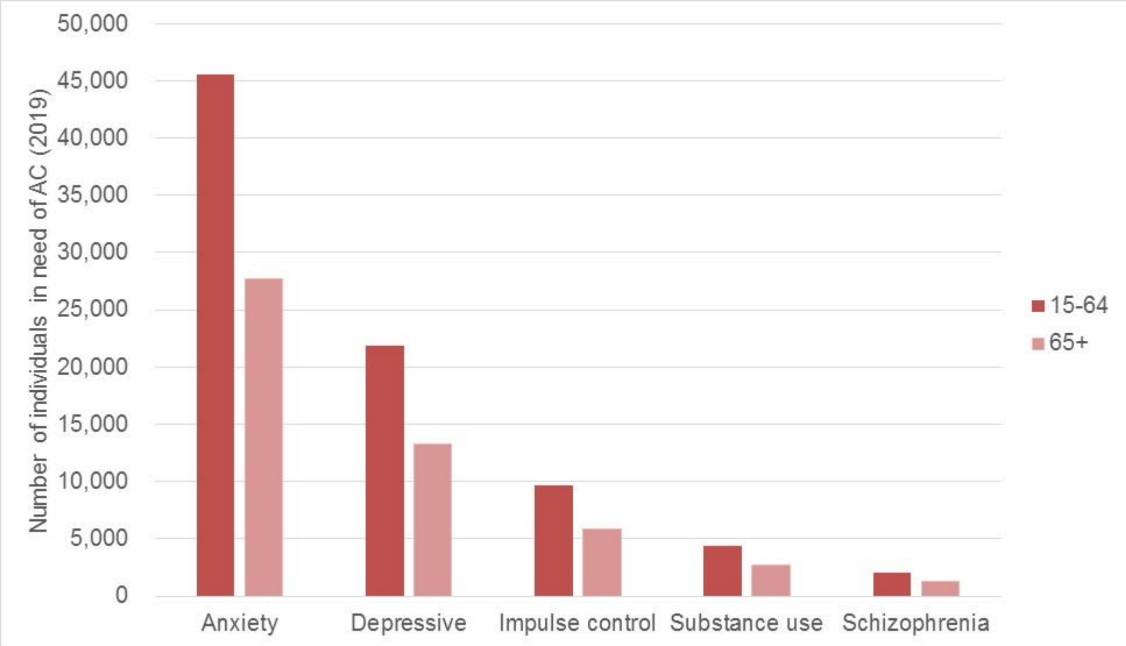

Figure 5.4: Number of individuals belonging to 15-64 and +65 age groups in need of AC in 2019

5.3 Planning contexts

5.3.1 Overview

In this section the different planning contexts explored to illustrate the usefulness of the proposed model are presented. In particular, three planning contexts are defined representing scenarios with potential interest for real DMs in the mental health care sector in Portugal. Thus, the model was used to explore how to reorganize the mental health care network in the following contexts: (i) when DMs aim at ensuring full demand satisfaction, while maximizing equity of access (Planning Context A); (ii) when DMs aim at minimizing costs while achieving equity targets (Planning Context B); and (iii) when DMs aim at maximizing equity dimensions and minimizing costs (Planning Context C).

One should bear in mind that the MHC model, by allowing the modelling of multiple policy objectives, is a key tool to be used so as to support planning under all these circumstances - not only when a single objective is pursued, but also when multiple key policy objectives need to be addressed.

Table 5.4 summarizes the planning questions and the aim for the three planning contexts considered in this case study. The three following sections explain in detail each one of the planning contexts including the adjustments made to the mathematical model (namely, the objectives selected and the additional constraints used).

Table 5.4: Planning questions and objective of the planning contexts under study

	Planning questions	Objective
A	How much would it cost to fully satisfy the demand?	Maximize EA
B	What is the lowest cost that ensures the achievement of all the equity targets?	Minimize Cost
C	What is the impact of the trade-off between cost and equity related objectives in the organization of the mental health care network?	Maximize EA, GE, ESU, EDU Minimize Cost

5.3.2 Planning Context A

5.3.2.1 Overview

Under this planning context, it is assumed that the DM aims to plan the mental health network so as to ensure full demand provision. To achieve this, the model is run by imposing an additional constraint that ensures full demand satisfaction (Constraint 5.1). In this situation, the geographical equity and both equities of utilization are already maximized (which corresponds to the value 0). Within this setting, in Planning Context A the equity of access is selected to be maximized, as represented in Figure 5.5, and the objective function is given by Eq. 4.3. The cost of satisfying all the demand is obtained, as well as the corresponding equity of access.

$$Q_{dpasljt} = 1 \quad \forall p \in P, a \in A, s \in S, l \in L : (s,l) \in M, (l,j) \in C, (d,l) \in F, t \in T \tag{5.1}$$

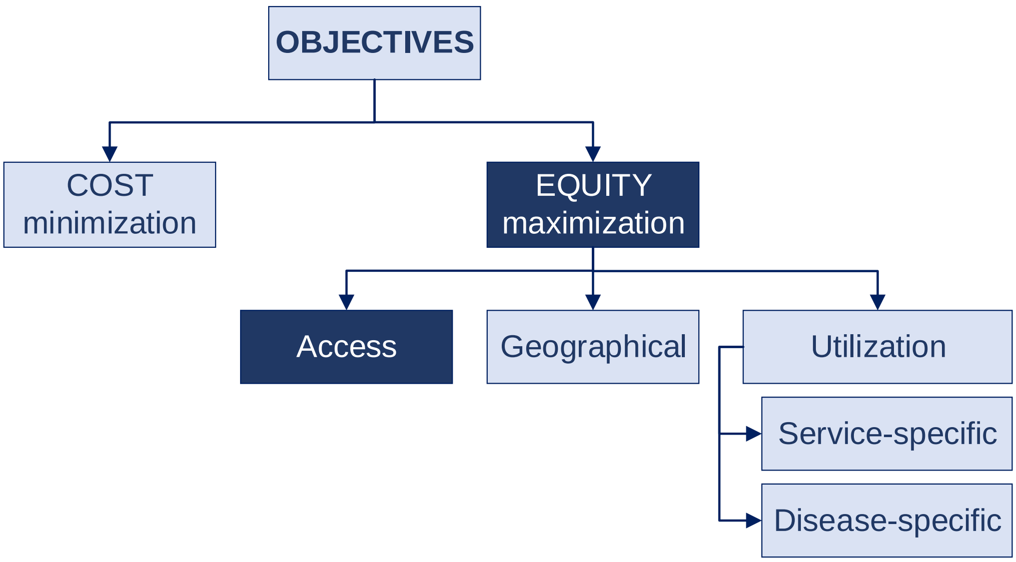

Figure 5.5: Objectives selected in Planning Context A

5.3.2.2 Results

Key results from this planning context are presented in this section, with information on: (i) where and which services should be opened and closed (Figure 5.6); (ii) which IC services should be used by which individuals in each county at the end of the planning horizon (Figure 5.7); (iii) which is the additional bed capacity one should invest over time (Table 5.5); (iv) how much capacity in terms of human resources (physicians and nurses) is needed for OU provision at the end of the planning horizon (Figure 5.8); and (v) what are the operational and investment costs associated with these changes (Table 5.6).

The mental health care network that corresponds to the network with the highest equity of access throughout the planning period is depicted in Figure 5.6. The opened services are identified with the respective coloured box with a black border and the closed services are identified with the respective faded coloured box.

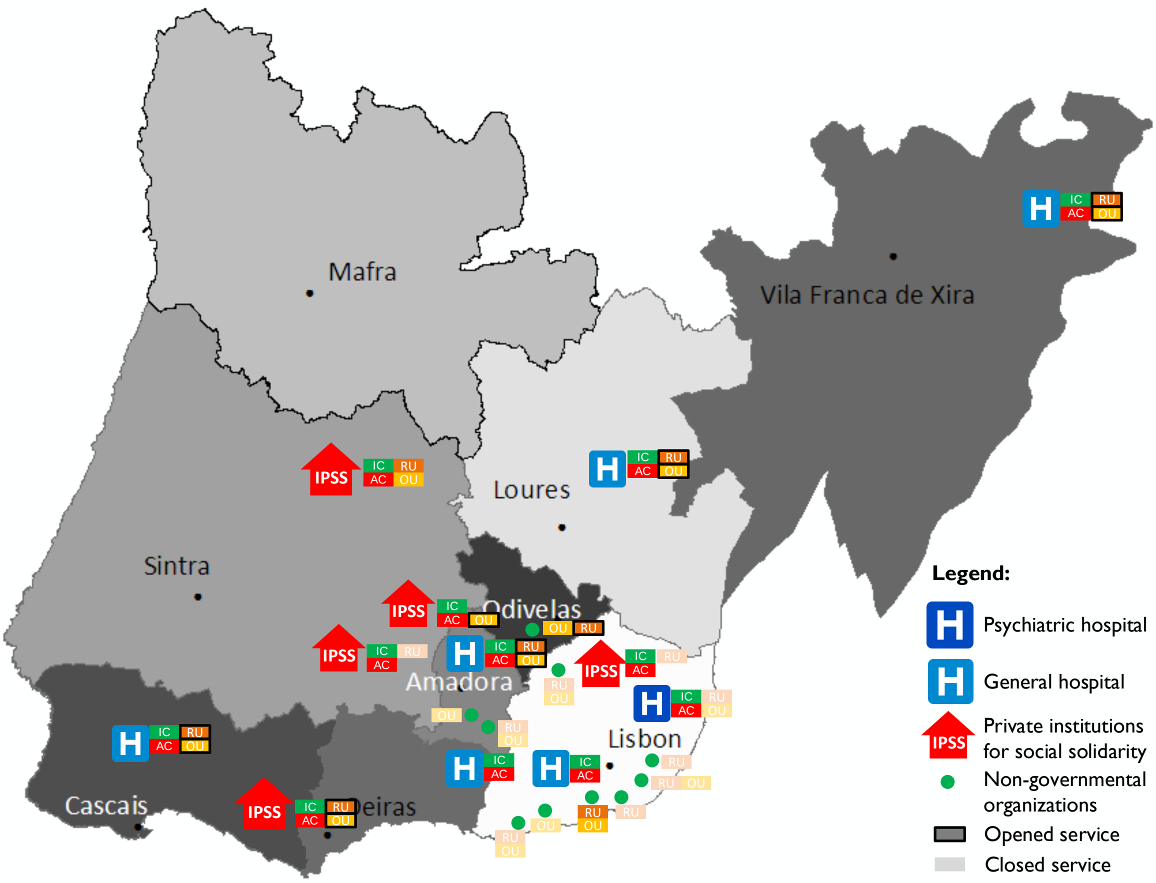

Figure 5.6: Opening and closure of mental health care services under Planning Context A. Legend: IC - institutional care, AC - ambulatory care, RU - residential unit, OU - occupational unit

It can be seen that only RU and OU services were opened and closed. As mentioned before, AC and HBC services cannot be opened or closed because they are provided within the scope of the primary care network, already established in Portugal. Regarding the closure of services, 9 RU services currently provided should be closed (7 in Lisbon, 1 in Amadora and 1 in Sintra) and 7 OU services (5 in Lisbon and 2 in Amadora). Concerning the opening of services, 6 RU and OU services should be opened. Particularly, in Cascais, Oeiras, Amadora, Loures and Vila Franca de Xira, both RU and OU services are opened. Furthermore, 1 RU and 1 OU services are also opened in Odivelas and Sintra, respectively.

One should however note that all these changes are towards the minimization of the total travel time for patients accessing services during the entire planning period. Since the closure and opening of services involves costs that are not being considered, this organization may not be the ideal solution to be implemented. Moreover, it is important to mention that the all the openings and closures of services occurred in the first period of the planning horizon (2017). This happens mainly due to three reasons: (i) services are only allowed to open or close once during the entire planning horizon; (ii) the objective function being minimized is the sum of the travel time over the three years, thus changes in the first year have stronger impact than in the other years; and (iii) there is not an abrupt change in the mental health care demand over time, which would justify changes in the second or third year.

Analyzing now in more detail the IC services, the allocation of mental health patients to existing IC services is presented in Figure 5.7. The coloured arrows indicate the institutions where the population located in each county (represented with a circle with the same colour) should receive the IC they need. One should note that patients will receive care in the closest available service, taking into account the capacity constraints, since the equity of access is being maximized.

It can be observed that not all the population from the same county receive care in the same institution. For instance, all the mental health patients from Mafra and Oeiras receive care in the same institution, whereas patients from Lisbon county receive care in 5 different institutions. This is expected since there is a maximum bed capacity in each location and some counties are more populated than others, thus having greater demand for care. However, if patients are redirected to the second closest location, it is not guaranteed that that they will stay there as that location may already be full with respective closest patients. This happens because the model aims at minimizing the total travel time for all patients, not on an individual level, during the entire planning horizon.

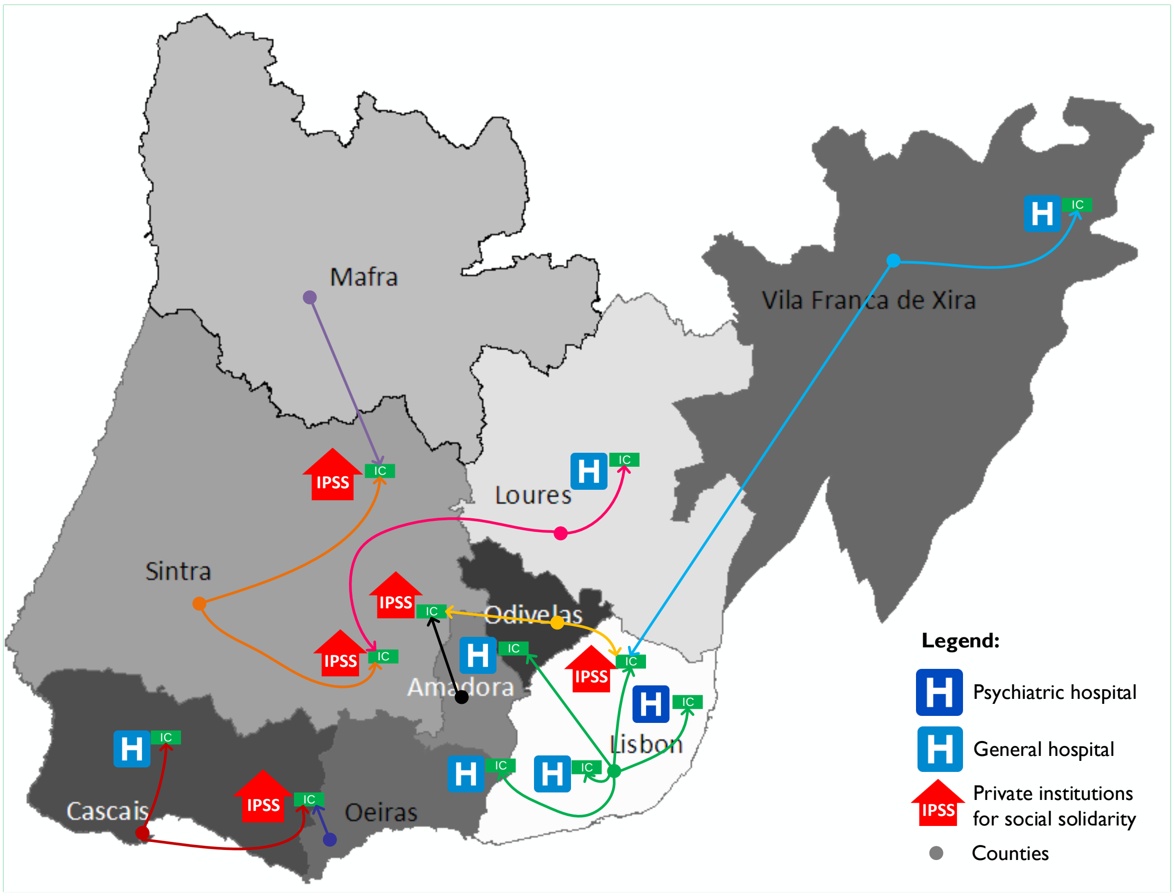

Figure 5.7: Allocation of patients requiring institutional care (IC) services at the end of the planning horizon under Planning Context A

Table 5.5 presents the number of new beds that are needed for IC and RU services over time, showing that a great investment in new beds is required in 2017. These results indicate that the current supply is far from being able to satisfy all the demand in the Great Lisbon region, and so the bed capacity should increase significantly to fulfil the whole demand. One should remind that most of the investment is planned for the first year due to the minimization of equity of access throughout the planning horizon. A more divided distributions of beds throughout time would be possible, but that would imply a worst performance for equity of access (that is influenced by the travel time of patients to services).

Table 5.5: Additional beds in which there is a need to invest over time under Planning Context A

	Additional beds		
Mental health service	2017	2018	2019
IC	885	12	13
RU	29	1	3

With respect to OU services, Figure 5.8 depicts the total number of hours of care to be provided by physicians and nurses in each OU service location at the end of the planning horizon (2019). It is possible to observe that the required number of hours of care strongly depend on the location due to the geographical differences for OU demand. One should remind that the numbers are used to distinguish different institutions in the same county (the geographical distribution of these institutions is represented in Figure 5.1).

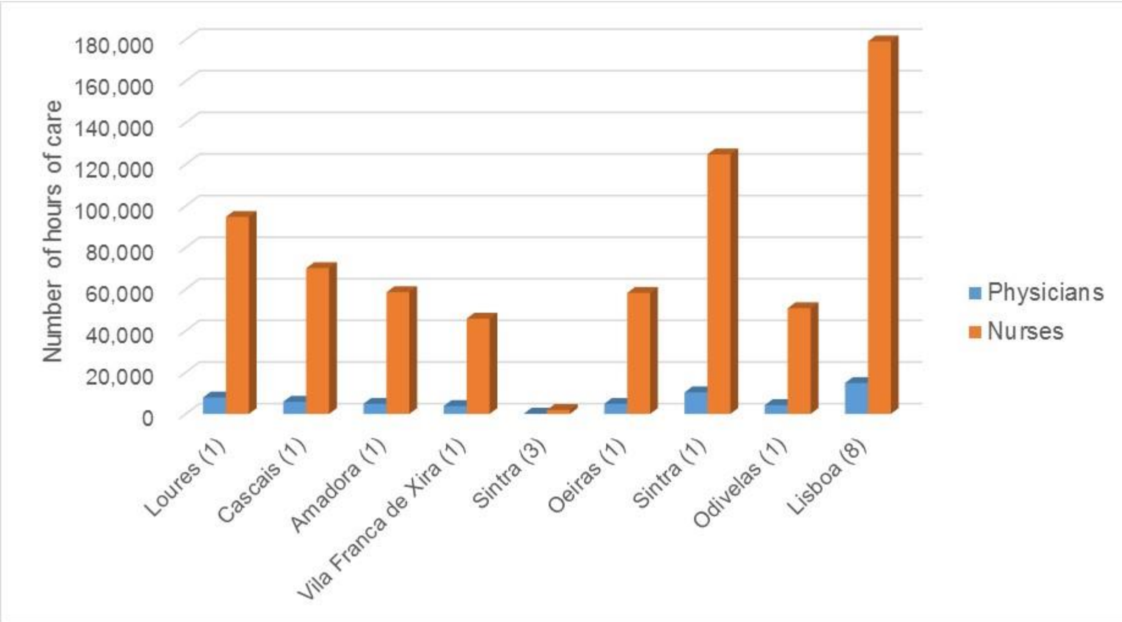

Figure 5.8: Number of hours of care to be provided by physicians and nurses for occupational unit (OU) provision at the end of the planning horizon under Planning Context A

The costs associated with the reorganization of the mental health care network so as to ensure full demand provision are presented in Table 5.6. It can be seen that the highest investment takes place at the beginning of the planning horizon (2017). This is an expected result since the investment is essentially related to the expansion in bed capacity (shown in Table 5.5) necessary to meet the demand. Regarding the operational costs, they are approximately constant over time since the number of installed beds and the number of patients receiving care do not vary significantly. The cost of fulfilling the whole demand is approximately 822 M€ for the entire planning period.

Table 5.6: Operational and investment costs associated with mental health care provision over time under Planning Context A

Costs (M€)	2017	2018	2019	2017-2019
Investment	19.08	0.26	0.32	19.67
Operational	266.19	268.53	268.88	802.60
Total	285.27	267.79	269.20	**822.25**

To sum up, the results show that the current supply is far from being enough to answer the mental health care demand in the Great Lisbon region.

5.3.3 Planning Context B

5.3.3.1 Overview

This planning context is relevant when the planner wants to reorganize the mental health care network so as to ensure the attainment of equity targets define by the DM at the lower possible cost. To do so, the cost objective is selected (Figure 5.9) and the objective function is given by Eq. 4.12 , which guarantees the minimization of operational and investment costs. Furthermore, the model is run by imposing the achievement of target levels of equity as constraints:

- EA: Constraint 5.3 ensures that the travel time per patient accessing mental health care services should not exceed the equity target defined for EA (Eq. 5.2) at the end of the planning horizon (t=3);

$$E_t^{EA} = \frac{TT_t}{\tau_t^{tot}} \quad \forall t \in T \tag{5.2}$$

$$E_{t=3}^{EA} \leq T^{EA} \tag{5.3}$$

- GE: Constraint 5.5 imposes that the proportion of patients belonging to each geographical area not receiving mental health care should not exceed the equity target defined for GE (Eq. 5.4) at the end of the planning horizon (t=3);

$$E_{dt}^{GE} = 1 - \frac{ID_{dt}}{niD_{dt}} \quad \forall d \in D, t \in T \tag{5.4}$$

$$E_{d(t=3)}^{GE} \leq T^{GE} \quad \forall d \in D \tag{5.5}$$

- ESU: Constraint 5.7 states that the expected proportion of patients in need of each type of mental health care service and not receiving it should not exceed the equity target defined for ESU (Eq. 5.6) at the end of the planning horizon (t=3);

$$E_{st}^{ESU} = 1 - \frac{IS_{st}}{niS_{st}} \quad \forall s \in S, t \in T \tag{5.6}$$

$$E_{s(t=3)}^{ESU} \leq T^{ESU} \quad \forall s \in S \tag{5.7}$$

- EDU: Constraint 5.9 defines that the expected proportion of patients belonging to each patient/disease group not receiving mental health care should not exceed the equity target defined for EDU (Eq. 5.8) at the end of the planning horizon (t=3).

$$E_{pt}^{EDU} = 1 - \frac{IP_{pt}}{niP_{pt}} \quad \forall p \in P, t \in T \tag{5.8}$$

$$E_{p(t=3)}^{EDU} \leq T^{EDU} \quad \forall p \in P \tag{5.9}$$

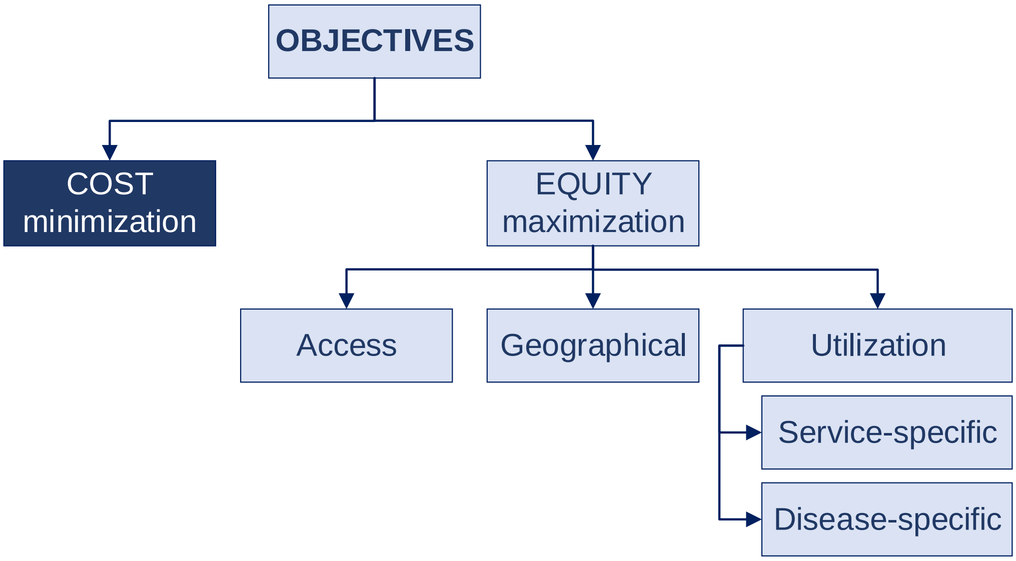

Figure 5.9: Objectives selected in Planning Context B

5.3.3.2 Results

Useful information for this planning context is generated by the model: (i) the opening and closure of mental health services (Figure 5.10); (ii) the evolution of bed capacity for IC provision over the period under analysis (Figure 5.11); (iii) the evolution of capacity in terms of human resources for all types of services (Figure 5.12); (iv) the evolution of equity levels (Figure 5.13); and (v) the costs associated with the reorganization of the network (Table 5.7).

The reorganization of the mental health care network in order to achieve all the equity targets at the end of the planning horizon is depicted in Figure 5.10. Results show some differences in the opening and closure of services when compared with the previous planning context. In particular, one can observe that three IC services should be closed: *Lisboa (1), Amadora (1)* and *Sintra (2)*. As in Planning Context A, all the openings and closures occurred during the first planning period (2017).

The RU and OU services closed in this planning context (identified with the respective faded coloured box) coincide with the respective ones closed in Planning Context A. In this planning context, 5 RU and OU services should be opened, one less than in the previous planning context. This result is expected, since in the present planning context the demand is not being fully satisfied. Regarding RU, three new services should be opened: *Loures (1)*, *Vila Franca de Xira (1)* and *Oeiras (1)*, coinciding with Planning Context A; and two in different locations: *Odivelas (1)* and *Sintra (3)*. Concerning OU, the services should be opened in the following locations: *Cascais (1)*, *Oeiras (1)*, *Amadora (1)*, *Loures (1)* and *Vila Franca de Xira (1)* - with no difference from the previous planning context. In total, the RU and OU services are delivered in 7 and 8 locations, respectively.

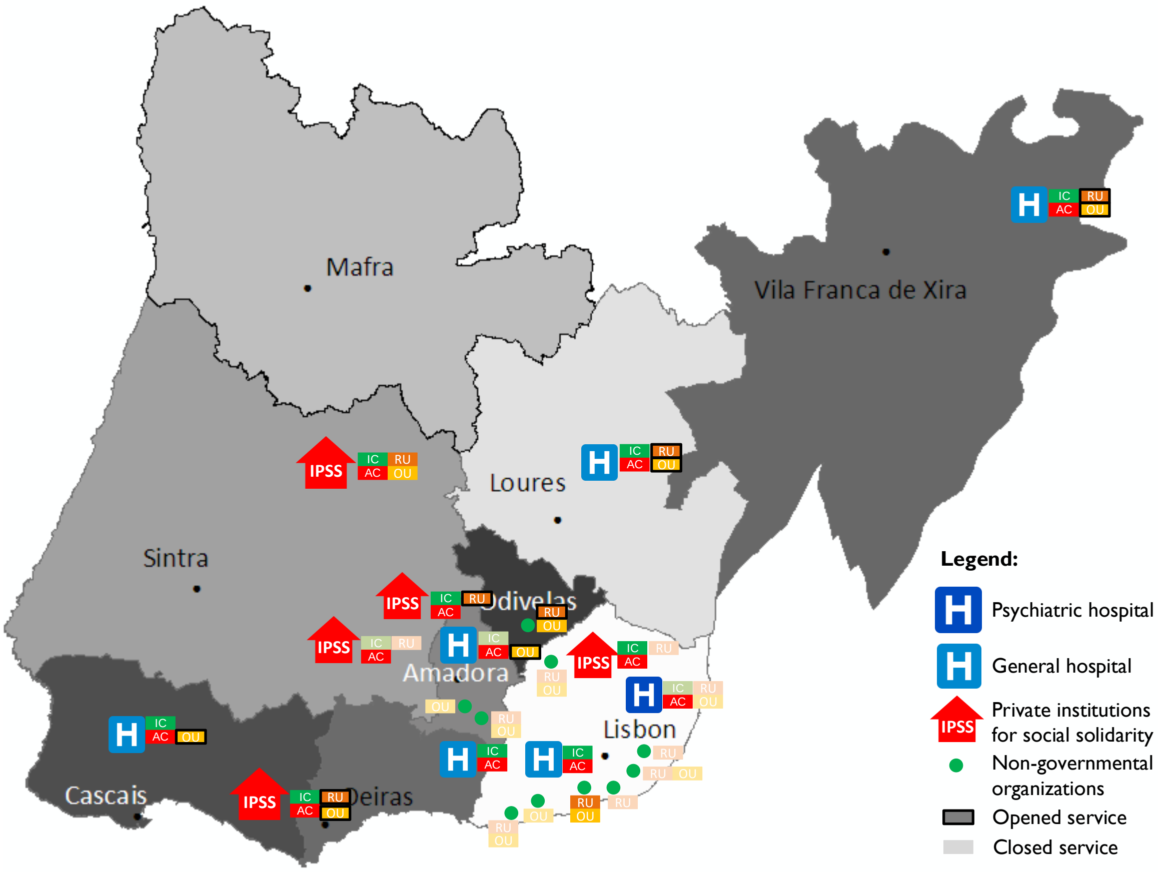

Figure 5.10: Opening and closure of mental health care services under Planning Context B. Legend: IC - institutional care, AC - ambulatory care, RU - residential unit, OU - occupational unit

The number of beds that are needed for IC provision in each location where this service is provided is depicted in Figure 5.11 over time. These results suggest that the bed capacity should increase in the end of the planning horizon (2019) so as to ensure that all the equity target levels are achieved. In fact, the total provision of IC beds goes from 1726 (in 2017) to 1825 (in 2019). It can be seen that during the first two years the provision of IC beds is approximately the same. This is because the model aims to minimize costs, and so the IC provision corresponds only to the satisfaction of the minimum level of demand imposed. Also, the maximum bed capacity allowed differs according to the type of provider (public or social). This explains the difference in the number of provided beds across institutions, e.g., between *Lisboa (2)* and *Sintra (1)*. Moreover, the number of beds provided in *Lisboa (3), Loures (1), Cascais (1)* and *Vila Franca de Xira (1)* institutions is the same for the three years. For this reason, the lines corresponding to these institutions overlap (yellow lines in the figure).

Figure 5.12 presents the total number of hours of care to be provided by physicians and nurses for each mental health care service (IC, AC, HBC, RU and OU) over time. A higher amount of human resources is required for AC and IC services, since these are the services with greatest demand. This is an expected result since the future demand was predicted based on the distribution of service utilization (see Figure 5.3).

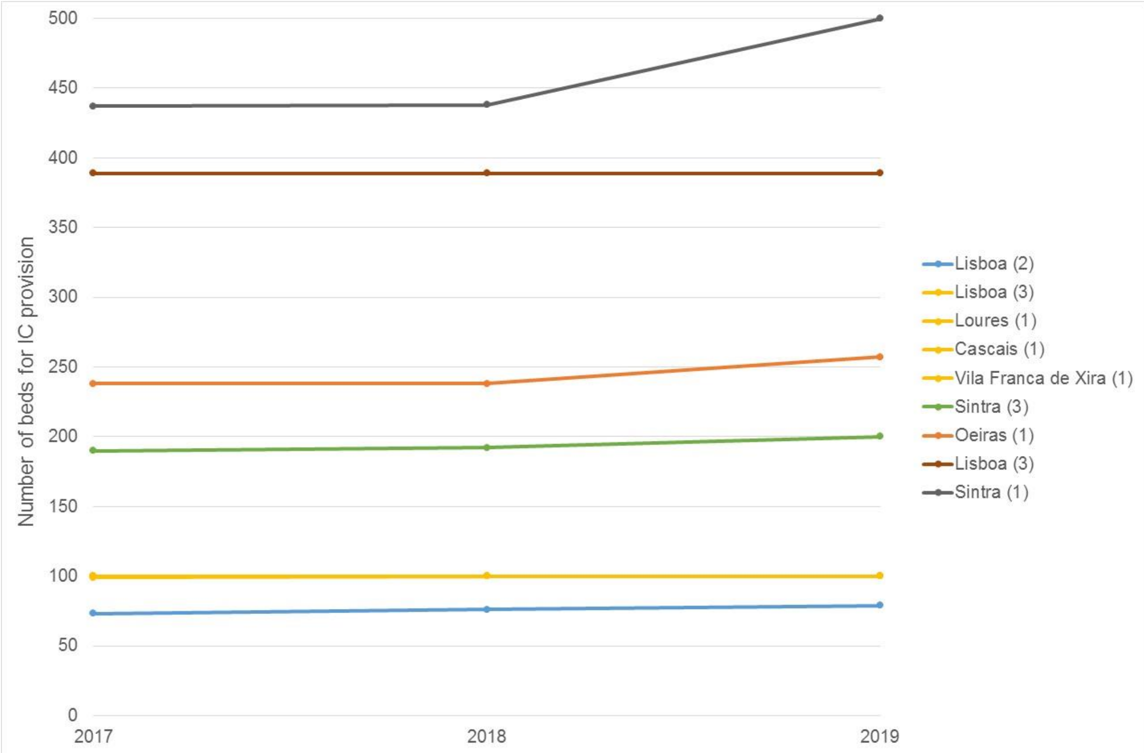

Figure 5.11: Evolution of bed capacity for institutional care (IC) under Planning Context B

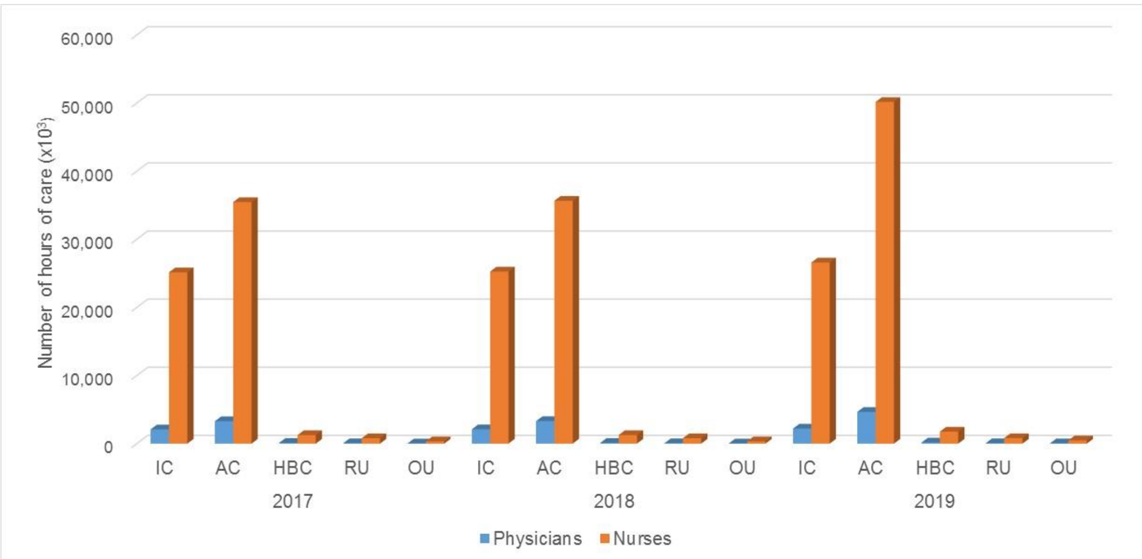

Figure 5.12: Evolution of the total number of hours of care to be provided by physicians and nurses for institutional care (IC), ambulatory care (AC), home-based care (HBC), residential unit (RU) and occupational unit (OU) provision under Planning Context B

The reported changes to the network of mental health care services are associated with the improvements in the equities measures so as to ensure the attainment of all the equity targets defined by the DM at the end of the planning horizon (2019). Particularly, the DM defined that in 2019 patients should not travel more than 25 minutes to access the care they need (corresponding to T^{EA} = 0.625). Furthermore, the DM also defined that the level of unsatisfied demand should not exceed: (ii) 30% across geographical areas (T^{GE} = 0.3); (ii) 30% across mental health care services (T^{ESU} = 0.3); and (iii) 60% across patient/disease groups (T^{EDU} = 0.6). To remind, a higher level of GE, ESU and EDU corresponds to higher levels of unsatisfied demand in the worst-off region, service and patient/disease group, respectively. So, GE, ESU and EDU equity improvements are achieved through the minimization of their value.

Figure 5.13 depicts the evolution of the several equity dimensions over the planning horizon. During the first two years, only the minimum level of demand has been satisfied since the model aims at minimizing costs. This explains why the GE, ESU and EDU levels remain constant in this period, with the value of 0.5. One can read that GE and ESU improve from 0.5 and 0.49 to 0.3 - attaining the respective targets (T^{GE} and T^{ESU}), and EDU from 0.5 to 0.39, achieving a value below the defined target (T^{GE}).

Regarding EA, its level is below the target during the entire planning period. As the other equities, the EA level is constant during the first two years for the same reason mentioned above. However, by contrast, EA worsens from 0.16 to 0.22 (value at the end of the planning horizon), which corresponds to an increase in the travel time from 7 minutes to 9 minutes (per patient). This is due to the fact that during the first two years only 50% of the demand is being satisfied, whereas in the third year 70% of the demand is satisfied, as a consequence of achieving all the equity targets. Therefore, at the end of the planning horizon, the total travel time increases, and consequently the value of EA too.

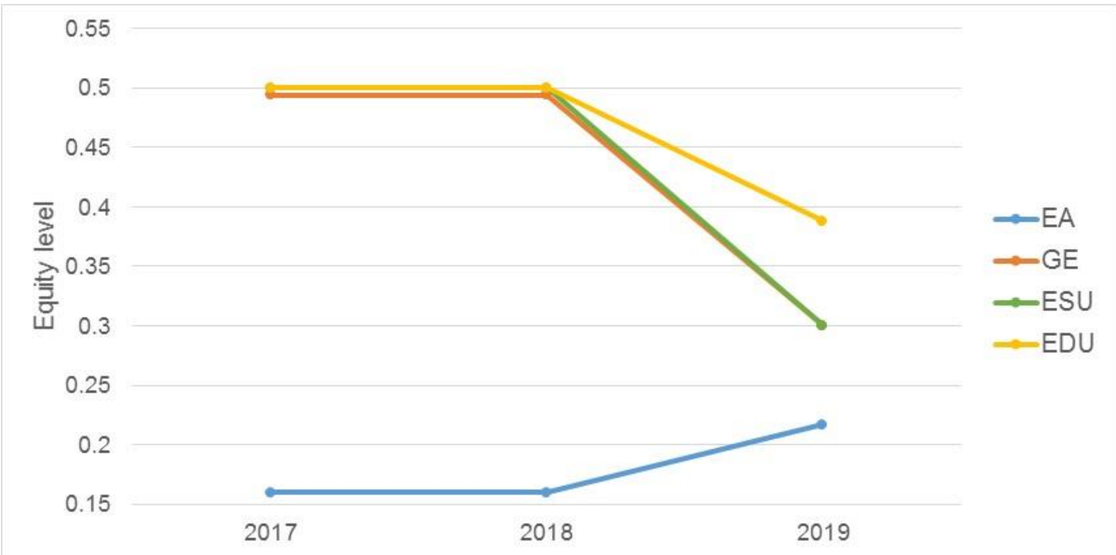

Figure 5.13: Evolution of equity levels over time under Planning Context B. Legend: EA - equity of access, GE - geographical equity, ESU - equity of service-specific utilization, EDU - equity of disease-specific utilization

Table 5.7 presents the minimum investment and operational costs that need to be incurred for reorganizing the mental health network in order to ensure the achievement of all the equity targets at the end of the planning horizon (2019). In the first year the investment cost is zero because the existing bed capacity is enough to satisfy the minimum level of demand. In the following year, there is a small investment due to an increase in demand caused by the population growth. In the last year the investment is higher because a greater demand is being satisfied as a consequence of the achievement of the equity target levels. The operational costs are approximately constant in the first two years and increase in the last year for the same reason. Accordingly, results show that the highest total cost takes place in the last year.

Table 5.7: Operational and investment costs associated with mental health care provision over time under Planning Context B

Costs (M€)	2017	2018	2019	2017-2019
Investment	0.00	0.17	1.86	2.03
Operational	139.23	139.93	188.22	466.68
Total	139.23	139.40	190.08	**468.71**

According to the table, achieving all the equity targets at 2019 requires a total cost of approximately 469 M€ for the entire planning period. Ideally one would compare this result with the budget currently available for delivering mental health care services in the Great Lisbon region. However, this information is not available because there is still no specific budget for mental health [7]. Nevertheless, according to Joint Action on Mental Health and Well-being [32], 5.2% of the health budget in Portugal is allocated to mental health, which corresponds approximately to 95 M€ for investments and operations per year in the Great Lisbon region, representing a total budget of 285 M€ for a three-period year.

Within this setting, the total cost of achieving all the equity targets is 60% higher than the budget available for that period. Therefore, the reorganization of the mental health care network associated with the attainment of the equity target levels defined by the DM is dependent on an increase of the available budget.

Comparison between Planning Contexts A and B

Figure 5.14 compares the Planning Contexts A and B in terms of the costs that need to be incurred for reorganizing the mental health care network so as to ensure full satisfaction of demand and the achievement of all equity targets, respectively. Obviously, the total cost for the entire planning period is higher in Planning Context A, since the whole demand is being satisfied for all the planning periods. By contrast, the total cost obtained under Planning Context B corresponds to satisfying only 50% of the demand in the first two years and 70% in the third year.

The highest total cost for Planning Context A occurs in the first year due to the expansion in bed capacity, whereas for Planning Context B it takes place in the last year due to the achievement of all the equity targets. Furthermore, one can see that for both planning contexts the total costs in each year are above the current budget available (per year) in the mental health care sector for the Great Lisbon region.

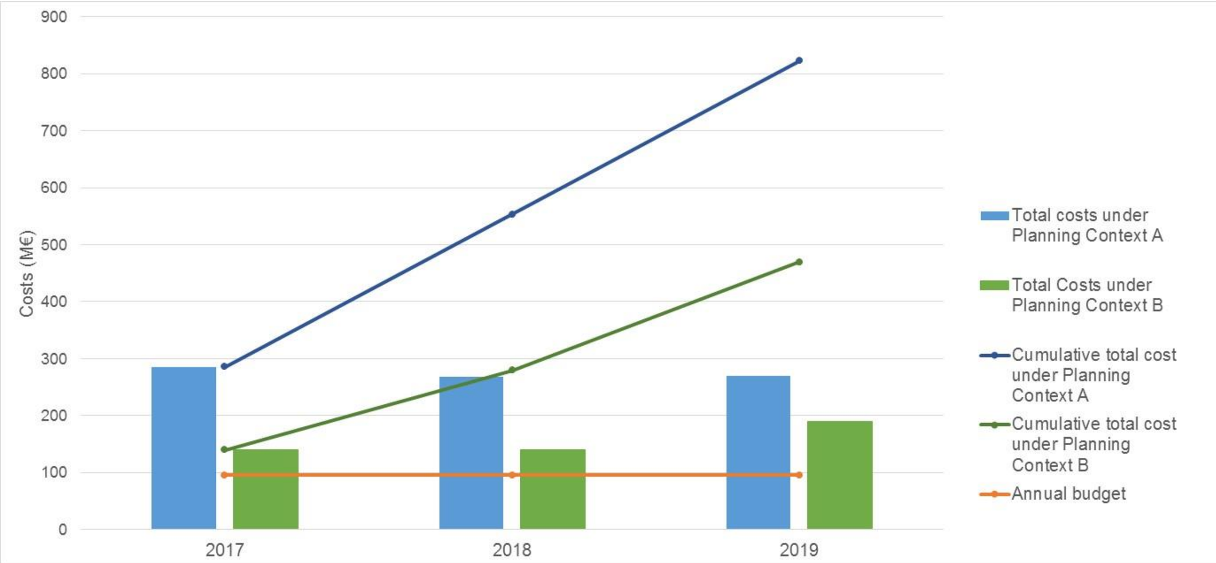

Figure 5.14: Costs comparison between Planning Context A and B

Summing up, the analysis of both Planning Contexts show a significant reorganization in the mental health care network of the Great Lisbon regions and increase in the installed capacity in terms of beds and human resources.

5.3.4 Planning Context C

5.3.4.1 Overview

In this planning context, it is explored how the current network of mental health care should evolve so that the multiple equity dimensions - EA, GE, ESU and EDU - are maximized and the cost is minimized. For this purpose, all the objectives are selected as objectives for the network planning as depicted in Figure 5.15, and the augmented ε-constraint method is used to explore the trade-off between them.

However, the computational time needed to run the model with the five objectives is very high. For this reason, the model is run only with three objectives: cost minimization, maximization of equity of access and maximization of other equity. Specifically, the model is run three times with the following objectives: (i) Cost, EA and GE (case C1); (ii) Cost, EA and ESU (case C2); and (iii) Cost, EA and EDU (case C3). The EA objective is included in all cases in order to ensure that patients receive the care they need as close as possible to their place of residence. As mentioned before, higher levels of GE, ESU and EDU correspond to higher levels of unsatisfied demand; and higher levels of EA correspond to a higher total travel time - meaning that equity maximization is achieved through the minimization of its value. The Pareto Frontiers obtained when running the multi-objective model to the county level in the Great Lisbon region in the 2016-2019 period for the three cases presented above are depicted in Figures 5.16, 5.17 and 5.18, respectively.

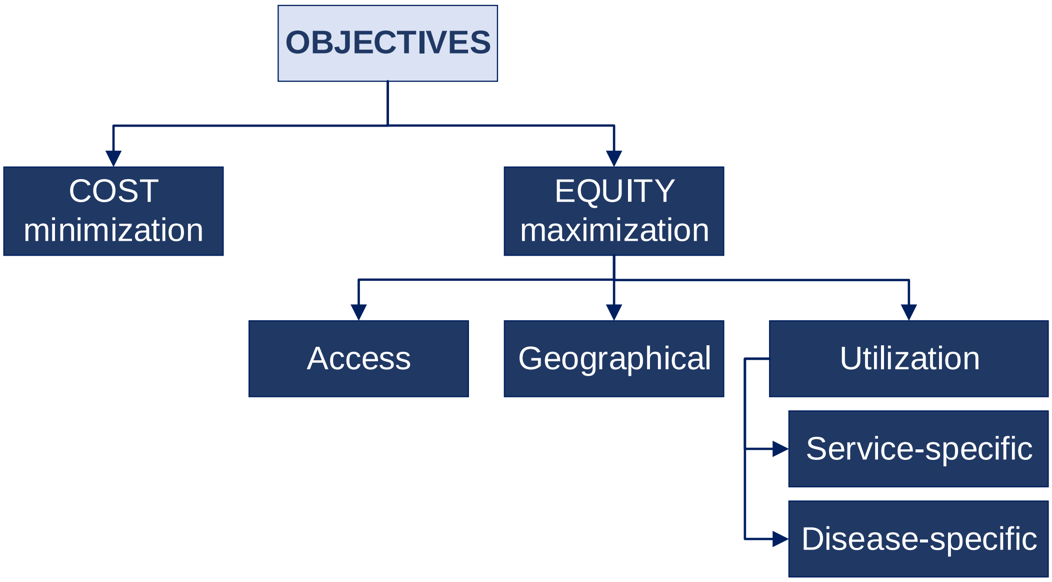

Figure 5.15: Objectives selected in Planning Context C

5.3.4.2 Results

Case C1

Figure 5.16 presents the Pareto Frontier obtained when running the MHC model with Cost, EA and GE objectives. All the solutions represented correspond to the (GE, Cost) solution with the minimum EA. Solution A represents the solution with the minimum total cost (418 M€) and the maximum level of GE (with the value 1), as measured by the level of unsatisfied demand in the geographical area with the lowest level of mental health care provision. The total cost of this solution is higher than the current budget available for mental health care provision in the Great Lisbon region for 2016-2019 period, which corresponds to 285 M€.

One one hand, as we move from solution A to E, the equity level decreases but the total cost remains constant. This means that it is possible to reorganize the mental health network so as to achieve lower levels of equity without increasing the bed capacity and thus incurring in more costs. Therefore, these solutions correspond to different configurations of the network across geographical areas.

On the other hand, as we move from solution E to I, the total cost of reorganizing the network increases, as well the mental health provision in the worst geographical area. This means that when the GE is equal to 0.5 in the worst geographical area, in order to improve the GE level, it is necessary to expand the bed capacity by investing in new beds and consequently increasing the costs. The maximum total cost (822 M€) and minimum equity level (with the value 0) is achieved under solution I, with the mental health network found under this solution allowing for full provision in all geographical areas, which corresponds to satisfying the whole demand (as observed in Planning Context A).

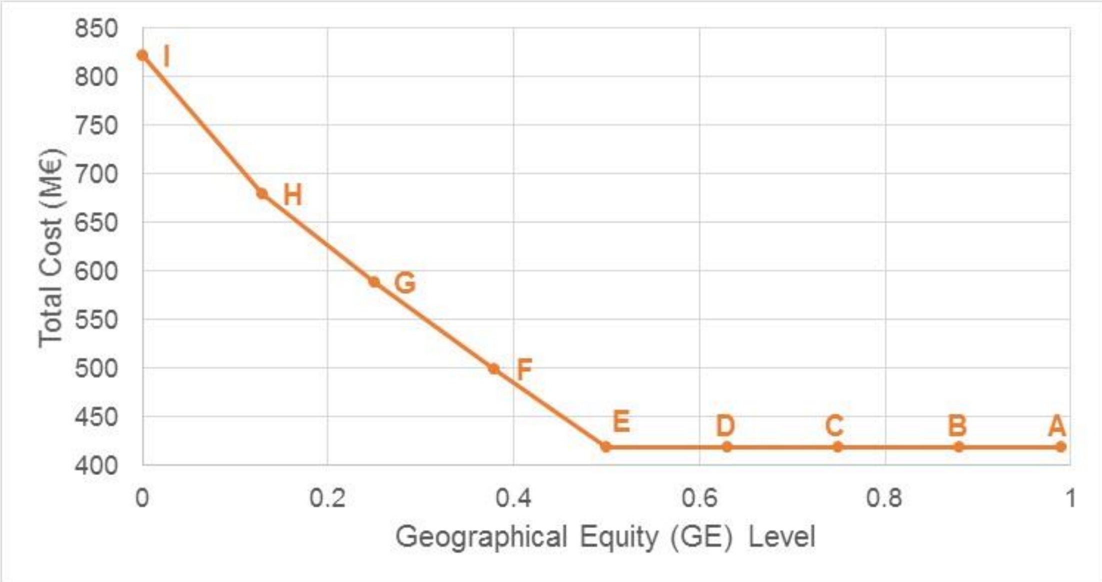

Figure 5.16: Pareto Frontier obtained when running the MHC model with Cost, EA and GE objectives

Case C2

The Pareto Frontier obtained when running the MHC model with Cost, EA and ESU objectives is depicted in Figure 5.17. All the solutions represented correspond to the (ESU, Cost) solution with the minimum EA.

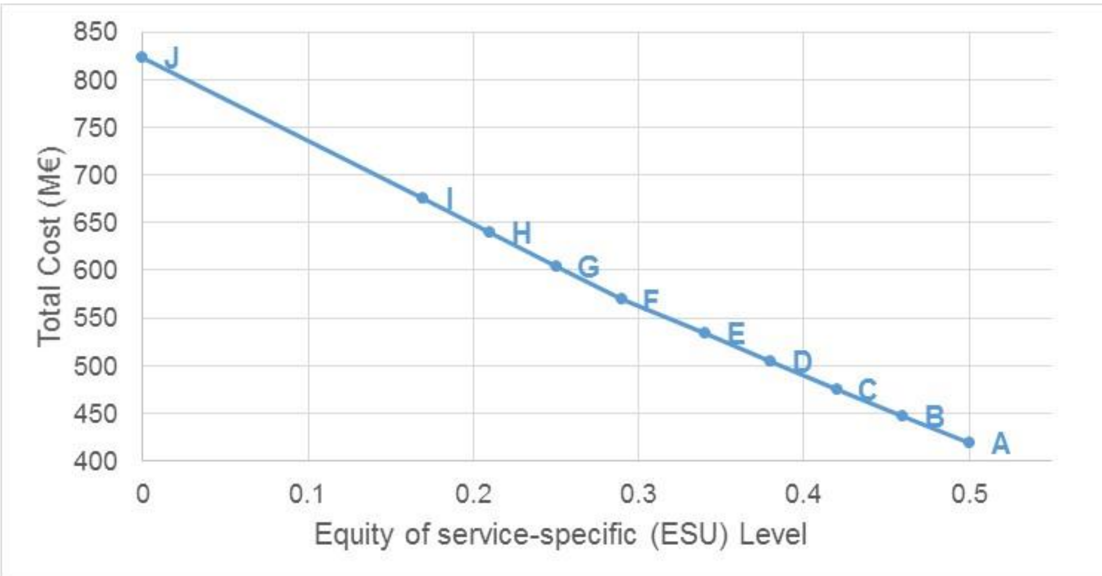

Figure 5.17: Pareto Frontier obtained when running the MHC model with Cost, EA and ESU objectives

Solution A represents the solution with the minimum total cost (418 M€) and a ESU level of 0.5, measured by the level of unsatisfied demand for the mental health care service with the lowest level of provision. As in the previous case, the total cost of this solution is higher than the available budget. The minimum level of satisfied demand per service that is imposed (Constraint 4.36) justifies the non existence of solutions with ESU levels higher than 0.5.

It can be observed that as the ESU level for the service with the lowest level of provision improves (i.e, its value decreases), the total cost associated with the reorganization of the mental health care network increases. On one hand, from solution A to I, to move from one solution to the next (decreasing in 0.04 the ESU level), the total cost increases approximately between 29 M€ and 36 M€. On the other hand, from solution I to solution J, the ESU level improves from 0.17 to 0, which corresponds to an increase of 147 M€ in total cost. Under solution J, the maximum total cost (822 M€) is achieved, along with a configuration of the mental health care network that ensures full provision of all mental health care services, and thus the satisfaction of all the demand.

Case C3

Figure 5.18 presents the Pareto Frontier obtained when running the MHC model with Cost, EA and EDU objectives. As in the previous cases, all the solutions represented correspond to the (EDU, Cost) solution with the minimum EA.

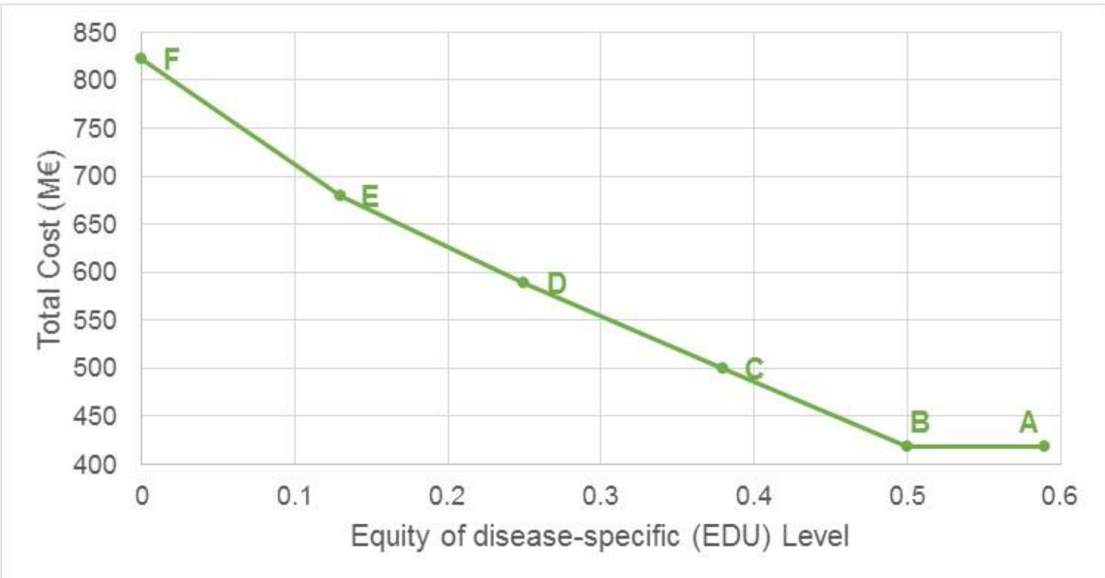

Figure 5.18: Pareto Frontier obtained when running the MHC model with Cost, EA and EDU objectives

Solution A represents the solution with the minimum total cost (418 M€) and a EDU level of 0.59, measured by the level of unsatisfied demand for the patient/disease group with the lowest level of provision. Solution B has a lower EDU level (0.5) when compared to solution A, but the same total cost, which indicates that for that value of total cost there is more than one configurations of the mental health care network, differing in the distribution of resources across patient/disease groups.

In order to obtain a EDU level lower than 0.5, a investment in new beds must be carried out, which increases the total cost. Particularly, as we move from solution B to F the mental health provision for the worst patient/disease group improves and consequently the total costs increase. The maximum EDU level (that corresponds to a 0 value) is achieved under solution F along with the maximum total cost of 822 M€, which corresponds to a configuration of the mental health care network that ensures that all the patient/disease groups receive the mental health care they need.

As seen, the solution with the minimum total cost for the three Pareto Frontiers obtained has a value of 412 M€, which is higher than the budget available for reorganizing the mental health care network in the Great Lisbon region (285 M€). This result makes clear that an increase in the budget is needed for improving the delivery of mental health care in this region.

Table 5.8 compares the solutions obtained for cases C1, C2 and C3 with a total cost of approximately 500 M€, which corresponds almost to the double of the current available budget. The equity values represented in bold correspond to the equity that is being maximized in each of the cases.

Table 5.8: Comparison of the results obtained under cases C1, C2 and C3

Case	Solution	Total Cost (M€)	EA	GE	ESU	EDU	Key changes in the network until 2019
C1	F	498.888	0.193	**0.375**	0.500	0.342	8 new services, 19 services closed
C2	D	503.929	0.136	0.983	**0.377**	0.464	10 new services, 21 services closed
C3	C	498.888	0.149	0.986	0.500	**0.375**	10 new services, 21 services closed

According to the table, it can be seen that solution F represent the option with less disparites across GE, ESU and EDU levels despite having the greater value for EA. Solutions D and C present the same changes in the mental health care network, but different equity levels, meaning that the distribution of capacity across geographical areas, services and patient/disease groups differs, as well as the allocation of patients to services. This type of analysis allows to explore how the improvements in one equity level compromises the other objectives - the same level of cost can be obtained with completely different network configurations; for instance, solution F obtained from case C1 represents a network of mental health care that ensures that the worst-off region only has 37.5% of unsatisfied demand, whereas solution C from case C3 has regions with almost 100% of unsatisfied demand, but with lower levels of unsatisfied demand for the worst-off patient/disease groups. Accordingly, Pareto Frontiers are very useful to guide the planning, as DMs can select his/her most preferred solution.

5.3.5 Sensitivity analysis

As an attempt to explore the impact of uncertainty on planning decisions, a sensitivity analysis to Planning Context B is employed - with this corresponding to the base case. Given the limitations of the data in use, a sensitivity analysis was carried out to evaluate the impact of changing key parameters on the model results. Specifically, sensitivity analysis was performed on the following parameters:

- The demand for all types of mental health care services (IC, AC, HBC, RU and OU), because of the uncertainty associated with forecasts, which depend on the prevalence rates of mental disorders that have already a high level of uncertainty associated;
- Length of stay (LOS) of IC and RU services, because it is known that there are wide variations in the LOS among patients.

Table 5.9: Results of Planning Context B obtained with sensitivity analysis on the: (i) demand for mental health care services and (ii) length of stay (LOS)

			Demand			LOS	
		Dem 1	Base case	Dem 2	LOS 1	Base case	LOS 2
Parameter values		-5%	–	+5%	18 (IC) 57 (RU)	19 (IC) 60 (RU)	20 (IC) 63 (RU)
Total bed capacity	IC	1734	1823	1915	1732	1823	1921
	RU	247	233	245	244	233	240
Opening of services	IC	0	0	0	0	0	0
	RU	6	5	5	6	5	5
	OU	5	5	5	4	5	4
Closure of services	IC	2	3	2	3	3	2
	RU	9	9	8	9	9	9
	OU	8	7	8	8	7	8
Equity levels	EA	0.158	0.159	0.160	0.158	0.159	0.160
	GE	0.30	0.30	0.30	0.30	0.30	0.30
	ESU	0.30	0.30	0.30	0.30	0.30	0.30
	EDU	0.39	0.40	0.53	0.37	0.40	0.58
Total Cost (M€)		447.068	469.413	492.412	466.582	469.413	472.740

Results in Table 5.9 show that the total bed capacity that should be installed in the Great Lisbon region in 2019 is sensitive to changes in the demand and LOS. Consequently, the total cost also shows to be sensitive to changes in these parameters, with higher costs being incurred for satisfying higher levels of demand (as expected).

Also, the locations for mental health care services are not robust to small changes in these parameters. For instance, a decrease of 5% in demand (case ‘Dem 1’) justifies the closure of 2 IC services instead of 3 (as happens in case ‘Base’). However, decreasing the LOS by one and three days in IC and RU services, respectively, results in closing the three IC services as in the case ‘Base’.

Furthermore, results show that the GE and ESU levels are insensitive to changes in the demand and LOS, and this happens due to the binding constraints related to the achievement of the equity targets defined by the DM. However, the EA and EDU levels vary below the value of the respective equity target, with lower equity improvements (corresponding to higher equity levels) being achieved for higher levels of demand. Summing up, these results show that the model outputs are sensitive to changes in the demand and LOS parameters, which indicates that their estimation should be done carefully.

5.3.6 Computational results

The computational results obtained when applying the MHC model for all the Planning Contexts under analysis are presented in Table 5.10. For cases C1, C2 and C3 the computational results obtained refer to the solutions F, D and C, respectively. It can be observed that optimality gaps equal to 0% are reached for all cases.

Table 5.10: Computational results

	Total equations	Total variables	Integer variables	Iterations	CPU (s)	GAP(%)
A	19,095	35,183	333	4504	1.26	0
B	17,877	35,243	333	7756	2.31	0
C1	17,901	35,271	333	6553	1.59	0
C2	17,901	35,271	333	4000	1.52	0
C3	17,901	35,271	333	4888	1.72	0

Chapter 6

Conclusions and Future Work

6.1 Conclusions

Nowadays, the planning of mental healthcare networks represents a health policy priority across European countries. There has been a worldwide awareness on this matter mainly due to the major demographic, social and economic changes that European countries are currently facing - population ageing, increase in the prevalence of mental disorders and severe budget cuts due to the current economic crisis.

Within this context, mathematical programming models have been proposed to aid health care planning in general. However, these models have been developed mainly in other health areas and specific applications for mental health are still scarce. Within this setting, one can argue that if mathematical programming models shown to be useful to support planning decisions in the health care sector in general, they have potential to be also used in the mental health care sector.

The aim of this thesis is thus to develop a mathematical programming model - MHC model - to aid health planners in the management, designing and planning of networks of mental health care services, both at a strategical and tactical level, within the context of NHS-based countries. Estimates on future demand for mental health care are built based on the characteristics of the population with potential need of such care, and are integrated in the MHC model.

In particular, this model supports mental health planning in terms of location of services, capacity planning and allocation of patients to services, while ensuring the attainment of multiple objectives considered relevant in the mental health care sector. These multiple objectives may be jointly considered depending on the planning circumstances. The proposed model provides information related to: (i) the opening and closure of mental health care services; (ii) the capacity, in terms of beds and human resources, needed in each service and location; (iii) the geographical distribution of the capacity across services and patient/disease groups; and (iv) the impact of the changes in the mental health care network on cost and equity-related objectives.

In summary, the MHC model was implemented in GAMS aiming to aid the planning of the entire range of mental health care services (IC, AC, HBC, RU and OU) while accounting for: a cost objective and multiple equity objectives - equity of access, geographical equity, equity of service-specific utilization and equity of disease-specific utilization. The MHC model by allowing the modelling of multiple objectives is a key tool to be used to support planning under different circumstances - no tonly when a single objective is pursued, but also when multiple key policy objectives need to be addressed.

This thesis thus contributes to the literature by: (i) predicting future demand for mental health care services in order to be integrated in mathematical programming models for planning purposes; and (ii) proposing a mathematical programming approach to support planning decisions in the mental health care sector (a health sector not widely studied in the literature) within the context of NHS-based countries. The mathematical programming model not only contributes by considering the specificities of the mental health care sector, but also by: (i) considering the multi-service nature of mental health care; (ii) accounting for multiple policy objectives relevant in this sector; and (iii) exploring the impact of uncertainty on planning decision through sensitivity analysis.

The MHC model was applied to the Great Lisbon region in Portugal for the 2016-2019 period under three planning contexts that represent scenarios with potential interest for real DMs in the mental health care sector in Portugal. Particularly, the model was used to explore how to reorganize the mental health care network in the following contexts: (i) when DMs aim at ensuring full satisfaction; (ii) when DMs aim at achieving equity targets; and (iii) when DMs aim at maximize equity dimensions and minimize costs.

The results obtained through the application of the MHC model to the Great Lisbon region show that the current mental health provision in this region is not adequate to meet its population needs, and the budget available for investment and operations is not enough to provide care with adequate levels of equities.

According to the results obtained under Planning Context A, the current supply is far from being enough to answer the mental health care demand in this region. In order to fulfil the whole demand, the bed capacity should increase significantly, and so a great investment is required. The total cost of satisfying all the demand is much higher than the current available budget.

Furthermore, the budget available is even not enough to achieve the equity targets under Planning Context B. The expenditure of obtaining the desired levels of equity is 60% higher than the budget. Therefore, the reorganization of the mental health care network associated with the attainment of all the equity targets defined by the DM is dependent on an increase of the budget. Also, the sensitivity analysis results demonstrate the relevance of considering uncertainty when planning the reorganization of a mental health care network, which approximates the model of reality, since planning decision in real life are taken under an uncertain environment.

Under Planning Context C, is explored the trade-off between cost and equity-related objectives in the organization in the mental health care network. The Pareto Frontiers obtained when running the model with multiple objectives prove to be very useful to guide the planning, as DMs can select his/her most preferred solution.

In conclusion, running the model under these different planning contexts demonstrates that the model performs efficiently in computational terms, which supports its use to aid DMS with planning. Also, the sensitivity analysis performed shows that the model outputs are sensitive to changes in the demand and LOS parameters, which suggests that proper attention should be given to their estimation. Thus, the impact of demand and uncertainty in the planning of a mental health care network should be analysed with a stochastic approach. Nevertheless, taking into account the information retrieved from the application of the MHC model, the DM is able to make more informed decisions when planning mental health care networks.

6.2 Future Work

At the end of this thesis, there are several developments that can be made in the future:

- Build more accurate estimates on future demand for mental health care services based on the characteristics of the population with potential need for mental health care. These estimates should be disaggregated by (i) age groups, since mental health patients with different ages require different types of care; and (ii) the type of mental disorder, since there is a wide variation in the amount of services required across different patient/disease groups;

- Extend the application of the MHC model to all the regions in Portugal (*Norte, Centro, Alentejo, Lisbon and Tagus Valley and Algarve*) and to the mental health sector within a NHS-based system in another country. Also, the spacial resolution of the model can be improved, i.e, consider a smaller area as the geographic unit of analysis, for instance *Freguesias* instead of *Concelhos*;

- Ensure the applicability of the MHC model in real life context, in particular in the mental health care sector in Portugal and verify with DMs in the area whether new features considered relevant to the network planning can be added to the MHC model. For instance, different planning objectives can be introduced, such as maximization of socioeconomic equity and maximization of health gains;

- Apply the MHC model for different planning contexts. For instance, explore how the current provision of mental health care can be improved (which equity levels can be achieved) with the current available budget. Also, the model can be applied for longer-term planning purposes (depending on whether data on demand for mental health care is available for longer periods);

- Extend the MHC model to account for different types of human resources, such as social assistants and occupational therapists, given the importance of multidisciplinary in the mental health area. Also, different mental disorders, such as demencia and alzheimer can be included, depending on the availability of the prevalence rate of these diseases;
- Adapt the MHC model so as to support also the planning of the Child and Adolescent Psychiatric Network. Accounting for both networks will allow a more detailed analysis of the mental health care system in Portugal ;
- Explore alternative approaches to deal with the multiple objectives, for instance the goal programming or weighting methods;
- Develop a stochastic model to analyse the impact of demand and supply uncertainty in the planning of a mental health care network;
- Integrate the model with a Decision Support System, in order to interactively assist DMs. Decision Support Systems with user-friendly interfaces enable the use of mathematical programming models by users without specific knowledge on these models, as usually is the case of health planners.

All in all, this thesis addresses the gap that exists in the area of mental health care planning, given that few studies exist proposing methods to support planning decisions in this area. The usefulness and applicability of the model is shown through its application to mental health care sector in the Great Lisbon region in Portugal under different contexts.

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