LTCPlanner: A Decision Support System to aid the management and planning of networks of Long-Term Care Services

Mariana Neves Costa

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Supervisors: Prof. Teresa Sofia Sardinha Cardoso de Gomes Grilo
Dr. Cristina Maria Pires Ribeiro Gomes

Examination Committee:

Chairperson: Prof. Cláudia Alexandra Martins Lobato da Silva
Supervisor: Prof. Teresa Sofia Sardinha Cardoso de Gomes Grilo
Members of the Committee: Prof. Susana Isabel Carvalho Relvas

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Abstract

New data indicates that the European population is growing old, with a rising prevalence of chronic diseases, creating an increasing demand for Long-Term Care (LTC). Nevertheless, the current supply of LTC is still scarce in many of these countries. A proper planning of LTC resources is thus a priority across European countries, as in Portugal. This requires the development of decision support systems that can potentially assist policy makers in the organization of LTC networks. In fact, mathematical programming models have been developed to aid in these tasks, but their formats and interfaces are not appropriate to interactively assist policy makers.

This study aims to develop a decision support system – *LTCPlanner* – to aid real health policy makers in the management and planning of networks of LTC services. The proposed tool integrates existing mathematical programming models with user-friendly interfaces. It is designed so as to enable the use of existing mathematical planning models by real health policy makers without requiring specific knowledge about these models. Specific functionalities of the tool include assisting in: i) inputting the data required to run the model; ii) interactively defining the objectives space, that can include single or multiple objectives; iii) defining the constraints space; iv) analysing the LTC network configurations obtained when different objectives are valued; and v) analysing model outputs through web enabled mapping tools, graphs and a summary report.

The applicability of the tool is shown through its application within the LTC sector of the Portuguese Great Lisbon region under different planning contexts.

Key words: Health care, Long-Term Care, Mathematical Programming Models, Decision Support Systems, Network Planning.

Resumo

Projeções recentes mostram que a população Europeia está a envelhecer, que há aumento da prevalência de doenças crónicas levando a um incremento na procura de Cuidados Continuados (CC). No entanto, a oferta disponível de CC é escassa na maioria destes países. Neste sentido, o planeamento adequado dos recursos existentes no setor dos CC é uma prioridade na Europa, como em Portugal. Este planeamento requer o desenvolvimento de sistemas de apoio à decisão que auxiliem os responsáveis pela organização de redes de CC. Têm sido desenvolvidos modelos de programação matemáticos para auxiliar nessas tarefas, mas os seus formatos e interfaces não são apropriadas para apoiar os decisores.

Neste estudo é apresentado um sistema de apoio à decisão – *LTCPlanner* – para apoiar os responsáveis pela gestão e política de saúde no planeamento de redes de CC. A ferramenta integra modelos de programação matemática existentes com interfaces de fácil utilização permitindo a utilização destes modelos por decisores reais no setor da saúde, sem a necessidade de conhecimento específico sobre os mesmos. Funcionalidades da ferramenta incluem auxiliar na: i) introdução dos dados necessários para correr o modelo ii) definição do espaço de objetivos, podendo incluir um ou múltiplos objetivos; iii) definição do espaço de constrangimentos; iv) análise das configurações da rede de CC obtidas aquando da valorização de diferentes objetivos; v) Analisar os resultados através de ferramentas de mapeamento da web, gráficos e um relatório.

A ferramenta é aplicada no sector dos CC em Portugal na região da Grande Lisboa sob diferentes contextos de planeamento.

Palavras-Chave: Cuidados médicos, Cuidados Continuados, Modelos de Programação Matemática, Sistemas de apoio à decisão, Planeamento da Rede.

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List of Abbreviations

ACES - Groups of primary care centres (Agrupamentos de Centros de Saúde)

ACSS - Central Administration for the Health System (Administração Central do Sistema de Saúde, I.P.)

ADL - Activities of Daily Living

CC - Convalescence Care

DM - Decision Maker

DSS - Decision Support Systems

EA - Equity of Access

EU - Equity of Utilization

GAMS - General Algebraic Modelling System

GE - Geographical Equity

GUI - Graphical User Interface

IADL - Instrumental Activities of Daily Living

LOS - Length of Stay

LTC - Long-Term Care

LTMC - Long-Term and Maintenance Care;

MACBETH - Measuring Attractiveness by Category–Based Evaluation Technique

MILP - Mixed Integer Linear Programming

MTRC - Medium-Term and Rehabilitation Care

NHS - National Health Service

OECD - Organisation for Economic Co-operation and Development

PC - Palliative Care

RHAs - Regional Health Administration

RNCCI - National Network of Long-term Care (Rede Nacional de Cuidados Continuados Integrados)

RNCP - National Palliative Care Network (Rede Nacional de Cuidados Paliativos)

SE - Socioeconomic Equity

VBA - Visual Basic for Applications

1. Introduction

Nowadays, European countries face major demographic and social changes. New data indicates that population is growing old, the share of population aged above 65 within the European countries has risen from 8.9% to 17.7% between 1950 and 2011. Which together with a rising prevalence of chronic diseases, and with a significant increase on female employment lead to an increase on the demand for Long-Term Care (LTC) (Barros et al. 2011) (OECD, 2013b).

Long-term Care is defined by the Organisation for Economic Co-operation and Development (OECD) in OECD (2013a, p10) "*as a range of services required by people with a reduced degree of functional capacity, physical or cognitive, and who are consequently dependent for an extended period of time on help with basic activities of daily living (ADL)*". LTC combines basic medical services (nursing care, prevention, rehabilitation and palliative care), and lower-level care services related to ADL or help with instrumental activities of daily living (IADL) (OECD, 2013a). The main goal of LTC is to maintain or improve functionality of all dependent and chronic patients or in terminal stage, regardless of their age. The principles are to rehabilitate, readapt and reinsert (OECD, 2013b)(Ministry of Health, 2015d).

Regarding the provision of LTC within the European countries there are two categories that can be distinguished: informal and formal care (OECD, 2013b). The informal carers are mainly family members or friends that provide help with ADL or/and IADL. Formal caregivers are paid workers who provide home-based or institutional care (OECD, 2013b). Among the European context, the Southern European countries (among which is Portugal and Italy) there's a strong culture of informal care, whereas in Northern countries there is a greater share of formal LTC services (OECD, 2013b).

Concerning LTC provision in Portugal, for a while, the Portuguese provision of formal LTC has been neglected. In fact, family and charity institutions (like *Misericordias*) have been the only possible answers in this sector until recent years (Instituto da Segurança Social, 2014). Demographic changes within Portugal - increase in the elderly segment of the population, increase on the number of people with chronic diseases, increase of women employment and migration of young family members to urban areas – led to a lack of informal care providers (Barros et al., 2011).

In this line of thought, the Portuguese National Network of Long-term Care (*Rede Nacional de Cuidados Continuados Integrados*, RNCCI) was created in 2006 within the scope of the Ministry of Health and the Ministry of Labour and Social Solidarity (Ministry of Health, 2006). Different typologies of services are provided within this network, namely, institutional care, home-based care and ambulatory care services, Regarding, inpatient services, these include the following typologies: convalescence care (CC) units, medium-term and rehabilitation care (MTRC) units, long-term care and maintenance care (LTMC) units and palliative care (PC) units (Ministry of Health, 2015b).

The LTC provision within this network has been improving over the years, for instance by the end of

2014 the total number of beds available was of 7160, 7.8% more than the previous year (Central Administration of the Health System, 2015). But there's still evidence of a clear lack of supply of LTC services to meet the increasing demand for LTC (Barros et al., 2011). In fact, the waiting list for receiving LTC within the RNCCI was of 844 patients in the beginning of 2015 (Central Administration of the Health System, 2015).

There has been a worldwide awareness on this matter, leading to high pressures and huge challenges concerning the development and improvement of LTC provision either in Portugal or in many other countries in the European Union. Within this context, a proper planning and use of LTC resources is a priority for these countries. The development of methods and Decision Support Systems (DSS) that are able to assist policy makers and planners in the organization of networks of LTC is one of the answers to this concern. In fact, mathematical programming models have been developed to aid in these tasks, but their formats and interfaces are not appropriate to interactively assist policy makers (Brailsford & Vissers, 2011) (Ritrovato et al. 2015).

Regarding the studies proposing the development of tools to aid health care planning, several authors have been developing mathematical programming models to support location-allocation decisions in the health care sector in general (Brailsford & Vissers, 2011). In particular, different types of mathematical programming models have been developed in the area for that purpose, namely: single and multi-objective models (see, for instance, Mitropoulos et al. (2006)); single and multi-service models (see, for instance, Teshebaeva & Jain (2007) as an example of a multiple service approach); and, deterministic and stochastic models (an example of a deterministic model is presented in Syam & Côté (2010), and an example of a stochastic approach can be found in Harper et al. (2005)). Regarding the particular case of the LTC sector, there is still a lack of models considering its specificities (OECD, 2013b). And when it comes to develop DSS that enables the use of these models, a lack of research exists in the health care sector in general, and in the LTC sector in particular. Nevertheless, since the relevance of DSS in many other areas is widely recognized (see for instance Relvas et al. (2011), Costa et al. (2014), Aboudi et al. (1989) and Ibn-Mohammed et al. (2014)), it is considered that these systems can also be valuable in the health care sector. In fact, DSS have already been used in the health care sector together with other methods, such as simulation models (see, for instance, Kadri et al. (2014) and De Angelis et al.(2003))

In this line of thought, the aim of this thesis is to develop a DSS – the *LTCPlanner* – to aid real health policy makers and health care planners in the management and planning of networks of LTC services, both at a strategical and tactical level. In particular, the tool provides detailed information on:

i) When and where to open/close services;
ii) How much bed capacity should be available in each service;
iii) How should LTC patients be allocated to existing services;
iv) Which is the impact on key policy objectives and on costs.

The developed tool provides information regarding a planning horizon composed by several periods (years) thus allowing decision support when planning in medium or long time period.

This tool makes use of existing mathematical programming models developed to aid decision makers (DM) planning decision on the location of multiple services and allocation patients to services over time. The *LTCPlanner* integrates these models with user-friendly interfaces that enable its use by real planners in the LTC sector. In particular, this tool is designed so as to assist interactively in:

- Inputting the data required to run the model, such as information on the current supply of services and on costs and available budget;
- Defining the objectives space, i.e., which objectives are addressed when planning the LTC network, which can include a single objective or multiple objectives. In this tool, the objectives that can be considered are: Equity objectives – namely, Equity of Access (EA), Geographical Equity (GE), Socioeconomic Equity (SE) and Equity of Utilization (EU) - since these represent objectives with relevance for any National Health Service (NHS) based system; and cost objectives, which are relevant in the current context of scarce resources and pressures to control public health care spending;
- Defining the constraints space, i.e., which constraints should be considered when planning the network, such as constraints imposing limited budgets or maximum distances that can be travelled by patients;
- Analysing the LTC network configurations that are obtained when different objectives and constrains are considered;
- Analysing model outputs, through web enabled mapping tools, graphs and a summary report.

The *LTCPlanner* is thus an innovative and easy-to-use decision support system that enables the use of mathematical programming models as a planning aid and that interactively helps policy makers on how to (re)organize LTC networks. This tool requires that LTC planning models are programmed in the General Algebraic Modelling System (GAMS) /CPLEX language.

Within this context, this study contributes to the literature by providing a tool that supports the planning of LTC networks, with LTC planning not being widely considered in the health care planning literature. The *LTCPlanner* also provides a solution that enables the use of mathematical models by real decision makers in the LTC sector, who in other situation may not have the necessary technical skills to use these models. This tool will thus aid and guide planners in the LTC sector for an adequate planning of networks of LTC, thus providing easy-to-use interfaces and allowing an easy interpretation of planning results.

This thesis is organized as follows. Chapter 2 presents background information on Long-Term Care and future prospects on the area, followed by Chapter 3 where a literature review on existing methods and tools developed for health care planning in general, and LTC planning in particular, is presented. This review clearly identifies the need to develop methods and easy-to-use tools to support planning decisions in the health care sector and in the LTC sector. Chapter 4 presents the main objective of this thesis, followed by Chapter 5 with a presentation of the *LTCPlanner* (with a description of the adaptation/changes made to the underlying mathematical programming model) and the too validation guidelines. A case study to the Portuguese context is presented in Chapter 6, which includes an overview on the dataset used for the application of the tool to support the reorganization of the RNCCI in the Great Lisbon region throughout the 2016-2020 period. This chapter also includes a detailed analysis on how to use the tool under different planning contexts, and for that purpose three possible scenarios are explored. Finally, Chapter 7 discusses the use of the *LTCPlanner* and provides a review on its main advantages and limitations. The main conclusions and final remarks are described in Chapter 8.

2. Background information

This chapter presents an overview on how LTC is currently provided throughout European countries, giving particular emphasis to the Portuguese case. Having as a starting point LTC networks provided within the context of countries with a National Health System (NHS) (such as Portugal), this chapter provides details on: how LTC has evolved over time; how LTC currently operates and is organized; and which challenges are currently in place in this sector. Special focus is provided to planning challenges in the LTC sector, representing this the key challenge to be addressed in this thesis.

This chapter is organized in three sections: The first is an overview on LTC with particular emphasis in the European Union countries. This is followed by an outline on how LTC is currently provided in Portugal, closing with a reference to the future prospects and challenges of this sector, providing evidence on the need to plan the LTC sector.

2.1. Long-Term Care

Throughout the years, Europe has experienced an increase on the share of elderly population (OECD, 2015). The average percentage of the population aged above 65 across European countries has increased from less than 8.9% in 1950 to 17.7% in 2011. This is mainly the result of a combination of factors such as the increasing life expectancy and decline in fertility rates (OECD, 2013b). As a result, the share of economically active population is declining, thus affecting the financing of social protection systems, the supply of labour in the economy and is also leading to a great demand for elderly care. This life’s expectancy increase has also been a major demographic change, as a result of improvements on access to health care service and life conditions (OECD, 2013b). Nonetheless, increasing life expectancy does not necessarily corresponds to an increase on healthy life. In fact, only 35% to 40% of elderly population (aged above 65) in Finland and France rate their health to be good, whereas in Portugal and Hungary this percentage is below 20% (OECD, 2013b). This context, together with the increase in the number of dependent people and with chronic diseases that currently exists in many European Union countries, results in an increasing number of people requiring LTC (OECD, 2013b).

LTC is defined by OECD (2013a) as a variety of services that are essential for people with a certain degree of functional, physical or cognitive incapacity that rely on help to perform their basic ADL. This type of care is a combination of help with medical services, such as nursing care, prevention, rehabilitation or palliative care, provided along with domestic help or help with IADL.

LTC can be provided by both informal and formal carers (OECD, 2013b). The informal carers are usually people who provide daily or weekly help to family members or friends who require help for ADL or/and IADL, whereas formal caregivers can be defined as paid LTC workers who provide home-based or institutional care. Besides qualified nurses, formal LTC include personal care workers who provide assistance with ADL and other personal support – 30% of formal LTC providers are nurses, while the other 70% are personal care workers) (OECD, 2013b). When analysing the European context, the percentage of informal carers is over 15% and are aged above 50. For the specific case of Southern

European countries, such as Portugal and Italy, there's a strong culture of informal care, whereas in countries like Sweden and Denmark there is a greater share of formal LTC services (OECD, 2013b).

Formal LTC can be provided through different schemes: Home-based care, ambulatory care and institutional care. Specifically, LTC can be delivered at home for people with functional restrictions that are mainly at home or that use institutions on a temporary basis, (with this representing ambulatory care provision) thus allowing and supporting continued living in home-based settings. The ambulatory care is mainly provided in community care and day-care centres and specially designed living arrangements Furthermore, LTC can also be provided in institutional settings to people with severe functional restrictions (Lipszyc et al. 2012) (OECD, 2013b).

In terms of expenditure, the provision of LTC in institutions is more expensive then home-based care due to higher staffing ratios and due to nourishing and accommodation's cost. Generally, LTC users prefer to stay at home but due to user circumstances, moving to LTC institutions might be the appropriate option. For example, people who live in isolated places or alone should be institutionalized in order to have a more accurate follow up (OECD, 2013b).

Since the beginning of the 21st Century, LTC institutions have risen in number throughout European countries (Lipszyc et al., 2012).This allowed the reallocation of an increasing number of patients inadequately receiving acute care in hospitals to these LTC facilities freeing up costly hospital beds, and, consequently, reducing the costs for the health care system as a whole (OECD, 2013b). Still, with the increase on the number of institutions and of the LTC supply, LTC expenditure has also grown. In fact, forecasts suggest that public resources allocated to LTC as a share of the Gross Domestic Product may double by 2060. For this reason, European countries will face one great challenge in the future, which is to ensure the right balance between the provision of appropriate LTC protection and ensuring it's financially sustainability in the long-term (OECD, 2013b).

2.2. Long-Term Care in Portugal

Portugal is one of the European countries in which a formal provision of LTC has recently been recognized as a key component of the health care system as whole. For some years new efforts to provide an integrated answer to the population's needs in terms of LTC have been made, reducing costly acute hospital care episodes and admissions by less costly alternatives (Barros et al., 2011).

2.2.1. Evolution of LTC in Portugal

Traditionally, Portuguese families have been the first line of care and for a long time formal LTC was neglected. Family and charity institutions (like *Misericordias*) have been the only possible answers in this sector until very recently (Instituto da Segurança Social, 2014). Following the European trend, demographic changes in Portugal lead to an increase in the elderly segment of the population, mainly due to the increase of the life expectancy. This was accompanied an increase of the number of people with incapacitating chronic diseases. In fact, recent projections show that the life expectancy at 65 in

2002 for the Portuguese population was of 17.2 years and increased to 19 years in 2012 (Pordata, 2015). The increase on the number of people aged above 65 and the decrease of the population under 15 leads to “double ageing” effect that will lead to a projected decline or stabilization of Portuguese population between 2008 and 2060. Furthermore, the increase of women employment – with women representing the traditional career – and migration of young family members to urban areas means that this sector is no longer able to rely on informal care (Barros et al., 2011). Portuguese government is aware of this reality, as well as of the need to propose alternatives to deal with the lack of recourses and services that has been characterizing this sector (Instituto da Segurança Social, 2014).

In this line of thought, in 2006 the RNCCI was created as result of collaboration between the Ministry of Health and the Ministry of Labour and Social Solidarity (Ministry of Health, 2006).

The implementation of the RNCCI was recognized as key factor to deal with the increasing needs for LTC, thus contributing for adjusting LTC delivery to existing needs, for the modernization and sustainability of the NHS system and for improving the performance of the health care system (Central Administration of the Health System, 2013). This reform is believed to promote a better use of available health care resources, for instance, by replacing costly acute care services by cheaper LTC services. (Central Administration of the Health System, 2013)

2.2.2. LTC provision in Portugal nowadays: the RNCCI

Formal LTC provision in Portugal within the RNCCI is in place in Portugal since 2006 (Ministry of Health, 2006). The RNCCI aims at promoting health care and social support in a continuous and integrated way for all dependent people, chronic patients and/or patients in terminal stage, regardless of their age (Ministry of Health, 2006). To rehabilitate and reinsert are the main principles of the network and these are accomplished with the promotion of autonomy, improvement of functionality of dependent people through social and familiar rehabilitation, readaptation and reinsertion (Instituto da Segurança Social, 2014). The LTC provision within the RNCCI recognizes the importance of an active ageing and provides teams for LTC, social support, prevention, rehabilitation and palliative care.

The RNCCI ensures the delivery of a wide range of health and social care services, and these can be provided either by public (such as hospitals and groups of primary care centres [*Agrupamentos de Centros de Saúde*, ACES], etc.) or private entities (profit and non-profit entities). Regarding all the LTC providers the majority are non-profit entities with a charitable background (Barros et al., 2011)

Concerning social care services, these are provided within the scope of the ministry of Labour and Social Solidarity (Ministry of Health, 2006). A range of services can be provided, such as activities, meals, bathing etc. For these a contribution is charged based on the financial capability of the beneficiary (means-tested).

Regarding health services, these include inpatient, ambulatory and home-based care services, and are provided within the scope of the Portuguese NHS by health professionals that are organized in hospital and home-based teams (Ministry of Health, 2015d). In this line of thought, the recently assembled network is a result of a continued political commitment to invest in the health care sector. The Portuguese NHS is available to all Portuguese citizens who according to economic and social background benefit from an approximately free-of-charge service, tax financed system of coverage (Barros et al., 2011)(Ministry of Health, 2015c). This system is designed to cover all integrated health care - promotion and surveillance of health, disease prevention, diagnosis and treatment and finally social and clinical rehabilitation. For this the Portuguese NHS has a system of primary, differentiated and continuous care networks.

Regarding the RNCCI inpatient services, these include the following typologies of services: CC, MTRC, LTMC and PC. According to Ministry of Health (2006), the financing of the RNCCI is based on the money earned in Social Gambling, and these funds are shared between the Ministry of Health and the Ministry of Labour and Social Solidarity, but the financing and payment systems are different for each unit:

- <u>CC units:</u> independent inpatient unit integrated within an acute hospital or in another institution (whenever associated with a hospital). The unit provides "*continuous and intensive clinic supervision and care and rehabilitating clinic car*e" (Ministry of Health, 2015b) resulting from hospital inpatient episode, recurrence of/or imbalance in chronic condition which led to transitory loss of autonomy, potentially recoverable. The estimated maximum length of stay (LOS) is of 30 days (Ministry of Health, 2015b). In terms of financing, CC are totally financed by the Ministry of Health. (Ministry of Health, 2006)
- <u>MTRC units:</u> According to Ministry of Health (2015a) this unit is associated with an acute hospital but has its own physical space to provide rehabilitation care and psychological support to people with a temporary loss of autonomy, which is potentially recoverable (Ministry of Health, 2015b). The aim of this unit is to evaluate, stabilize the clinical condition and fully rehabilitate MTRC patients. Patients are estimated to stay between 30 and 90 days (Instituto da Segurança Social, 2014). MTRC units are mainly covered by the Ministry of Health (70%) and the remaining by the Ministry of Labour and Social Solidarity. (Ministry of Health, 2006).
- <u>LTMC units:</u> this unit has its own physical space and offers a temporary or permanent inpatient service to provide social support and health care for people with chronic diseases with different levels of dependency and that do not fulfil the conditions to be cared at home. For a period usually longer than 90 days (or less for temporary situations due to family support struggles or to allow the principal career to rest), this unit aims at providing care, prevent and delay increasing dependency and favouring comfort and quality of life (Ministry of Health, 2015b). LTMC units are 20% financed by the Ministry of Health and 80% by the Ministry of Labour and Social Solidarity (Ministry of Health, 2006).
- <u>PC units:</u> Similarly to LTMC, PC also have their own physical space, but these units should be integrated within a hospital in order to have a better follow up, treatment and clinical supervision of severely ill patients in complex/advanced clinical situation (Ministry of Health, 2015b). Palliative care has the objective of promoting quality of life, and well-being to patients in severe stages of sickness, suffering from incurable diseases with rapid progress. So the unit seizes to

ease the pain and to reduce symptoms (Barros et al., 2011). In these type of units there's no limited LOS (Instituto da Segurança Social, 2014). In terms of financing PC are totally financed by the Ministry of Health (Ministry of Health, 2006).

One should however note that the National Network of Palliative Care Services (*Rede Nacional de Cuidados Paliativos, RNCP*) was created in 2012 and all the units and teams of palliative care previously integrated within the RNCCI are now part of the new RNCP (Ministry of Health, 2012).

As mentioned before, the budget assigned to RNCCI is divided between the Ministry of Health and the Ministry of Labour and Social Solidarity, but one should however note that the Ministry of Health covers the expenditure on health care provision and the social care component of LTC is financed by the Ministry of Labour and Social Solidarity through contributions that are related with the annual income statement for the household (Instituto da Segurança Social, 2014) (Ministry of Health, 2013).

The RNCCI also provides teams for home-based care and palliative care provision targeted to patients that do not need to be institutionalized but cannot move from home. Within the setting of the primary care centres and social support entities, these teams provide support and counselling in LTC and palliative care.(Ministry of Health, 2015b). If however, the degree of functional, physical or cognitive incapacity is not sufficient to be institutionalized and neither to receive home based-care, the RNCCI has units of ambulatory care, which are called Day Care and Autonomy Promotion units (*Unidades de Dia e de Promoção da Autonomia*). These units were assembled in order to provide social support and autonomy promotion i.e. health care, periodic nursing care, periodic physiatrist surveillance, social support. (Ministry of Health, 2006).

The network is coordinated at a national level by the *Administração Central do Sistema de Saúde, I.P. (ACSS),* whose aim is to establish the link between the Ministry of Health and the Ministry of Labour and Social Solidarity. In addition to the coordination at a national level, there are also coordination teams at both regional and local level. The first are established on the regional health administrations (RHA), and so there are five teams formed by RHAs and by social solidarity district centres representatives. Having at least a doctor, a nurse, a social assistant, a technical assistant and a higher technician, the this team is aims to guarantee i) equity of access to care, ii) the adequacy of service provision (i.e., assuring quality conditions in health care provided by teams and units within the RNCCI), iii) the interlink between national teams, local teams and among the different partners and entities belonging to the RNCCI, and finally iv) the efficient use of the budget contracted for different LTC units (Ministry of Health, 2006).

Similarly, local coordination teams are cantered in the ACES or in each local unit (in case no ACES exists) and are formed by a doctor, a nurse, a higher technician and, if needed, a representative from the local county (Ministry of Health, 2014b). In general these teams have the purpose of establishing the interlink between the regional coordination teams and the local services of the network (Ministry of Health, 2006).

Patients can be referred to any service of the RNCCI in two different situations:

- If previously institutionalized in a hospital, the discharge management team (*Equipa de Gestão de Altas*) is responsible for referring the patient to the local coordinating team (*Equipa coordenadora Local*) and inform the need for assignment to a LTC service, depending on a previous evaluation of their condition;
- If patients are in the community (at home or in a private hospital), they need to be assessed within a primary care provider by a family doctor, nurse or social assistant who reports to the local coordinating team (Ministry of Health, 2015e).

It was estimated that, by the end of 2014, 901 beds would be added to the RNCCI, corresponding to an increase of 13.6% compared to the end of 2013. And this increase is higher when compared to the period of 2012-2013 (12.4%). Still, even with this increase in capacity, the existing LTC supply is not enough to meet existing needs (Cardoso, Oliveira, Barbosa-Póvoa, & Nickel, 2012). Although the number of assisted patients is rising (more 11.3% between 2013 and 2014), the waiting list is still increasing. In 2012 the list was of 1010 individuals a number that increased to 1479 in the mid of 2014 (Central Administration of the Health System, 2012) (Central Administration of the Health System, 2014). These figures clearly show that the current provision of LTC within the RNCCI is still not enough to meet existing needs, thus making planning the delivery of LTC a key challenge and policy concern in Portugal.

It is important to mention that the provision of LTC in Portugal is not restricted to the RNCCI services. In fact, there is still a great amount of LTC provision in private institutions and informal (family based) provision.(OECD, 2011).

2.2.3. Policy objectives in the LTC sector in Portugal

According to Ministry of Health (1990) the health policies in Portugal have an evolving nature, with continuous adaptions to the conditions of the national reality, their needs and their resources. In this line of thought, this network was created to fill the gap in the lack of resources in the Portuguese LTC network resulting from the increasing number of people with incapacitating chronic diseases (Barros et al., 2011).

As mentioned before, the RNNCI provides health care and social care services within the scope of the Ministry of Health and the Ministry of labour and Social Solidarity, respectively. Accordingly, the Heath care component is provided within the scope of the Portuguese NHS. (Barros et al., 2011)

This system, is available to all Portuguese citizens in an approximately free-of-charge service through a tax financed system of coverage and is designed to cover all integrated health care that includes the LTC. The social care component of LTC is financed by the Ministry of Labour and Social Solidarity and is means-tested. (Barros et al., 2011). Within this context, this network aims to ensure universal coverage of LTC demand (with access nearly free at the point of use), promoting equal access to health care for all citizens (irrespective of their socioeconomic condition and geographical location) and promoting equity in the distribution of resources and use of health care services (Barros et al., 2011)(Baker, 2000)

Furthermore, taking into account the European Union countries and in particular the Portuguese present economic situation, budgeting constraints is also a reality, and so there is a high pressure to control and reduce public spending in health care. If no control is applied, the expenses on formal care will increase (Colombo et al. 2011).

We can thus argue that an adequate planning of LTC provision should take into account all this environment – the objectives underlying any NHS based system should be accounted for, such as equity and efficiency objectives, but the pursue of these objectives should always be evaluated taking into account the current economic crisis.

2.3. Future Challenges in the LTC sector

In summary, European countries are currently facing many challenges in the LTC sector. In particular, an increasing pressure to improve the provision and financing of formal LTC is expected, since under no policy changes the gap between the number of citizens in need of LTC and the actual supply of formal LTC services is fated to increase (Lipszyc et al., 2012). This increasing gap is mainly related to the joint effects caused by:

- The continued increase in the number of individuals in need of LTC (related with aging population growth and rising prevalence of chronic diseases);
- The low supply of formal LTC
- A declining informal sector due to a typically diminishing family size, an increasing on women employment (typical caregivers – middle aged daughters or spouses – are getting more involved in labour activities) and family structures giving less support to older generations. Due to a typically diminishing family size and an increasing on women employment. This declining share of informal caregivers puts an extra pressure to formal LTC provision (OECD, 2013b).
- An increase on female employment and the low supply of formal LTC.

And this gap is becoming more pronounced due to changes in the informal sector, given that this sector is likely to decline due to the fact that typical caregivers – middle aged daughters or spouses – are getting more involved in labour activities and family structures are giving less support to older generations. Moreover, even though family careers are able to provide a great amount of caring services, this care provision is strongly hindered when dependency is very severe. In some European countries policies were implemented in order to support family careers (OECD, 2013b). Unfortunately, it is easy to understand that over-reliance on informal caregivers has undesirable consequences, both from a social and health care quality perspective. At a professional level it has implications in the caregiver's participation in the labour market.

A recent report (Central Administration of the Health System, 2012) states that LTC is an international concern due to populations ageing and the increase on dependency. Granting and improving the quality of LTC is thus one of the priorities in the OECD countries in 2010.

Within this context, it is easy to understand that increasing the provision of different types of formal LTC services along with a balance between them is key for improving the delivery of care in the LTC sector (Lipszyc et al., 2012). Consequently, the expenses on the formal sector will increase if no control over expenses is applied (Colombo et al. 2011). Colombo et al. (2011) states that governments need to address key elements that include improving the organization and the provision of formal LTC care while accounting for existing needs, as well as while accounting for key policy concerns, such as equity and cost concerns, since there is a limited budget available for these improvements and an increasing need to control public expenditure.

For that purpose, in order to achieve an adequate provision of LTC services, there is a need to consider different objectives (such as equity- and cost-related objectives) while planning how to organize a network of LTC services in terms of location of services and allocation of resources and patients. Moreover, since health care systems are complex and many variables have to be considered planning the delivery of care in the LTC sector is not easy. And although only few studies have been developed in the LTC sector (see Chapter 3 for more details), it has been shown that tools to plan the health care sector have potential to be used by decision makers and planners when managing and planning networks of LTC ((Harper et al., 2005), (Schuurman et al. 2008), (Davari et al. 2011)). For instance, one of the measurements taken in Portugal was the creation of *GestCare CCI*, a platform that allows management and monitoring of RNCCI, in real time. Reports on Portuguese LTC are made to evaluate the quality of the services provided in RNCCI. (Central Administration of the Health System, 2012).

All in all, according to Lipszyc et al. (2012), there is evidence that an adequate planning of the health care sector can reduce future expenditure. Considering the lack of research on methods and tools that can be used to aid the management and planning in the LTC sector, and the potential contribution that these are expected to have in this sector, (e.g. balancing the demand and supply, while accounting for budgets constrains), one can argue that the development of these models and tools represent a key challenge that need to be addressed, with a potential impact for future generations. This challenge applies to Portugal and many European countries.

Within this setting, this thesis proposes a DSS – the *LTCPlanner* – to support decision making when planning networks of LTC. In particular, the developed tool will aid decision makers and planners by providing detailed information on of the location of LTC services and on the allocation of resources and patients to services, while analysing the impact on key policy objectives and on costs.

3. State of the art

This chapter provides a revision on the models and tools developed to support the planning of the health sector in general and of the LTC sector in particular. Since little research exists on tools to support the planning of health care delivery, the overview of tools is made with examples not only in health care but also with applications in other sectors. Regarding the tools developed, this chapter provides a comprehensive explanation on Decision Support Systems. This chapter provides evidence on the need to plan the health care sector and shows that there is scope for developing easy-to-use tools to aid healthcare planning in general and LTC planning in particular.

The keywords used in this search were mainly “Health care”, “Long-term care”, “Decision support systems”, “DSS”, ”Decision Support tools”, “mathematical models”, ”mathematical programming models” and “optimization”.

3.1. Methods to plan the delivery of Health Care services

The health care sector has experienced increasing pressures on various levels, including management, planning, policy making and decision making. This is mainly due to a combination of several factors (Harper et al., 2005) (Barjis et al. 2013) (Ahmed & Alkhamis, 2009): there is an increasing demand for health care services and associated costs; there is a limited budget and resources for operating and improving health care delivery; the health care sector operates in a continuous changing environment where variability and uncertainty are a reality; and the expectations of patients are also growing. As a result, accessibility and efficiency have become the pivotal concerns of the 21st century (Barjis et al., 2013). In the genesis of this subject, there is a vast complexity of interrelated themes, such as health care processes management, policy, innovation, decision making, supporting technology, socio-cultural and economic realities (Barjis et al., 2013). Health care managers often have to optimize service delivery while using available resources and while respecting severe budget constraints. To do so, managers need to have methods that help them making decisions on how to use available resources and minimize costs and still provide a certain level of care. For example, in the public health care sector a typical requirement is to provide quality care, as well as to provide adequate care to the highest number of patients with the lowest waiting times and achieving the highest patient satisfaction, and all this while using the minimum levels of resources. (Harper et al., 2005) (Ahmed & Alkhamis, 2009)

Moreover in the health care sector there are different levels of planning: Strategic, tactical and operational. Strategic level of planning is concerned with structural decision making which translates into the design, dimensioning and development of the health care delivery process, and therefore has a long planning horizon and is based on highly aggregated information and forecasts. Tactical planning addresses the organization of the operations/execution of the health care delivery process, and therefore translates strategic planning decisions to guidelines that facilitate operational planning decisions (short-term decision making related to the execution of the health care delivery process) (Hulshof et al. 2012). The tool presented in this thesis address strategic and tactical planning levels.

Policy makers are this increasingly recognizing the importance of modelling complex health care systems, as well as on building tools that enable them to make knowledgeable decisions on how to manage and plan health care delivery (Harper et al., 2005). Different methods have been proposed in the literature to be used to support health care management and planning. In particular, mathematical programming models represent one of the approaches most widely used for that purpose, making use of the available scientific developments (Brailsford & Vissers, 2011).

Mathematical Programming Models are able to represent mathematical relationships between real life variables written with mathematical interactions, such as equations. These equations typically are independent from the data model. These models aim at maximizing or minimizing and objective function that, in the particular case of the health care sector, usually include equity, efficiency, costs and health gains objectives. Most of the literature in this is typically concerned with the definition of the location of facilities and their capacity (Rais & Viana, 2011). Mathematical programming models can be classified as linear programming models, non-linear programming models and integer programming models. Linear programming is widely spread and used when compared with non-linear programming models because they are easier to solve and to understand (Williams 2013, p.4,5,6). Within linear programming model, a particular class of models is the Mixed Integer Linear Programming (MILP). The mathematical models in this class are capable of modelling a wide variety of problems. This is because they are able to represent mathematical relationships between variables from discrete sets to logical decision-making procedures. They are characterized by models containing both continuous (real) and discrete (integer) variables and for only being composed by linear expressions on these variables as their constraints and objective functions (like linear programming problems (Natali, 2008).

As noted before, mathematical programming models have been widely used for planning purposes in the health care sector. Nevertheless, existing studies in the area differ in several aspects, namely: in the purpose for which the model is developed; in the number and types of objectives to be pursued; in the number and types of services under consideration; and in the consideration of not of uncertainty aspects. Concerning the different purposes for which Mathematical Programming Models have been developed in the health care sector, the main tendencies of the last decade are the development of these models so as to:

- Location and allocation of services while accounting for a wide variety of objectives, where cost and equity objectives have been the preferred ones (Teshebaeva & Jain, 2007) (Shariff et al. 2012) (Mitropoulos et al., 2006);
- Scheduling medical personal (M'Hallah & Alkhabbaz, 2013);
- Layout Planning (Arnolds & Nickel, 2013);
- Hospital and services merging (Gunes & Yaman, 2006).

Mathematical programming models can also be distinguished based on the number of objectives accounted for, given that mathematical models can have a single or multiple objectives. Historically multi-objective models have not been widely used in the health care sector mainly due to the challenges associated with the management of conflicting objectives (Stummer et al. 2004). Consequently, most of the studies on health care propose single-objective models (Rahman & Smith, 2000). Nevertheless, the tendency in the past years has been an increasing interest in the development of models relying on multiple objectives (Mitropoulos et al., 2006)(Smith et al. 2012). For instance, when looking at the literature in the last decade we can find some studies proposing the analysis of multiple objectives in the health care sector. Mitropoulos et al. (2006) considered two objectives when locating hospitals and primary health care centres: (1) minimization of distances between patients and facilities, and (2) equitable distribution of facilities among citizens. Similarly, Syam & Côté (2010) included two primary criteria: (1) the Veterans Affairs' cost of providing service (fixed and variable treatment costs and cost per patient not treated); and (2) the service rate provided to the Veterans Affairs' patients (proportion of eligible patients served by the VA for a given geographical area). Also, Smith et al. (2012) developed a mathematical model considering efficiency and equity objectives to aid DM when planning the location of new facilities.

Another way to categorize mathematical models in the health care sector relies on whether only a single service is modelled or whether multiple services are accounted for. In the past years the trend has been to develop multi-service models, but there is still little research on these. For instance, Teshebaeva & Jain (2007) made use of mathematical models to optimize the location of several public services. The model is able to determine the location of a certain number of facilities while minimizing the distance between demands points and facilities. Also, Mestre et al. (2011) developed a multiple service mathematical programming model to aid DM when deciding when and where to locate and how to organize hospital services (inpatient care, emergency care and external consultations) while improving geographical equity of access – maximization of patients access to the hospital network- and considering efficiency and cost issues. Other studies such as: Santibáñez et al. (2009) and Hulshof et al. (2012) also consider multiple services approaches.

The mathematical programming models can also be divided in Deterministic and Stochastic. The first is based on parameters values and initial conditions with no uncertainty associated and the second considers that there is uncertainty associated with model parameters (Williams, 2013). An example of a deterministic model is presented in Syam & Côté (2010). Examples of a stochastic models are discussed in Harper et al. (2005) and Cardoso et al. (2015). Within the health care area, the main studies developed regard deterministic approaches, and there is still little literature considering stochastic approaches.

Nevertheless, although it has been recognized that mathematical programming models have potential to aid planners and policy makers managing and planning decisions in a wide variety of sectors (Ritrovato et al., 2015) a great number of studies and models developed in the health sector fail to aid in real life use. This is due to the fact that these models may be complex and hard to use and interpret since their formats and interfaces are not appropriate to interactively assist real health policy makers who typically lack specific knowledge to make use of these models (Ritrovato et al., 2015).

Lately there has been a great amount of research and development in the Decision Support Systems (DSS) field. DSS are computer solutions that can integrate analytical and scientific methods to aid decision making (Shim et al., 2002)(Bhargava et al. 1999). The following section presents a review on studies relying on the development of DSS in a wide range of areas, exploring in more detail applications in the health care sector.

3.2. Decision Support Systems

DSS are software products that are designed to facilitate decision processes and assist their users (they can be managers and decision makers from a wide variety of sectors, including the health care sector) using analytical methods and supporting them solving their problems and making informed decisions (Power, 2002). One should however note that DSS allow the management of data and use of analytical models, thus supporting decision making, but are not intended to replace the decision maker (Gayialis & Tatsiopoulos, 2004). Decision making can be associated with different levels structuredness i.e. how routine and repetitive are the decisions. Decision making can vary between structured, semi-structured and unstructured (Burstein & Holsapple, 2008).

According to Figure 1 different systems can be used to support the decision making process depending on the decision situation. Particularly, Automated Decision Systems are associated with structured decisions. These are repetitive decisions where alternatives are clear and the implications of these are straightforward. An example of this is to send a reminder notice if the medical exams are available. Also, Computerized Decision Support Systems are associated with semi-structured decisions. These aim to aid decision making where the users have a fundamental role but a portion of the knowledge is still located in a computer system. An example is for instance to decide on where to create a new health service when potential locations for new services are known. Finally, Computerized Analyses for special Studies are associated with unstructured decision making. These are related to infrequent decisions where the alternatives are not clear and the implications are undetermined, normally relying on human intuition. An example is the structuring/planning a new health service; (Power & Sharda, 2007) (Burstein & Holsapple, 2008)

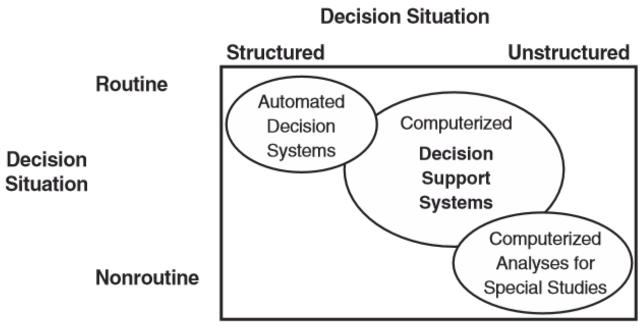


Figure 1 – Computerized Support for different decisions situations (Power & Sharda (2007))

As a conclusion, DSS should be used when the decision maker is facing a semi-structured decision, i.e., DSS should be provided with data, and if no information is provided by the user, DSS cannot provide a solution, and therefore cannot aid decision making. This review will thus be focused in DSS.

3.2.1. Decision Support Systems overview

DSS operate alongside with quantitative models and algorithms from various subjects (such as mathematical programming and simulation), and are able to interactively support users applying these models, manipulating inputs and analysing their outputs over different scenarios. These systems are able to deal with models that need the decision maker's judgment to solve de model, promoting the interaction between human and the machine (Bhargava et al., 1999) (Shim et al., 2002) (Ritrovato et al., 2015).

There are five families of DSS:

i. Data driven DSS that involves database management systems (organization, analysation and retrieving of data). (Schuurman et al., 2008)(Bhargava et al. 2007). These DSS allow the user to retrieve and manipulate a great amount of structured data (Power & Sharda, 2007)(Power 2002 p.13);
ii. Model driven DSS make use of formal representations of decision models (e.g., accounting and financial, representational and optimizing models) providing analytical support. (Schuurman et al., 2008)(Bhargava et al., 2007)This family is designated by Power & Sharda (2007) as to enable the user to manipulate model parameters and examine outputs sensitivity. Summing up, in a model-driven DSS the users provide data that are used as inputs to the model framework, and the DSS is able to aid in the analysis (Power 2002 p.13);
iii. Knowledge driven DSS advises and proposes alternatives based on statistical tools. (Schuurman et al., 2008)(Bhargava et al., 2007) These are "a person-computer systems with specialized problem solving expertize" i.e. have knowledge on a particular domain, have the ability to understand and solve problems in the same domain (Power 2002 p.13);
iv. Communication driven DSS is able to link multiple decision makers over space and time, making use of electronic communication technologies; (Schuurman et al., 2008)(Bhargava et al., 2007)
v. Document driven DSS make use of storage and processing technologies to deliver document retrieval and analysis. (Schuurman et al., 2008)(Bhargava et al., 2007)

Special focus will be provided to the second type of DSS – Model Driven DSS – since it represents the type of DSS that was built in this thesis.

Based on the literature review, it was possible to identify two main types of DSS (a) Optimization-based; and (b) Simulation-based (Power & Sharda, 2007). Simulation models try to mimic real world processes through a series of simulations where the parameters may vary within a set of constraints (Velten, 2009).

The central purpose of DSS is to enable non-technical users to take advantage of models and algorithms without needing to interact with them or to have the technical skills to do it (Schuurman et al., 2008). In the past there was a gap between this two different worlds, since users with no expertise had difficulty in using these tools. Today, a Graphical User Interface (GUI) is the subsystem in a DSS that makes this bridge and is the key to the success of a DSS (Power & Sharda, 2007). Schuurman et al. (2008) argue that the user interface has to present the information in a planned and structured way as to be able to reduce cognitive load and therefore provide a comfortable decision making environment. Through this framework, users take conclusions and assumptions that in other ways were not possible (Schuurman et al., 2008). For example, in a model driven DSS, a GUI can be used to introduce and change values (with these corresponding to the inputs of the models) and can also be used to present the results of the model. (Power & Sharda, 2007).

Power & Sharda (2007) say that the information may be introduced in a GUI following these three approaches: (1) numerical, (2) graphical, and (3) verbally. The approach chosen when designing the DSS will influence the response given by the users and the choice of the approach should be adequate to the DM background. Therefore this choice is a critical factor when considering the design of the DSS since it may reduce or increase errors and determine user acceptance. Due the fact that different people process information in different ways, Power & Sharda (2007) also refer that there is still need to do research on this field, especially on the design of the user interface, design on the type of the task to be performed and particularly on users expertize.

The user interfaces commonly work with different approaches like graphs, images and maps to better deliver information and therefore enhance information retrieval (Shim et al., 2002). Considering the DSS development and delivery mechanisms, there are different types of DDS:

- Spreadsheet-based DSS are very common since spreadsheets applications are popular amongst the population (e.g., Microsoft Excel). Moreover, a spreadsheet package has graphic and data handling abilities, providing sensitivity and 'what if' analysis, thus justifying its extensive used for Model driven DSS (Power & Sharda, 2007). See for instance: (Tillman, Fred, 2009)
- Web based DSS can be used by any category of DSS since the user does not have to have any particular decision support software installed in his computer. The only requirement is a web browser to interact with the application (Power & Sharda, 2007). As an example see (Schuurman et al., 2008)

Special focus will be provided to the first type since in this thesis the tool presented is a spreadsheet-based DSS.

There has not been many developments of DSS in the health care sector, nevertheless one should note that the relevance of these tools has been widely recognized in a wide range of areas. For instance, Relvas et al. (2011) used MILP models integrated with a DSS to aid scheduling operations while applying in real life multiproduct pipelines systems. To aid on efficient supply chain design, Costa et al. (2014) developed a DSS that takes advantage of optimization models to allow scenario contrast while planning network structures. This tool was tested in real life to show its applicability on a daily base. In the petroleum industry, Aboudi et al. (1989) developed a user-friendly DSS that uses a mathematical programming model to sequence petroleum production activities, in particular, the development of petroleum transport system from the gas fields to costumers and terminals onshore.

More recently, Ibn-Mohammed et al. (2014) took into account current climate change policies, economic and net environmental benefits providing a methodology that enables policy makers to make reliable and efficient decisions taking into account financial and environmental concerns. This tool is based on a model driven DSS that, when compared with other models, is able to integrate economic considerations with operational and embodied emissions.

The following chapter provides examples of the research made on DSS in the health care sector.

3.2.2. Decision Support Systems for Health Care Planning Purposes

In the health care sector there is evidence of only few studies regarding the development of DSS. For instance, Schuurman et al. (2008) designed a DSS to provide information about the population receiving and in need of care in remote areas of British Columbia. This tool enables policy makers and administrators with variable levels of expertise to make evidence decision making on location and allocation of time sensitive service capacities. In this tool a new concept of DSS is used, namely, spatial decision support Systems (SDSS), where decision alternatives and outcomes vary spatially. (Schuurman et al., 2008)

Chongwatpol & Sharda (2010) created a tool that is able to perform a cost revenue analysis considering minimal equity levels. Through this the DM is able to determine their pricing model choice based on three factors: data availability, social impact, and political acceptance.

In Harper & Shahani (2003) a tool was developed to aid decision-making by clinicians and managers, regarding the provision of effective and efficient care to the many HIV and AIDS patients throughout India. This tool is used along with a simulation model developed to predict future patient numbers and associated health care costs, and in this study the authors stress out the relevance of developing this type of tools for supporting planning decisions in the health care sector.

A simulation based DSS was also developed in Harper (2002) to aid the planning and management of hospital beds, operating theatres and work-force needs. It enables hospital managers to understand and quantify the consequences of planning and management policies.

Accordingly, although there has been some developments in DSS applied in health care, the major uses of DSS in the health sector are in Clinical DSS (CDSS) and Simulation based DSS, with a lack of studies proposing optimization-based DSS in this area. (Ahmed & Alkhamis, 2009)(Berner, 2007). CDSS aim to give clinical advice through evidence based medicine. The CDSS are basically a knowledge based DSS, in the sense that these DSSs are used to give recommendation for a specific patient, taking into account multiple items of a patient data. CDSS are able to compare patient specific features with knowledge data in an automated way and provide recommendations or reminders during decision making process (Oxendine et al. 2014) (Berner, 2007).

There has also been major developments in simulation-based DSS. For instance, Kadri et al. (2014) uses a simulation-based DSS to simulate patient flow in emergency departments. Also, the simulation driven DSS designed by De Angelis et al.(2003) allowed an effective management in a transfusion health care centre.

As mentioned before the aim of this thesis is to develop an optimization model driven DSS to aid in LTC sector planning. Accordingly, the following subchapter presents the developments made in this area.

3.3. Long-Term Care planning

Although the relevance of an adequate management and planning of networks of LTC is increasingly recognized in the literature, there's still a lack of research on methods and DSS applied to the LTC sector, for instance regarding mathematical programming model or simulation based DSS (OECD, 2013b). In fact, for the specific case of DSS, no study was found reporting the development of such tools for planning purposes in this sector.

Concerning the development of mathematical programming models for supporting LTC planning, in the last decades an increasing body of research has arisen in this area. For instance, Greene et al. (1998) and Lin et al. (2012) developed single objective models to analyse cost-effective home based LTC and to determine home based infrastructure capacity while minimizing expenditures, respectively. In the area of locating LTC facilities, Kim & Kim, (2010) assigned a branch and bound algorithm to balance the number of patients allocated to each facility.

Cardoso et al. (2016) developed a mathematical programming model within a multi-objective and multi-period MILP model − LTC_{MOPE} − to aid planning a LTC network in the context of NHS-based countries, in terms of capacity planning, location selection and cost savings. For that, three equity objectives were taken into account, namely, Equity of Access (EA), Geographical Equity (GE) and Socioeconomic Equity (SE), cost considerations were also taken into account. To each equity objectives was assigned a different weighting coefficient. For this the software Measuring Attractiveness by Category–Based Evaluation Technique (MACBETH) was used as to consider the judgment of the decision maker. The MACBETH approach follows a constructive view and asks DMs, through qualitative judgements, difference of attractiveness between options. Through this the software is able to generate weights for each criteria.(Bana e Costa et al. 2012). LTC_{MOPE} considers the provision in four different types of institutional services: CC, MTRC, LTMC and PC. This model aids in a set of decisions regarding the location and capacity planning for different levels of expenditure.

Cardoso et al. (2015) extended the deterministic version of the model developed in Cardoso et al. (2016) so as to develop a stochastic MILP model to aid in LTC planning. These models provide the decision maker with information as to where and when to allocate services and with which capacity, how to distribute this capacity throughout the different services, socioeconomic groups and suggest which changes must be done.

Summing up, this thesis' major focus is on the development of model driven DSS, in particular optimization driven DSS for supporting planning decisions in the LTC sector, but this literature review has shown that this type of systems have not been widely used in the health sector in general, nor in the LTC sector in particular. Table 1 presents a summary on the research done in tools to support decision making in the health care sector, particularly a comparison on optimization driven DSS and optimization based mathematical programming models. In this table it can be seen that there is little development in optimization driven DSS in the health care sector, with no developments in the LTC area, despite of representing systems greatly developed in other sectors.

Table 1 – Studies and the important features

Studies	Optimization models	Optimization based DSS	LTC Sector	Other Health Care Sectors
Relvas et al. (2011)	X	X		
Costa et al. (2014)	X	X		
Aboudi et al. (1989)	X	X		
Ibn-Mohammed et al. (2014)	X	X		
Katok & Ott (2000)	X	X		
Gayialis & Tatsiopoulos (2004)	X	X		
Greene et al. (1998)	X		X	
Lin et al. (2012)	X		X	
Kim & Kim, (2010)	X		X	
Cardoso et al. (2016)	X		X	
Cardoso et al. (2015)	X		X	
LTCPlanner	X	X	X	X

All in all, after a bibliographic research it is clear that even though some studies providing methods to aid LTC planning were developed, there is no evidence of any research on DSS in this area. It is thus clear that there is need for developing research in this area. Moreover, regarding the fact that DSS have already shown evidence to be successful tools for aiding the planning in different sectors, including in the health care sector, one can argue that the these tools will also have a key role when planning LTC

4. Goal

The aim of this thesis is to develop a Decision Support System (DSS) – the *LTCPlanner* – that can potentially aid real health policy makers and planners in the management and planning of networks of LTC services. In particular, planning decisions include: i) when and where to open/close services; ii) how much bed capacity should be available in each unit; iii) how should LTC patients be allocated to existing services; and iv) which is the impact on key policy objectives and on costs.

This tool makes use of a previously developed mathematical programming model (Cardoso et al., 2016) whose formats and interfaces are currently not appropriate to interactively assist policy makers and planners in their decision-making process.

The mathematical model used as a baseline is a multi-objective and multi-period MILP model that provides information to aid planning a LTC network in the context of NHS-based countries. For this, the model provides detailed information to support decisions regarding location and capacity planning for different levels of spending, and considering four typologies of institutional services: CC, MTRC, LTMC and PC.

Three equity objectives were accounted: EA, GE and SE. These equity objectives are assigned with different weighting coefficients considering the judgment of the decision maker. Nonetheless, this three equity objectives could not prevent situations in which some typologies had levels of LTC provision equal to zero. In this line of thought the LTC Planner adds to this mathematical model a new equity objective – maximization of equity of utilization- that's ensures that the maximization of provision in the typology with the worst levels of LTC provision.

Moreover, the LTCPlanner also considers another objective – Minimization of costs – and additional constraints allow modelling the temporal progression of equity improvements this new features are thought to be important for network planers

The proposed tool thus integrates this model with a user-friendly interface that is designed so as to enable its use by real health policy makers without requiring specific knowledge and technical skills on mathematical programming and mathematical programming software. Specific functionalities of the tool include: (1) assisting in the introduction of a wide range of data that is required to run the model; (2) assisting in the definition of the constraints space, such as imposing budget limitations or the achievement of minimum service levels; (3) assisting interactively in defining the objectives space, that can include a single objective or multiple and conflicting objectives; (4) analysing the LTC network configurations obtained when different objectives are valued and under different planning contexts; and (5) analysing the model outputs with the use of a web enabled mapping tool, graphs and a summary report.

In order to build a tool with all the basic functionalities that may be relevant when planning a network of LTC services within the context of a NHS-based system, some adaptions were made to the mathematical programming model developed by Cardoso et al. (2016). In particular, additional objectives were introduced in the model, as well as the possibility for the decision maker selecting how each objective will improve over time.

This thesis seizes to address the gap that exists in the area of LTC planning, given that few studies exist proposing methods to support planning decisions in this area, and based on the reviewed literature no easy-to use tool exist for aiding real planners in the LTC sector. The usefulness and applicability of the tool is shown through its application to the LTC sector in the Great Lisbon region in Portugal and under different planning contexts.

5. Methodology

This chapter begins with a presentation of the developed tool – the *LTCPlanner* – followed by a description of the adaptation/changes made to the underlying mathematical programming model and concluding with an explanation of the validation guidelines to validate the tool.

5.1. Decision Support System Development: *LTCPlanner*

There has been a worldwide awareness on the importance of an adequate planning in the LTC sector and within this context, a proper planning and use of LTC resources is a key priority for these countries. The development of methods and decision support tools that are able to assist policy makers and planners in the organization of networks of LTC is one of the answers to this concern.

Decision makers and key planners in the health care sector in general may not be familiar with the mathematical details underlying most of the methodologies most widely used to support planning decisions in the health care sector. This because they may not have the technical ability to work with the model or because the interfaces they have are not easy to use and do not allow for an easy interpretation of the results (Ritrovato et al., 2015). A DSS to aid the planning process in the health care sector in general, and in the LTC sector in particular, may be the answer to this concern, since these typically provide a user-friendly interface and diminish the contact with the model framework. This thesis aims at building a DSS – the *LTCPlanner* – that aims to support planning decisions in the LTC sector, both at a strategical and tactical level. In particular, the developed tool will aid decision makers and planners in the LTC sector planning networks of institutional LTC services within the context of a NHS-based system, by providing detailed information on i) when and where to open/close services; ii) which should the bed capacity of each service, iii) how should LTC patients be allocated to existing services, and iv) which is the impact on key policy objectives and on costs. The *LTCPlanner* was developed in a way that it can be used by non-expert on mathematical formulation users. The mathematical programming model used as a basis for developing the *LTCPlanner* was adapted from Cardoso et al. (2016).

The key users of this DSS are the decision makers responsible for the organization and planning of LTC provision. The Portuguese state through regional health administrations is responsible for this task (Mission Unit for Integrated Continuing Care, 2009). Particularly the regional coordination teams (*Equipa Coordenadora Regional*) are responsible, among others things, for (Ministry of Health, 2015a):

- Developing a proposal on how to organize LTC supply so as to meet existing needs and propose action plans in an annual basis for the development of the network and its periodic adjustment to needs;
- Guide and consolidate the annual budgeted plans of actions and their implementation reports and submit them to the national coordination;

Potential users of the *LTCPlanner* tool are these regional coordination teams that in the particular case of Portugal exist in the five regions: Lisbon and Tagus Valey, *Alentejo, Algarve, Norte* and *Centro*.

The following section presents an overview on the DSS developed - *LTCPlanner*. The main features, modules and components are presented in this section.

5.1.1. Overview of the *LTCPlanner*

The Decision Support System developed aims to aid health care decision making, particularly in the area of LTC. For this reason the tool was developed so as to allow its use by non-expert on mathematical formulation users, and since these are typically familiar and have access to Microsoft Excel, the tool was developed in Excel's programming language Visual Basic for Applications (VBA). The DSS also takes advantage of the program GAMS – a high-level modelling system for mathematical programming problems – to implement the mathematical programming model adapted from Cardoso et al. (2016). More details on this model are present in section 5.2. To enhance information retrieval a web enabled mapping tool – Google maps – was used.

As mentioned before, the DSS was developed in the Microsoft Excel environment. This tool is embedded with a VBA user interface that provides a real time, user-friendly, graphical user interface (Chongwatpol & Sharda, 2010). Also, VBA enables the user to have minimum contact with the data, and the different programs that are used in the developed DSS (Schuurman et al., 2008).

Figure 2 shows how the different referred before (the User interface, Excel and the mathematical programming model) are interlinked. As can be seen in this figure the tool is composed by five modules: Data Gathering, Data Storage, Data Processing, Outputs and Decision Making. The modules will be described in detail in the following sections.

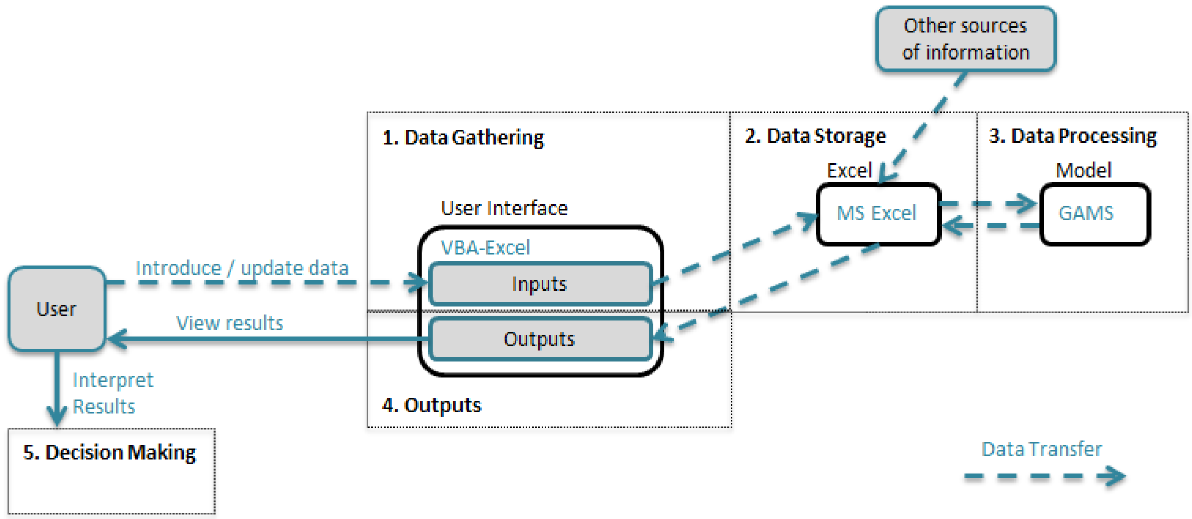


Figure 2 – Architecture of LTCPlanner.

5.1.2. *LTCPlanner* modules description

The *LTCPlanner* is composed by 5 modules:

- Data Gathering: Module in which part of the inputs required to run the mathematical programing model are introduced by the user. This module presents pre-defined values for these inputs, and the user is asked to verify its validity and update it whenever required. The data Gathering module (user interface) was developed in VBA of Microsoft Excel, and is the only component that the user as access to and interacts with. Here the DM has the ability to change/introduce the information required as input to the mathematical program planning model, including a wide range of inputs, constraints, as well as the objectives to be used in the mathematical model (that can be seen in detail in Figure 3).
- Data Storage: module in which all the information required as input to the mathematical programming model (inputs introduced by the user and other information from external sources, such as information collected from literature in the area) and the outputs retrieved once the model is solved is stored. The DM has no access to this module. The values stored in the Data Gathering module are saved in various excel spreadsheets that afterwards are used in Data Processing module. When the Data processing module comes to and end the outputs are then saved in excel files in various spreadsheets;
- Data Processing: module comprising the mathematical programming model. The decision maker does not have access to this module. The mathematical programming model underlying this module is implemented in GAMS and is an adapted version of the model proposed by Cardoso et al. (2016) (see section 5.2). This module uses data (either captured as input from the user or as other information from external sources) and processes it to find the optimal solution. Once the optimal solution is found, the outputs are migrated back to the Data Storage module and are then displayed in the Outputs module so as to be visualized and analysed by the DM;
- Outputs: VBA developed Graphical User Interface enabling the visualization and analysis by the DM of the results in the form of graphs and maps (based on google maps) that will aid in the Decision Making module;
- Decision Making: module that comprises the decisions made by the user, with these decisions being informed on the outputs displayed in the Outputs module. By exploring several scenarios and visualizing their outputs the user can make informed decisions on the use of available resources. The display of these outputs can influence how the DM interprets the results and therefore the decisions taken (Power & Sharda (2007)).

In terms of inputs and outputs, these are detailed in Figure 3. Accordingly, the inputs required for an adequate operation of the tool are divided in two types (enumerated in Figure 3):

i. Inputs introduced by the user, representing those that can be changed or introduced by the decision maker and that are updated in the excel file. The DM is provided with predefined values for each input, that can be changed during the Data Gathering module if necessary;

ii. Other sources of data from other sources, that cannot be changed in the user interface, and to which the end-user has no access. This information is required by the mathematical model, is stored in excel spreadsheets and is imported to GAMS to run the planning model.

Subsequently, when the model is solved, the outputs provided by GAMS are transferred back to the excel files and spreadsheets. The output data (enumerated in Figure 3) is afterwards visualized in the form of graphs in the user interface of the Output module. This includes geolocation data visualized in this module through a VBA Google Maps developed component, and it also includes an additional description on the main conclusions that can be taken from the results.

Inputs introduced by the user

General information:
- Geographical area of interest
- Annual budgets of operations and investments
- Equity objectives

Objective-related inputs:
- Equity improvement in the 1^{st} half of the period
- Status Quo
- Target
- Maximum distance traveled by patients
- Preferences related to each objective

Service-related inputs:
- Current geographical distribution of services
- Number of beds per unit
- Minimum number of beds per unit
- Average length of stay (LOS)
- Operational and investment Costs

Inputs from other sources

- Demand per service
- Distance between services and demand points
- Efficiency factor associated with the provision of institutional services

Outputs

- N^{er} of beds per service, unit and year
- Investment and operational costs per year
- N^{er} of individuals receiving each type of service per socioeconomic group, demand point and year
- Equity improvements
- Geographical distribution of services per year
- Geographical distribution of patients per unit, service and year

Figure 3 – Inputs and Outputs of the LTCPlanner

To summarize, in the user interface module the DM has the ability to change/introduce the information required as input to the mathematical program planning model. The values introduced are saved in excel files that are used in GAMS, which in turns runs the mathematical model adapted from Cardoso et al. (2016). Once the optimal solution is achieved, the outputs are then saved in excel files, which are afterwards displayed in the User Interface through graphs and maps (based on google maps). Through this sequence of actions, decision makers have information in user-friendly formats that will support them making planning decisions. All this sequence of actions and flow of information are represented in Figure 2.

5.1.2.1. Data Gathering Module

In Figure 4, the *LTCPlanner* overall scheme for the data gathering module is shown.

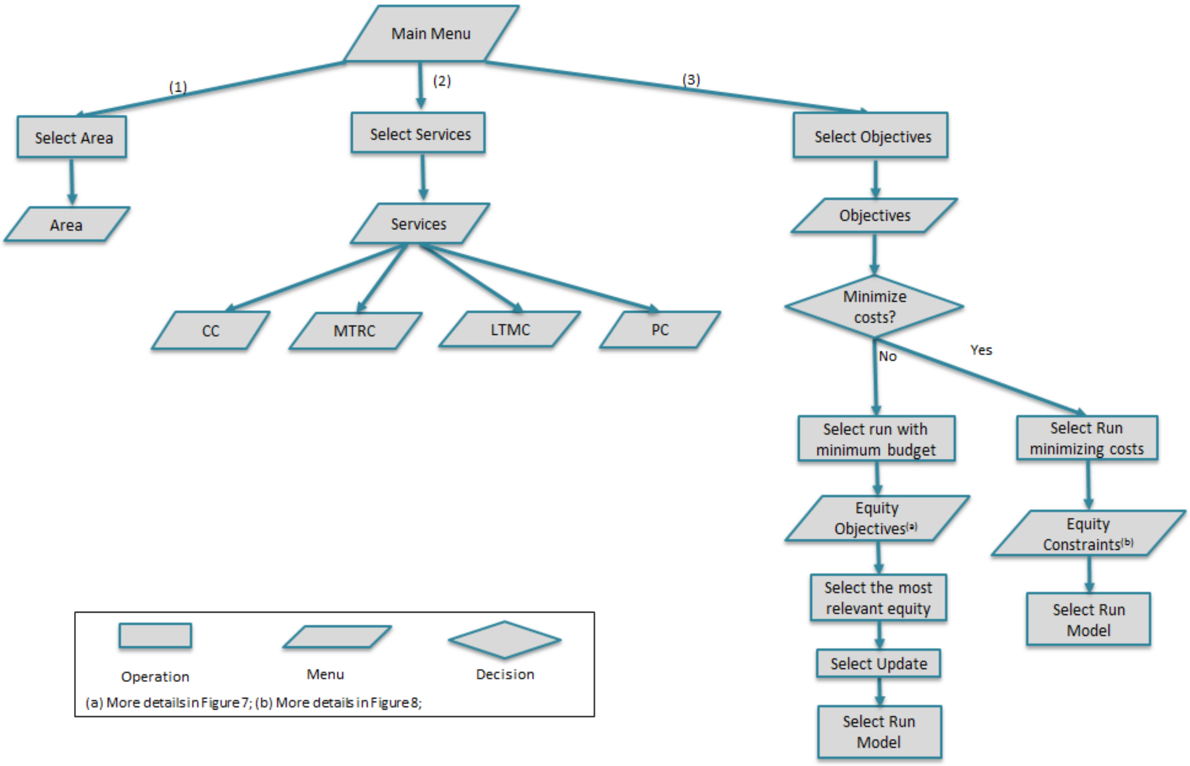


Figure 4 – LTCPlanner Main Menu. Legend: CC – convalescence care; MTRC - medium-term and rehabilitation care, LTMC - long-term care and maintenance care; PC - palliative care units.

The Data Gathering module is organized in three major parameter capture windows: (a) *Area*; (b) *Services*; and (c) *Objectives*. These menus are used to introduce/update inputs (as it can be seen in Figure 4). The *Main Menu* frame is used to navigate between this menus.

The Data Gathering Framework involves several steps, as described below.

Step 1: Select the *Area* form

This form (detailed in Figure 5) is used to select the geographical area to analyse and gives the opportunity to introduce the annual budget available for operations and investments, if the DM considers it relevant. The budget available for operations refer to expenditures with inpatient services, whereas the budget for investments are meant as expenses on new beds. The tool is predefined for a planning of five years, therefore the budget is defined for each of the five years.

When selecting the geographical area the DM is provided with a map which is divided in five areas (Lisbon and Tagus Valley, *Centro, Norte, Algarve* and *Alentejo*) that the DM can select by clicking. Afterwards, the DM is able to update or maintain the values assigned to the annual budgets available for operations and investments. Following these steps, the DM has to select the *Menu* button to return to the *Main Menu* form.

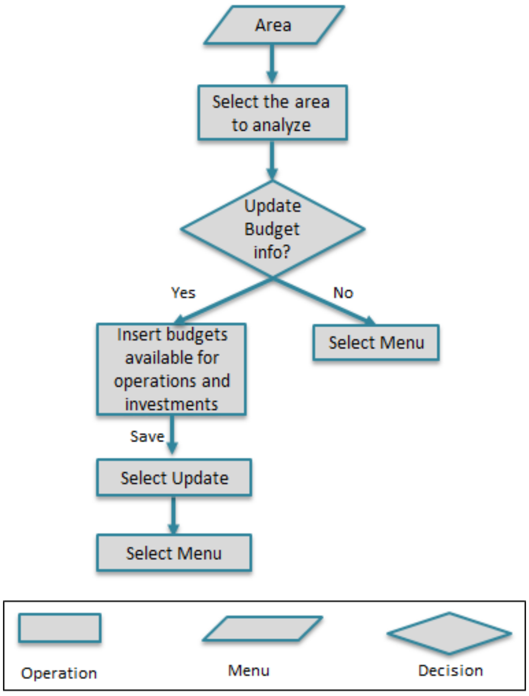


Figure 5 – Area menu

Step 2: Update the service information

Here, the DM can verify and update, or not, the information related to each of the four institutional services available within the RNCCI, selecting the *Services* option. The *Services* menu is then displayed, with four sub sections, each related to each of the institutional care services: (1) Convalescence Care units (CC), (2) Medium-term and rehabilitation Care units (MTRC), (3) Long-term and Maintenance Care units (LTMC) and (4) Palliative Care units (PC).

As it can been seen in Figure 6 in all the previous sub-menus the DM has the opportunity, for each type of service, to insert the values for operations and investment costs, LOS and minimum number of beds per unit. In this window the DM also has the ability to change information related to the opening and closure of units and changing the number of beds in each unit. In particular, when:

- There is a new unit providing a certain type of service that does not appear in the list of available units, the DM can add it. E.g. if the DM wants to open a new unit with a CC service, then in the CC sub-section the DM selects "*Create new unit*" which leads to a new window where the name of the unit has to be selected and the number of beds needs to be assigned. After selecting OK the new unit is inserted in the list of units providing CC and the DM returns to the Services framework.
- A service is no longer providing care, the DM can close it by changing to zero the value of beds assigned to that unit. If for instance a unit providing CC is no longer providing this type of

service, then in the CC sub-section the DM selects the name of the unit and changes the number of beds to zero and selects update. After this the unit is no longer in the list of units providing CC.

- The number of beds of a certain unit providing a certain type of service does not correspond to the value shown in the interface, the DM can update this number to the correct one. E.g., if a given unit providing CC services changed the number of beds from 10 to 15, then the DM can update this value. The procedure is the same when closing the unit but in the end the unit is still in the list of units providing Convalescence care but with 15 beds.

In the previous steps the DM is only able to update the list of units providing services with locations that are already providing at least one type of LTC service, i.e., The *LTCPlanner* is only able to use units that are already operating in the network.

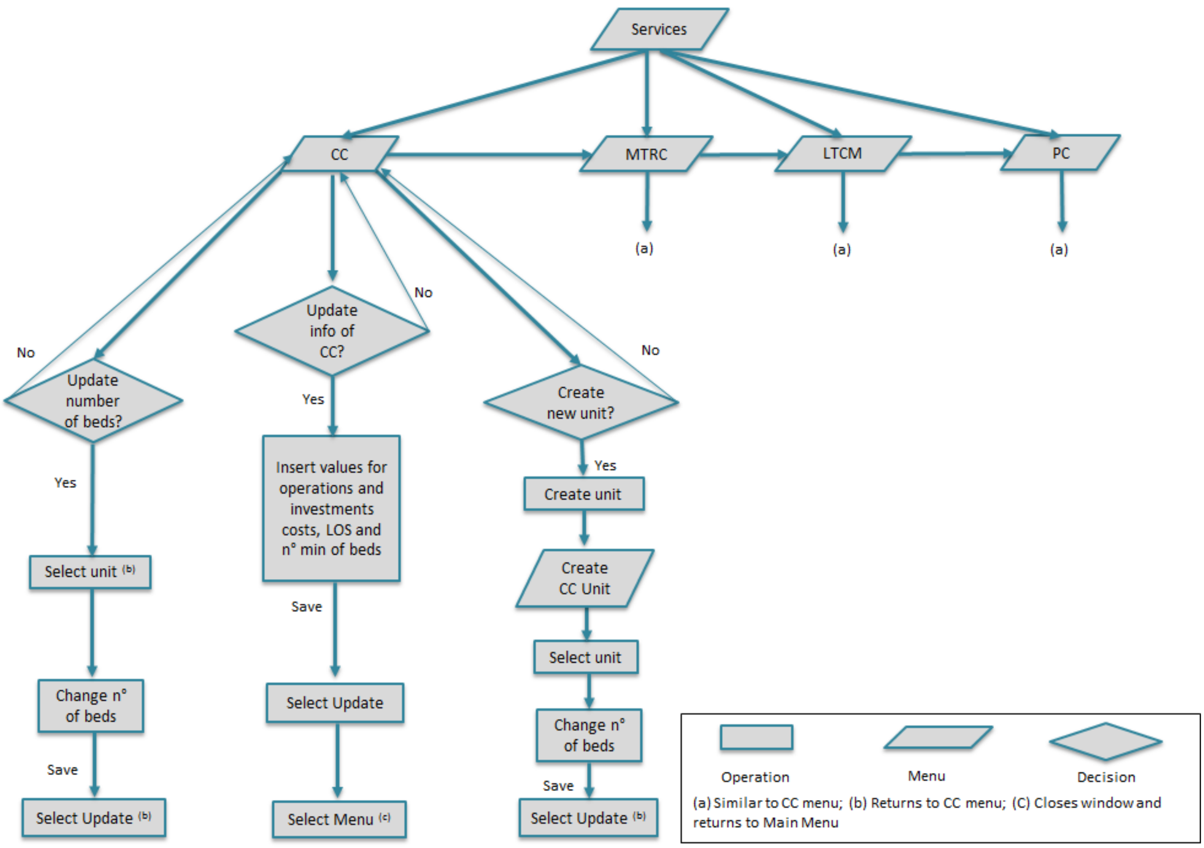


Figure 6 – Services menu: Steps involved in the Convalescence care units (CC), Medium-term and rehabilitation care units (MTRC), Long-term and maintenance care units (LTMC) and Palliative care units (PC) windows.

Step 3: Select the Objectives

For the purpose of this thesis, and according to Section 2.2.3, key policy objectives include providing the equitable distribution of resources and access to care regardless of socioeconomic conditions and location, and these also represent key objectives for health care services when provided within the scope of a NHS-based system (Ministry of Health 1990). Accordingly, four different equity concerns are accounted for in the tool: Equity of Access (EA), Geographical Equity (GE), Socioeconomic Equity (SE) and Equity of Utilization (EU).

In this line of thought, once the *Objectives* menu is selected, the DM needs to select which context of planning is to be considered in the LTC network (re)organization:

i. Planning context A: There is a minimum budget assigned to plan the LTC network that cannot be exceeded and equity improvements are the most relevant objectives when (re)organizing the network (i.e., these are the objectives to be maximized in the model). One should bear in mind that equity-related objectives are key concerns of any NHS-based country (as noted above).

ii. Planning context B: There is no budget limit and the DM seizes to plan the network with a minimum cost. The aim here is to improve LTC delivery so as to achieve several equity targets at a minimum cost. Accordingly, the DM has to select the equities in which a minimum satisfactory value is wanted (i.e., these equity concerns are considered as constraints of the model);

The two alternatives are illustrated in Figure 16 (see chapter 6), in which the DM has to choose between the two planning contexts (A or B)

As it can be seen in Figure 4 the procedure behind the Data Gathering module is similar when comparing these two planning contexts. Figure 7 and Figure 8 represent the steps to be taken by the DM when selecting planning context A and planning context B, respectively. In both planning contexts, it is asked which are the equities that are to take into account when the planning the network. And for each equity selected it is asked to update, or not, the information regarding the equity selected (Present Situation, the Target, and for the case of EA the Maximum distance that can be travelled by each patient).

The equities that can be selected in the different planning contexts are: EA, GE, SE and EU. These will be described in more detail afterwards. It is necessary to mention that the DM is able to select one or multiple equity objectives when planning the LTC network.

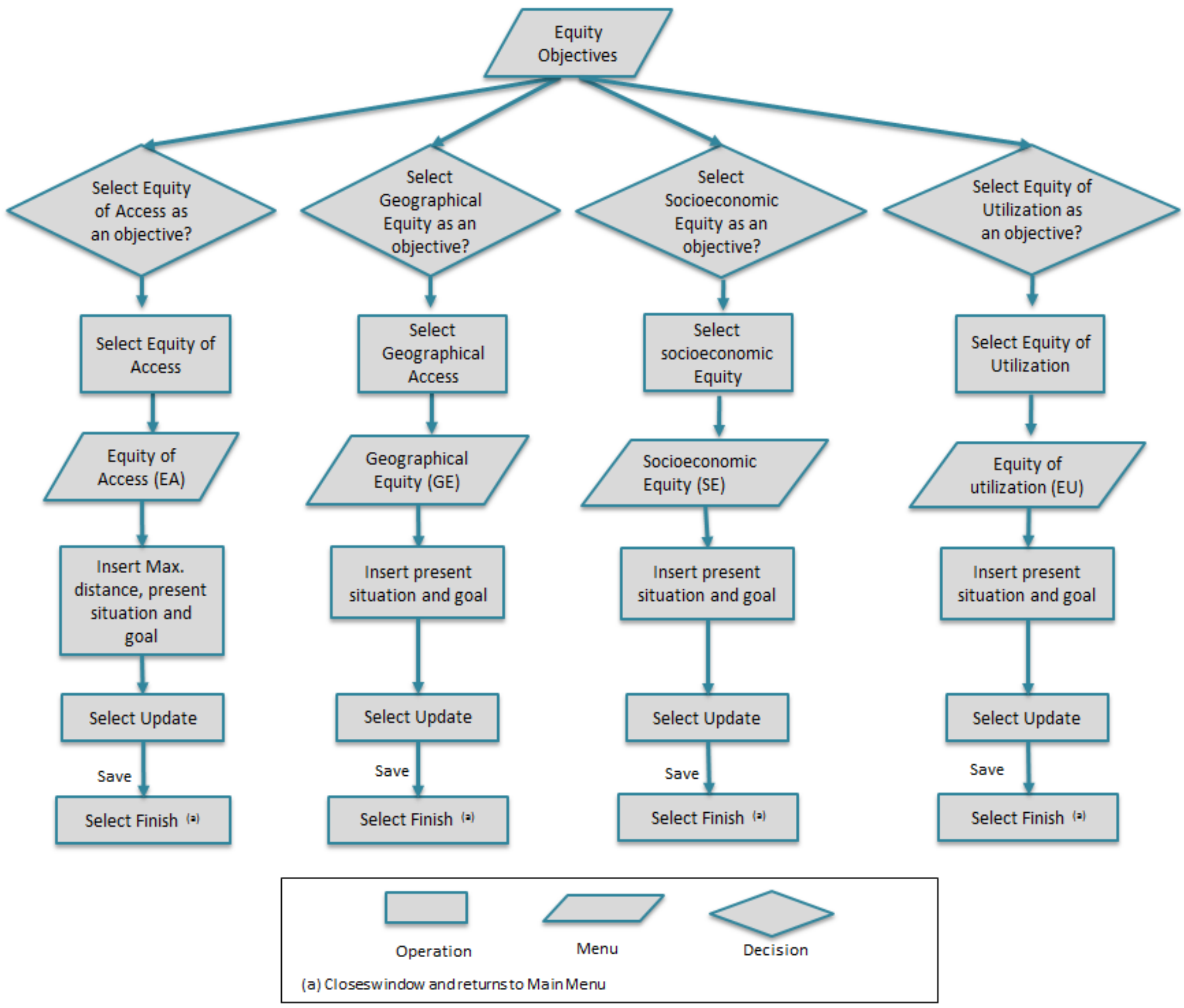


Figure 7 – Steps followed to select the equity objectives, namely, Equity of Access, Geographical Equity, Socioeconomic Equity and Equity of Utilization under planning context A

Under planning context A, after selecting the minimum budget option (see Figure 16 in chapter 6) the DM is presented with a new window to select the relevant equities to the network planning. For each equity that is selected, a second window is shown, similarly to Figure 18 shown in chapter 6 (this is the window that is shown if EA is selected) and Figure 19 shown in chapter 6 (this is the window shown if EU is selected, with the windows associated with GE and SE being similar to Figure 19 [see chapter 6]). In these windows, the DM can find the information regarding the equity selected where the following values have to be inserted: Present Situation, the Target, and for the case of EA the Maximum distance that can be travelled by each patient. In particular, the different types of equity that are available for selection by the DM are as follows:

i. EA: ensures that LTC provision takes place as close as possible to the patient's residence, and at the same satisfy the greater number of patients possible. The EA is defined in minutes. The Present Situation refers to the average travelling time that a patient takes to access LTC services, and the Target is the ideal average travelling time that the patient should take to access services (from the DM's point of view). The maximum distance is the maximum travelling time a patient takes to get to the unit (also from the DM's point of view).

ii. EU: allows maximizing the provision of institutional LTC for the type of service with the lowest level of provision. It's measured in percentage of patients that are not receiving care. The Present Situation is the percentage of patients that do not receive care nowadays. The Target is the percentage of patients with no access to the type of service with the lowest provision that is desired to be achieved by the DM until the end of the planning horizon.
iii. GE: ensures the maximization of LTC delivery in the geographical region with the worst level of provision. It's measured as the percentage of patients in a certain area not receiving care. The Present Situation is the current percentage of patients not receiving care in the demand point with the worst level of LTC provision. The Target is the percentage of patients with no access to LTC that is desired to be achieved by the DM until the end of the planning horizon.
iv. SE: ensures the minimization of unmet need for the lower income groups. The SE is measured in percentage of patients with low income not receiving care. The Present Situation refers to the current percentage of patients of lower income groups not receiving care. And the Target is the percentage of lower income patients with no access to LTC that is desired to be achieved by the DM until the end of the planning horizon.

It is important to refer that when the DM has to insert the previously mentioned inputs the tool provides suggestions that can be altered by the DM. See for instance Figure 18 (in chapter 6), where the maximum distance travelled by patients is suggested to be 30 min but if the DM does not agree with this value it can be changed by inserting the value in the same box and selecting *Update*.

It is also important to note that the DM is able to select one or more equities. After selecting all the equities wanted as objectives to plan the network, the DM has to select which (and if any) of the equities is the most relevant in the (re)organization of the LTC network. And through this, a higher value is assigned to the weight of this equity. Particularly, the following cases are considered:

i. If two equity objectives are selected, the most important objective is assigned with a weight of 0.7 and the other with 0.3;
ii. If three equity objectives are selected, the most important objective is assigned with a weight of 0.5 and the others with 0.25 each;
iii. If the four equity objectives are selected, the most important objective is assigned with a weight of 0.4 and the others with 0.2 each;

Once the DM has selected the equities considered as relevant to plan the network, as well as the most relevant of them, the DM has conditions to select the *Run* button to start modelling the network.

Under planning context B, and similarly to planning context A, the DM is provided with a window where the relevant equities have to be selected, but in this case these are not considered as the main objectives of the mathematical model but as constraints that impose the achievement of satisficing levels of equity (more details can be found in section 5.2).

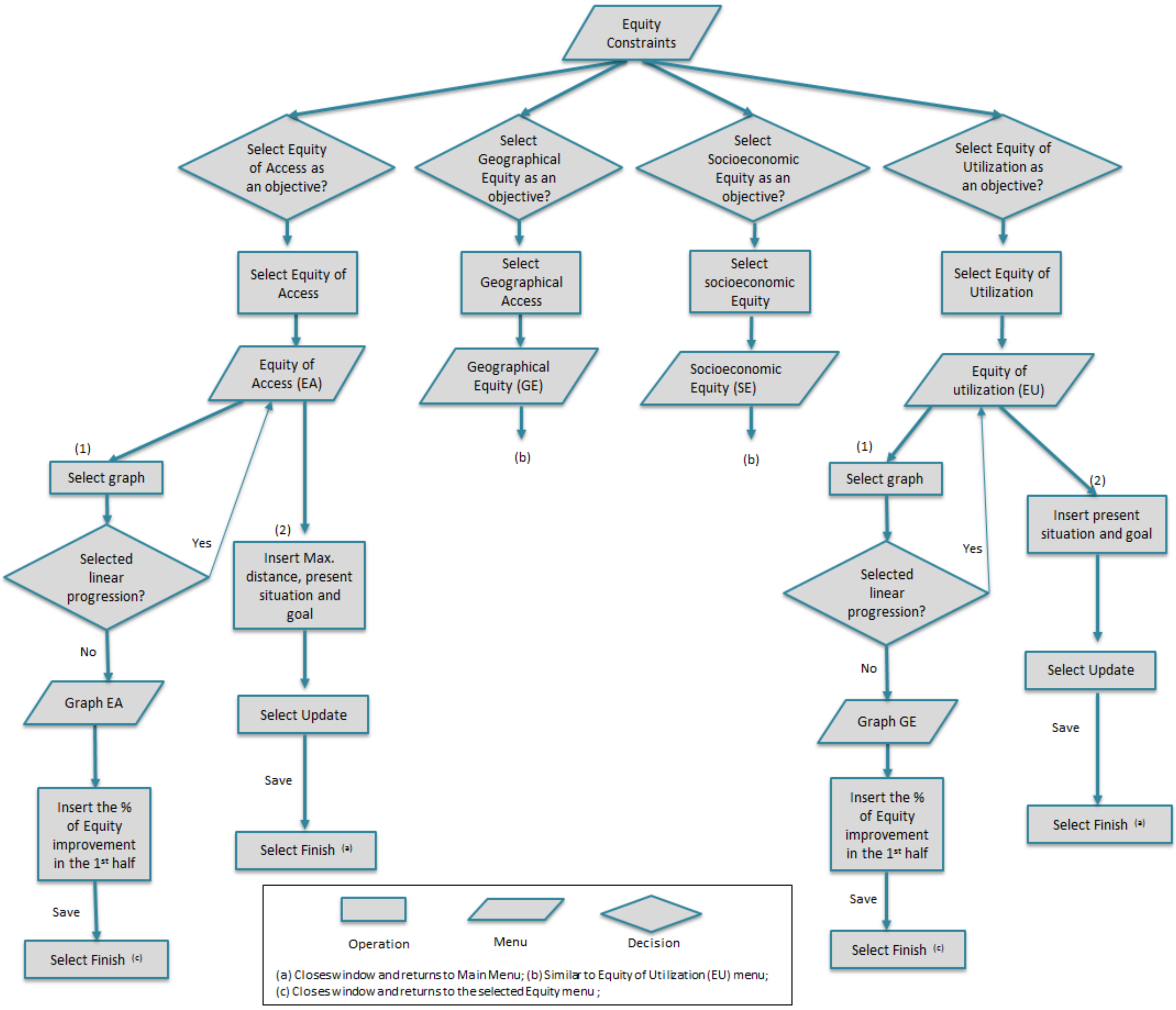


Figure 8 – Steps followed to select the relevant equity satisficing levels, namely Equity of Access, Geographical Equity, Socioeconomic Equity and Equity of Utilization under planning context B

For each equity selected, the DM is presented with a new window (see Figure 22 in chapter 6) where there is need to select the graph that better shows how each equity improves over time. For this, the DM has to select one of the three graphs displayed in Figure 22 (see chapter 6): if the DM prefers that equity improvements are verified mainly in the first or second half of the time period, the DM should select the graph in the middle or in the left, respectively: whereas if this improvement should be equally distributed over time, the graph in the right should be selected. If the linear progression is not selected, a new window opens so that the DM is able to select the percentage of improvements wanted for the first half of the time period. In the case of the linear progression this value is not necessary since it implies equally distributed improvements for each period. Still, this value should be defined for the other two types of temporal progressions. For instance, if most of the improvements should take place in the first half of the planning horizon, the DM needs to set a value higher than 50% for the percentage of improvements during that period. On the other hand, a value lower than 50% should be defined for the percentage of improvements in the first half whenever the DM aims to obtain most of the improvements in the second half of the time period.

After introducing all the information related to temporal progression of equity and selecting *Conclude,* the decision maker returns to the Equity window where the following values have to be inserted (similarly to the described for planning context A): Present Situation, the Target and in case Equity of Access is selected Maximum distance.

When the DM has finished inserting all the objectives-related information, the DM has all the conditions to select the *Run* Button and start the modelling procedure (details in chapter 5.2)

The main differences in these procedures are mainly found when characterizing the equities selected:

- Temporal Equity improvements: Under planning context B (minimization of costs) the DM is able to choose different temporal progressions for each equity selected, whereas under planning context A this choice is not allowed. And this because under planning context A the budgets available are annual, and therefore there is no reason for allowing the selection of which period should be used for making the majority of the investments in the network.
- Most important equity: Under planning context A, after selecting the relevant equities objectives for the network planning, the DM has to select which of the selected equities is the most important, when compared to the remaining ones. Under planning context B, since the minimization of costs is the single objective, all the equities are considered as constraints and their relative importance is not asked.

Summing up, the User interface is the only module of the *LTCPlanner* to which the decision maker has access to. And is constituted by the Data Gathering and Outputs modules.

5.1.2.2. Data Storage Module

The Data Storage module was developed in Microsoft Excel, a popular spreadsheet application that is significantly used in articulation with model driven DSS (Power & Sharda, 2007). Microsoft Excel provides a spreadsheet package, and therefore has many advantages if one wants to build a DSS (see chapter 3.2), and in this particular DSS where the mathematical model was developed in GAMS, Microsoft Excel also has the advantage of being capable to be linked with GAMS (Katok & Ott, 2000). The Microsoft Excel is also embedded with VBA that provides a real time, user-friendly, graphical user interface (Chongwatpol & Sharda, 2010). Also, VBA enables the DM to have minimum contact with the data, as well as with the different programs that are used in the DSS developed (Schuurman et al., 2008).

In this module, all data related with the inputs (either introduced by the user and from other sources, such as information collected from literature in the area of LTC) and outputs is stored as Microsoft excel spreadsheets. The DM has no direct access to this module: the link to the user interface is automatic, i.e. the DM does not have to introduce manually the data in the spreadsheets nor have the outputs to be interpreted directly from the spreadsheet. This implies that, to make planning decisions, the DM does not need to interpret the data stored in the spread sheets, since it is displayed in graphs and maps in the Outputs module (more details can be found below). This module also does the connection with the Data processing module, where the mathematical programming model is solved. The software GAMS receives the information automatically from excel, and when the model is solved the outputs are transferred back to excel. Taking all these factors into account, the Data Storage module promotes an easier decision making, diminishes errors and time expenditure.

5.1.2.3. Data Processing Module

The Data Processing module includes the mathematical programming model that is implemented in GAMS and solved with CPLEX. The mathematical model is adapted from Cardoso et al. (2016) (details on the changes made in the model can be found in Chapter 5.2), who proposes a multi-objective and multiple-period model to support planning decisions in LTC sector. It provides information on where and when to allocate services and with which capacity, how to distribute this capacity throughout the different types of services, socioeconomic groups and suggest which changes must be done over time.

Once again, the DM has no access to this module: the link between excel and GAMS is made automatically. Further information on the mathematical models will be given in the Chapter 5.2.

The output of the Data processing Module is stored in excel spreadsheets and are afterwards shown in the user interface through graphs and maps.

5.1.2.4. Outputs Module

The Outputs module provides the DM with graphs and maps to aid in the decision making process. These graphs and maps reflect the results of the mathematical model in accessible formats that allow an easy interpretation and analysis. The results window opens after the mathematical model has been solved and shows seven sub-sections:

i. *Units*, the number of beds per unit and type of service throughout the years;
ii. *N^re of beds*, number of beds per type of service in each year;
iii. iii. *Budgets*, annual budget available and costs that were incurred for operations and investments;
iv. *Demand Points*, The number of patients in different socioeconomic groups per demand point and year;
v. *Objectives*, the values of equity obtained compared with the initial and wanted values of equity;
vi. *Maps* the geographical distribution of units per service, unit and year and vii.
vii. *Access* the geographical allocation of patients to units and services.

A Microsoft Word Document is automatically created with a summary of the results obtained.

In Figure 9 the Results menu is shown. This window is available to the DM once the modelling routine is conclude. The DM can navigate through the seven different sub-sections mentioned above.

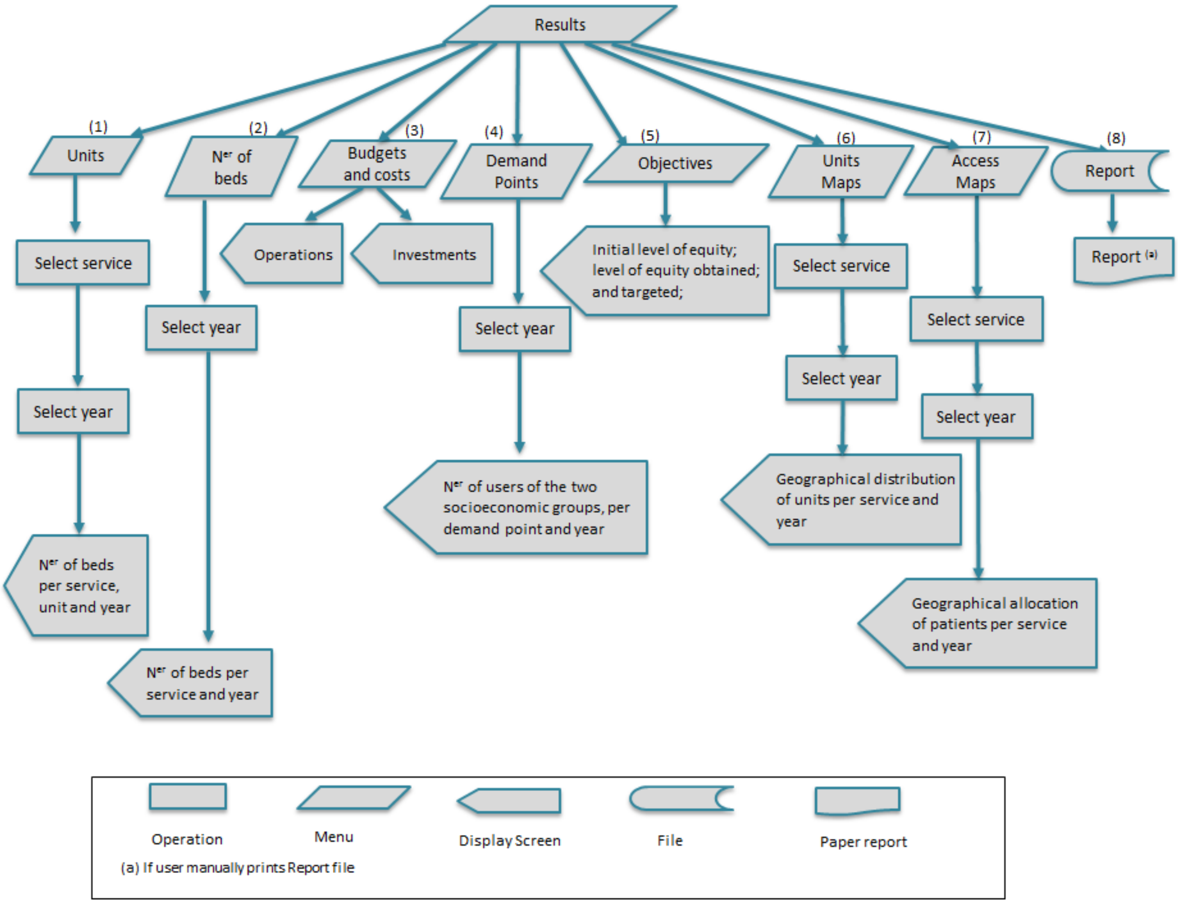


Figure 9 – Results Window

Firstly, the DM is presented with the window *Units* where the DM is able to view the number of beds per service, unit and year by choosing the type of service and year. The second window, *N^{re} of beds*, allows the decision maker to analyse the temporal changes on the number of beds available in the four types of services. This window allows the DM to see in detail the number of beds per service in each year, where the previous window provides a broad view on the number of beds during all the temporal resolution. The third window is a graphic comparison on the annual budgets available and the costs that were actually incurred. In the *Demand Points* window, the DM can verify the number of individuals belonging to different socioeconomic groups and receiving institutional LTC per demand point and year. The last window with graphical representations is the *Objectives* where a spider diagram is used to enable the DM to evaluate which equity improvements are obtained with the planning process. In particular, this diagram allows two different analysis:

- Comparing the initial level of equity with the achieved level of equity, allowing the quantification of equity improvements for the entire planning period (with this improvement being explicitly shown and described below the diagram [Figure 28 in chapter 6]);
- Comparing the achieved level of equity with the target defined by the decision maker as the desired level to be achieved.

The maps window provides the geographical distribution of services per unit and year (see Figure 29 in chapter 6), together with a graphical representation on the allocation of patients across services - Access window (see Figure 30 in chapter 6).

At the end of the modelling procedure, a report on the results is generated. This is a Microsoft Word Document with the main conclusions of each of previous graphs.

5.1.2.5. Decision Making Module

The Decision Making module is where the DM has the main influence and the *LTCPlanner* has a supporting role. The DM has to make a decision based on the outputs provided by the DSS. Here the DM is expected to make use of the results shown in the different windows of the Results menu, and in the automatically generated Microsoft word report. It is important to mention that the display of the outputs influences how the DM retrieves the information (Power & Sharda (2007)). The DM can find details on the main conclusions and facts to be considered when interpreting the results presented in the previous mentioned windows. Further information on the results interpretation will be provided in Chapter 6.

5.2. Mathematical Programming

As mentioned before, the LTCPlanner is a model driven DSS to be applied to the LTC sector in countries based on a NHS- based system, representing an easy to use tool to aid decision making. The mathematical model used as a basis to build this tool is adapted from Cardoso et al. (2016). These authors developed a multi-objective and multi-period MILP model – LTC_{MOPE} – to provide information to aid planning a LTC network in the context of NHS-based countries, providing detailed information to support a set of decisions regarding the location and capacity planning for different levels of spending, considering the provision in four different types of institutional services: CC, MTRC, LTMC and PC.

For that, three equity objectives were accounted for, namely, EA, GE and SE. These equity objectives are assigned with different weighting coefficients considering the judgment of the decision maker. For this, the Measuring Attractiveness by Category–Based Evaluation Technique (MACBETH) was used. MACBETH follows a constructive view that through qualitative judgements evaluates the difference of attractiveness between options and generate weights for each criteria.(Bana e Costa et al., 2012).

Still, the LTCPlanner makes use of the mathematical model developed in Cardoso et al. (2016) with some changes based on a more recent version of it presented in Cardoso et al. (2015) and also with new features that are thought to be important for network planers. In particular, new objectives are introduced in the model, namely, maximization of equity of utilization (EU) and minimization of costs (based on Cardoso et al. (2015)), and additional constraints that allow modelling how each objective will improve over time.

Regarding these additional constraints (see Figure 10), they will allow modelling the temporal progression of equity improvements (choosing between graph1 - 3 in Figure 10) in line with the requirements of the DM. In particular, the DM can decide whether to have equity improvements mainly in the first half of the planning period (graph 2), or in the second half (graph 1) or even to have a steady growth of equity improvements (graph 3).

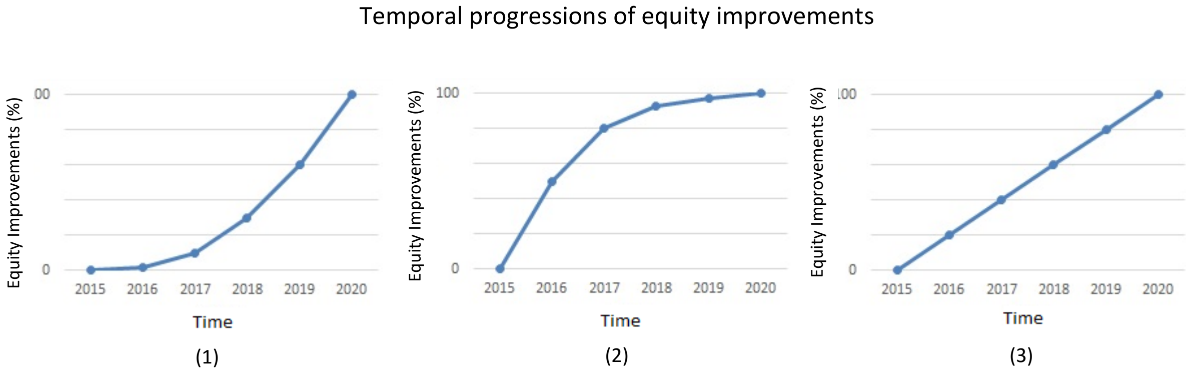


Figure 10 – Equity improvements with different temporal progression. From the left to the right: (1) the improvements are particularly in the second half of the temporal resolution; (2) the improvements are particularly in the first half of the temporal resolution (3) the improvements are equal for all the years

This new feature is intended to provide more flexibility in the use of the budgets, since it allows the DM to select different equity progressions over time when investments are made:

i. If the planner believes it is better to save some money in the following years, investments will be delayed for the last years of the planning horizon. This may be relevant when, for instance, planners have other policy priorities at hand for the coming years. For this, graph 1 of Figure 10 should be selected;

ii. If achieving equity improvements as fast as possible is a priority for the planner, investments will take place in the first years, as soon as possible. This may be relevant, for instance, when elections are approaching, and governments need to show positive results. For this, graph 2 of Figure 10 should be selected;

iii. If the planner has no particular interest on delaying or anticipating the expenditures regarding the equity improvements then graph 3 of Figure 10 should be selected;

All the adaptions made to the mathematical model (including an additional objective of equity of utilization and cost objectives, as well as modelling the temporal equity improvement) are thought to be relevant to the LTC network planning. The mathematical details underlying these adaptions are presented in detail below.

5.2.1. Building the mathematical programming model

This section presents the mathematical details on the adaptations made to the model proposed in Cardoso et al. (2016). All the mathematical details that were not changed for the purpose of this thesis are not shown here. The entire model formulation was implemented in GAMS and used in the *LTCPlanner* Data Processing module (and can be found in Cardoso et al. (2016)).

This chapter is organized as follows. First, the indices, sets, parameters and variables that were used to formulate the model changes are listed. Then, the objectives and the new constraints added to the mathematical programming model are presented.

5.2.1.1. List of Indices, Sets, Parameters and Variables

The following tables sumarize the list of indices, sets, parameters and variables that are used when formulating the new objectives and constraints of the mathematical programming model used in the *LTCPlanner*. When comparing to the original model, the following parameters and variables were added:

a) Parameters related to the new objective of EU: weight associated with this objective (w^{EU}), status quo (i.e., current level of achievement) for EU (SQ^{EU}) and target for EU (MT^{EU});
b) Weight associated with the cost objective (w^{CC});
c) Percentage of equity improvements desired for the first half of the planning period for all the types of equity ($Gr^{EA}, Gr^{GE}, Gr^{SE}, Gr^{EU}$);
d) Variables related to the new objective of EU: equity objective (f^{EU}) and equity measure at t (E_{st}^{EU}).
e) Weighted sum of equity improvements ($EqMax$) and weighted sum of total costs ($CostMin$).

Table 2 – List of indices

Indices	Description
t,w,c	Time periods
d	Demand Points
g	Socioeconomic Groups
l,j	Location for Services
s,p	Institutional LTC Services

Table 3 – List of Sets

Sets	Description
T	Set of time periods
D	Set of demand Points
$G = G^P \cup G^{NP}$	Set of socioeconomic groups divided into subsets G^P(groups of individuals with priority due to low levels of income, $g \in G^P \subseteq G$) and G^{NP}(groups of individuals without priority due to high levels of income, $g \in G^W \subseteq G$)
L	Sets of location for services
S	Set of institutional LTC services

Table 4 – List of Parameters

Parameters	Description
I_{dgst}	Number of individuals from demand point *d* and socioeconomic group *g* requiring service *s* at *t*
IS_{st}	Number of individuals requiring service *s* at *t*
α_s	Investment cost (€) per new bed in institutional service *s*
β_s	Operational cost (€) per bed in institutional service *s*
χ_s	Cost (€) of reallocating a bed to institutional service *s* from a service delivered in a different location
δ_s	Cost (€) of reallocating a bed to institutional service *s* from a service delivered in the same location
$w^{EA}, w^{GE}, w^{SE}, w^{EU}, w^{CC}$	Weights (%) for each objective (equities and cost considerations)
$SQ^{EA}, SQ^{GE}, SQ^{SE}, SQ^{EU}$	Current levels of achievement (%) for each equity objective
$Gr^{EA}, Gr^{GE}, Gr^{SE}, Gr^{EU}$	% of Equity improvement in the first half of the planning horizon
$MT^{EA}, MT^{GE}, MT^{SE}, MT^{EU}$	Medium – term targets (%) set by the decision makers for each equity

Table 5 – List of Variables

Variables	Description
R_{dgslt}	Proportion of individuals from demand point *d* and socioeconomic group *g* receiving service *s* in location *l* and at *t*
RS_{st}	Number of individuals receiving service *s* at *t*
$f^{EA}, f^{GE}, f^{SE}, f^{EU}$	Equity objectives
$E_t^{EA}, E_{dt}^{GE}, E_t^{SE}, E_{st}^{EU}$	Equity measure defined for each equity objective at *t* (at service *s* for EU and for demand point *d* for GE)
AB_{slt}	Number of additional beds in which there is need to invest for institutional service *s* located in *l* at *t*
B_{dgslt}	Number of beds made available for individuals from demand point d belonging to socioeconomic group *g* and receiving service *s* in location *l* at *t*
RB_{slpjt}^{in}	Number of beds reallocated to services located in *l* from service *p* located in *j* at *t*
$EqMax$	Weighted sum of the equity objectives
$CostMin$	Weighted sum of the Total costs

5.2.1.2. Objectives

As mentioned before, the DM is able to select which context of planning is to be considered in the LTC network (re)organization: maximization of equity improvements when a limited budget needs to be respected (Planning context A); or cost minimization with the achievement of equity targets (Planning context B). Therefore, the objective function given by equations (1-3) is constituted by two parcels that reflect the mentioned alternatives (maximization of equity and minimization of costs).

$$Min\ (EqMax + CostMin) \tag{1}$$

$$EqMax = w^{EA} f^{EA} + w^{GE} f^{GE} + w^{SE} f^{SE} + w^{EU} f^{EU} \tag{2}$$

$$CostMin = w^{CC} \sum_{t \in T} \sum_{l \in L} \sum_{s \in S} \left(AB_{slt} \times \alpha_s + \sum_{p \in S} \sum_{\substack{j \in L \\ j \neq l}} \chi_s \times RB_{slpjt}^{in} + \sum_{p \in S} \delta_s \times RB_{slplt}^{in} + \sum_{d \in D} \sum_{g \in G} B_{dgslt} \times \beta_s \right) \tag{3}$$

Equation (1) represents the global objective function that allows maximizing equity improvements and minimizing costs. The maximization of equity improvements (equation (2)) is achieved by minimizing the equity levels obtained for each type of equity ($f^{EA}, f^{GE}, f^{SE}, f^{EU}$), with different weights assigned to each equity objective ($w^{EA}, w^{GE}, w^{SE}, w^{EU}$). In particular:

- f^{EA} represents the average travelling time for individuals accessing institutional services.
- f^{GE} represents theunmet need in the geographical area with the highest levels of unmet need.
- f^{SE}represents the unmet need for the lower income groups.

- f^{EU} represents the level of unmet need for the institutional LTC service with the worst level of provision.

In equation (3) the w^{CC} corresponds to the weight assigned to the cost-related objective. This equation sums all the expenditure related to: investments in new beds (first parcel), to the reallocation of beds between services within the same location (third parcel) or between services in different locations (second parcel) and to the operational costs per each bed used in the LTC network (fourth parcel).

Equation (2) includes the three equity objectives already considered in the model proposed by Cardoso et al. (2016) (EA, GE and SE). Nevertheless, and as noted by Cardoso et al. (2016), the joint consideration of these three equity objectives do not 'avoid situations in which patients that have the longest LOS do not receive the care they need'. To address this issue, and following the same reasoning used in Cardoso et al. (2015), additional conditions were added to the model developed in Cardoso et al. (2016) so as to allow the use of an additional objective, namely, equity of utilization (Equations.(4-6)). These equations ensure the minimization of unmet need for the type of service with the lowest level of provision. By doing so, one can ensures that no institutional LTC service is left behind, without any provision. This is achieved by minimizing f^{EU}, which represents the value of equity of utilization for the service with the worst provision of LTC.

$$Min\ f^{EU} \geq E^{EU}_{s(t=|T|)} \quad (4)$$

$$E^{EU}_{st} = \left(1 - \frac{RS_{st}}{IS_{st}}\right) \forall\ s \in S, t \in T \quad (5)$$

$$RS_{st} = \sum_{g \in G} \sum_{d \in D} \sum_{l \in L} R_{dgslt} I_{dgst}\ \forall\ s \in S, t \in T \quad (6)$$

As the model relies on multiple objectives, we considered an objective function written as the weighted sum of the objectives (Equations (1-3)). In this line of thought, $w^{EA}, w^{GE}, w^{SE}, w^{EU}, w^{CC}$ represent the weights assigned to each objective. For the purpose of this thesis, the approach followed to define these weights is different from Cardoso et al. (2016). In particular, these authors used the Measuring Attractiveness by a Category-Based Evaluation Technique-MACBETH to build and interpret these weights together with the decision maker. In this thesis, the *LTCPlanner* cannot make use of MACBETH to calculate the attractiveness of each equity, since it is not possible to automatically read the results from MACBETH to excel. So, to overcome this limitation, the DM is asked to identify which of the selected equities is the most relevant to the network planning process, and then the value assigned to the weight of the equity selected is higher than the others. For instance if three equity are selected the one with more relevance is weighted with 0.5 and the other two equities are valued with 0.25.

Depending on the planning context considered by the decision maker when planning the LTC network, different values are assigned to these weights:

i. If the decision maker has the objective to plan the network improving the selected equities with a limited budget, the value of w^{CC} in equation (3) is equal to zero;

ii. If, on the other hand, the decision maker wants to (re)organize the network considering the improvement of the equities selected with the minimum budget possible, the minimization of costs is considered as an objective and the equity improvements are modelled as constraints (see section below). In this context, the values of w^{EA}, w^{GE}, w^{SE} and w^{EU} are equal to zero.

5.2.1.3. Constraints

Once the objective function is defined, several constraints need to be defined. According to Cardoso et al. (2016), the constraints are grouped as follows:

i. Resource requirements, calculates the number of beds that should be made available;
ii. Reallocation of beds, ensures that the reallocation of beds follow a set of conditions;
iii. Minimum and maximum capacity, ensures that the total number of beds is not lower that the total number of beds additionally created in previous periods;
iv. Opening and closure of services, ensures that a service cannot be closed/opened if the same service was opened/closed, respectively, in the previous time period;
v. Assignment of patients, individuals should only receive service s in locations where the required service is available;
vi. Single and closest assignments, ensures that the individuals in each demand point d will receive the care they need in the closes available service;
vii. Gradual equity improvements: Ensure the gradual improvements on equity along the planning horizon;
viii. Budget limitation constraints: guarantee that the annual operational and investment costs in the LTC network are within the available operational and investment budgets. In this thesis this constraint is only applied in the planning context A, when there is a minimum budget assigned to plan the LTC network that cannot be exceeded and equity improvements are the most relevant objectives when (re)organizing the network.

So as to adapt the model as described in the beginning of section 5.2, it is now necessary to define an additional set of constraints so as to allow the integration of the model within the proposed tool, namely equity improvements' constraints. These additional constraints are used whenever no budget limitation is considered and the decision maker aims at organizing the network so as to achieve a certain level of equity improvement at a minimum cost

These constraints can be stated according to equations (7-26). Particularly, equations (7-10) impose that each level of equity (at the end of the planning horizon) should not be higher than the medium-term target (MT) defined for each type of equity. Note that higher levels of equity represent worst levels of provision (i.e., higher values of EA represent lower access due to higher travelling times, and higher values of GE, SE and EU represent higher percentages of patients with no access to LTC), and so minimum satisfactory values are imposed in these cases.

$$E^{EA}_{(t=|T|)} \leq MT^{EA} \tag{7}$$

$$E^{GE}_{d(t=|T|)} \leq MT^{GE} \tag{8}$$

$$E^{SE}_{(t=|T|)} \leq MT^{SE} \tag{9}$$

$$E^{EU}_{s(t=|T|)} \leq MT^{EU} \tag{10}$$

Furthermore, an additional set of constraints is also defined to model the improvements of each type of equity over time (equations (11-26). This is relevant because it gives the opportunity of investing earlier in the network, or saving money for investments in the future, depending on what is considered as relevant for the decision maker. In particular, if the DM wants to obtain most of the equity improvements in the second half of the planning horizon, equations (11-14) should be used .In this, it is imposed that in the first half of the planning horizon a certain percentage of equity improvement is achieved (GR^{EA}, and defined similarly for the remaining equities) and cannot be exceeded.

$$E^{EA}_{(t=|T|/2)} \geq SQ^{EA} - \left(SQ^{EA} - E^{EA}_{(t=|T|)}\right) \times GR^{EA} \tag{11}$$

$$E^{GE}_{d(t=|T|/2)} \geq SQ^{GE} - \left(SQ^{GE} - E^{GE}_{d(t=|T|)}\right) \times GR^{GE} \tag{12}$$

$$E^{SE}_{(t=|T|/2)} \geq SQ^{SE} - \left(SQ^{SE} - E^{SE}_{(t=|T|)}\right) \times GR^{SE} \tag{13}$$

$$E^{EU}_{s(t=|T|/2)} \geq SQ^{EU} - \left(SQ^{EU} - E^{EU}_{s(t=|T|)}\right) \times GR^{EU} \tag{14}$$

On the other hand, if the DM aims at achieving major improvements in the first half of the time period, equations (15-18) should be used.

$$E^{EA}_{(t=|T|/2)} \leq SQ^{EA} - \left(SQ^{EA} - E^{EA}_{(t=|T|)}\right) \times GR^{EA} \tag{15}$$

$$E^{GE}_{d(t=|T|/2)} \leq SQ^{GE} - \left(SQ^{GE} - E^{GE}_{d(t=|T|)}\right) \times GR^{GE} \tag{16}$$

$$E^{SE}_{(t=|T|/2)} \leq SQ^{SE} - \left(SQ^{SE} - E^{SE}_{(t=|T|)}\right) \times GR^{SE} \tag{17}$$

$$E^{EU}_{s(t=|T|/2)} \leq SQ^{EU} - \left(SQ^{EU} - E^{EU}_{s(t=|T|)}\right) \times GR^{EU} \tag{18}$$

In this case, for each objective it is imposed that at half of the planning horizon a certain percentage of equity improvement (GR) is achieved. For the type of temporal progression where the major improvements should occur in the first half of the time period (graph 2 in Figure 10, Equations (15-18)) GR value should be around 0.6, whereas if the DM wants to have equity improvements mainly in the end of the period (graph 1 in Figure 10, Equations (11-14)) then this value should be around 0.4. Nevertheless, both values can be changed according to the DM point of view.

An additional possibility is also considered. In the case that a linear equity progression is selected Equations (19-22) reflect the conditions that should be followed. These constraints impose that the improvements between consecutive years should be equal.

$$E^{EA}_{t} - E^{EA}_{w} = E^{EA}_{w} - E^{EA}_{c} \; \forall \; w = t+1, c = w+1 \tag{19}$$

$$E^{GE}_{d,t} - E^{GE}_{d,w} = E^{GE}_{d,w} - E^{GE}_{d,c} \; \forall \; w = t+1, c = w+1 \tag{20}$$

$$E^{SE}_{t} - E^{SE}_{w} = E^{SE}_{w} - E^{SE}_{c} \; \forall \; w = t+1, c = w+1 \tag{21}$$

$$E_{s,t}^{EU} - E_{s,w}^{EU} = (E_{s,w}^{EU} - E_{s,c}^{EU})\ \forall\ w = t+1, c = w+1 \quad (22)$$

Still, to obtain an optimal solution under these conditions would be rather difficult in an acceptable computational time, and therefore Equations (23-26) are used instead: these conditions allow improvements between consecutive years that can vary within strict intervals. Through this, it is only imposed that the improvements between consecutive years have similar equity improvements

$$\begin{cases} E_t^{EA} - E_w^{EA} \leq (E_w^{EA} - E_c^{EA}) \times 1{,}2 \\ E_t^{EA} - E_w^{EA} \geq (E_w^{EA} - E_c^{EA}) \times 0{,}8 \end{cases} \forall\ w = t+1, c = w+1 \quad (23)$$

$$\begin{cases} E_{d,t}^{GE} - E_{d,w}^{GE} \leq (E_{d,w}^{GE} - E_{d,c}^{GE}) \times 1{,}2 \\ E_{d,t}^{GE} - E_{d,w}^{GE} \geq (E_{d,w}^{GE} - E_{d,c}^{GE}) \times 0{,}8 \end{cases} \forall\ w = t+1, c = w+1 \quad (24)$$

$$\begin{cases} E_t^{SE} - E_w^{SE} \leq (E_w^{SE} - E_c^{SE}) \times 1{,}2 \\ E_t^{SE} - E_w^{SE} \geq (E_w^{SE} - E_c^{SE}) \times 0{,}8 \end{cases} \forall\ w = t+1, c = w+1 \quad (25)$$

$$\begin{cases} E_{s,t}^{EU} - E_{s,w}^{EU} \leq (E_{s,w}^{EU} - E_{s,c}^{EU}) \times 1{,}2 \\ E_{s,t}^{EU} - E_{s,w}^{EU} \geq (E_{s,w}^{EU} - E_{s,c}^{EU}) \times 0{,}8 \end{cases} \forall\ w = t+1, c = w+1 \quad (26)$$

Summing up, Table 6 identifies the objectives and constraints that are active in the model under each planning context.

Table 6 – Summary of Objectives and Constraints applied within the planning context A and B.

	Planning Context A	**Planning Context B**
Objectives	Equations (1-6) with $w^{CC} = 0$	Equations (1-6) with $w^{EA} = w^{GE} = w^{SE} = w^{EU} = 0$
Constraints	Constraints based on Cardoso et al. (2016): i. Resource requirements ii. Reallocation of beds iii. Minimum and maximum capacity iv. Opening and closure of services v. Assignment of patients vi. Single and closest assignments vii. Gradual equity improvements	
	Constraints based on Cardoso et al. (2016): i. Budget limitation constraints	Equations (7-26)

5.3. *LTCPlanner* validation

Although the applicability of DSS in the healthcare sector has already been proven in Chapter 3, it is still necessary to ensure the applicability of the *LTCPlanner* in a real life context, particularly in the area of LTC. The mathematical model was already tested in a real context and has been proven that it provides valuable information for planning networks of LTC (Cardoso et al., 2016). But the *LTCPlanner* is still untested in real life situation. The main steps that should be followed as to validate this tool with real planners are as follows:

- Test the usability and layout of the *LTCPlanner* with a DM responsible for decisions regarding the planning of LTC networks. In Portugal, one can resort to professionals belonging to the regional coordinating teams (as justified in the beginning of this chapter).
- Verify if whether the new features added to the mathematical model Cardoso et al. (2016) - maximization of equity of utilization (EU), minimization of costs and additional constraints that allow modelling how each objective will improve over time - are relevant to the network planning.
- Explore which additional objectives and constraints may be relevant from the point of view of real decision makers and that can be accounted for in future versions of the *LTCPlanner*.
- This validation will provide the information on the improvements and changes that have to be done before applying the tool in a real life context. After the changes are done, this validation should be re-done, and this process should be repeated until no more changes are suggested. Meaning that the *LTCPlanner* is ready to be used for aiding real life decisions. In particular, the following steps should be as follows: Use the *LTCPlanner* to support planning the LTC network, thus aiding the decisions based on the results provided by the tool.
- Evaluate the improvements achieved by using the *LTCPlanner* and asses the viability of the *LTCPlanner* when planning networks of LTC in a real context.
- Apply the *LTCPlanner* in different contexts of LTC network planning, such as for planning networks in different geographical areas and in different countries with a similar LTC system based on a NHS system.

Nevertheless, although this validation with real planners still needs to be made, the correct operation of the tool was tested. It was possible verify that the transfer of information between the different modules of the *LTCPlanner* was made without any error, thus ensuring that the correct results are received by the DM in the interface. In particular, it was verified that the results obtained when solving the mathematical programming model in GAMS were correctly written in the excel files, and this information was then correctly shown through maps and graphs.

6. Case Study

In the Decision Support System Development: *LTCPlanner* chapter, it was shown the main menu of the tool and how it is organized. It was also explained how each module was implemented. This chapter now presents the case study used to show the applicability of the *LTCPlanner* and is divided in the following sections: Dataset Used, Scenarios under study, LTCPlanner Application and Results.

In the first section, an overview on the dataset used for the development of *LTCPlanner* is provided, along with the identification of which information should also be provided by the DM. This is followed by a detailed description of the scenarios explored to illustrate the potential of the tool, and then a detailed description on the steps followed to apply this tool are presented. The results obtained with this application are explored in the final section.

In this sub-chapter we explain how to use the tool with some illustrative pictures. As case study, the tool is applied to the Portuguese LTC network (RNCCI), in particular in the Great Lisbon region, during the planning period between 2016 and 2020. Afterwards, a comparison of results obtained under the different scenarios is provided. These results were obtained by running the *LTCPlanner* in Intel ® Core ™2 Quad CPU Q8200, 2,33GHz computer with 5GB RAM and the mathematical model proposed in Cardoso et al. (2016) was implemented in the *General Algebraic Modelling System* (GAMS) 24.4.

6.1. Dataset Used

The aim of this thesis is to develop a Decision Support System (DSS) to support real DM in the management and planning of networks of LTC Services. The case study was made considering the Portuguese LTC network (RNCCI), in particular the Great Lisbon region.

A wide range of data was gathered to apply the *LTCPlanner* and assist in the planning of the LTC network in the Great Lisbon area. The key data is summarized in Table 7, Table 8 and Table 9 with a brief explanation on the data and its sources is provided.

Table 7 provides details on the data gathered from literature that can be changed or updated by the DM. While using the tool, and for each of these data, the DM is presented with a suggestion that can be manually changed. So, the DM has the ability to choose different values for the fallowing data: Annual budgets of operations and investments; Current geographical distribution of services; Number of beds per unit and also the minimum number of beds per unit; Average LOS; Operational and Investment Costs; Status Quo; and the maximum distance travelled by patients.

In Table 8 the data gathered from literature that cannot be changed by the DM with a brief explanation and the sources is detailed. The DM has no influence on the values of demand per services and the distances between services and demand points.

Finally in Table 9, is detailed data that has to be introduced by the DM. The values regarding the Geographical area of interest, Equity Objectives; Equity improvement in the 1st half of the period (for more information see Chapter 5.2); Targets and Preferences Related to each objective have to be inserted by the DM. Considering the Equity Objectives data, the tool provides five different objectives (improve the Equity of Access, Geographical Equity, Socioeconomic Equity, Equity of utilization or even the minimization of Costs), where one or more can be selected to take into account in the network planning (as detailed in the previous chapter). Note that, since the proposed tool was not yet applied with a real DM, this data could not be gathered together with real DMs, and so, for the purpose of this thesis this information was assumed (see section 6.2 for more details) so as to illustrate the applicability of the tool.

Table 7 – Data gathered from Literature that can be changed or updated by the DM with a brief explanation and the sources.

Data that can be changed by the user		**Details**	**Source**
General	Annual budgets (€) of operations and investments	The budget (€) assigned for investments relates to the expenditure in new beds. The budget assigned for operations is used so ensure the operation of inpatient services.	(Ministry of labour and Social Solidarity, 2011)
Per type of service	Current geographical distribution of services	Location of institutional LTC (CC, MTRC, LTMC and PC) at the beginning of 2015	(Ministry of Health, 2015b)
	Ner of beds per unit	Number of beds available in each location at the beginning of 2015	(Ministry of Health, 2014a)
	Minimum ner of beds per unit	Minimum number of beds allowed for each institutional service	(Cardoso et al., 2016)
	Average length of stay (LOS)	Average LOS (in days) for each institutional service	(Central Administration of the Health System, 2015)
	Operational and Investment Costs (€)	Operational and investment costs (€) per bed in each institutional service	(Portuguese Observatory on Health Systems, 2011)(Algarve Health Region, 2004)
Per objective	Status Quo (%)	Equity levels (%) in the beginning of the time period	(Cardoso et al., 2016)
	Maximum distance travelled by patients	Maximum travel time allowed per LTC patient accessing institutional services (in minutes)	(Health Regulatory Authority, 2011)

Table 8 – Data gathered from literature that cannot be changed by the DM with a brief explanation and the sources.

Data that cannot be changed by the user		**Details**	**Source**
General	Demand per service	Demand for institutional LTC in each county disaggregated by socioeconomic groups	Predicted by detailed simulation model in (Cardoso et al., 2012)
	Distance between services and demand points	Travel time (in minutes) between each county and each institutional LTC service	Calculated using Google Maps

Table 9 – Data to be introduced by the DM with a brief explanation.

Data to be introduced by the user		**Details**
General	Geographical area of interest	Five areas of Portugal (Lisbon and Tagus Valley, *Norte, Algarve, Alentejo, Centro)*
	Objectives	The DM can select as objectives the maximization of several types of equity objectives or the minimization of costs
Per objective	Equity improvement in the 1st half of the planning period (%)	For each equity, the DM can decide on how much equity improvements (%) should take place in the 1st half of the planning period
	Targets (%)	The desired levels of equity (%) targeted by the DM
	Preferences related to each objective (%)	The weights (%) assigned for each equity

6.2. Scenarios under study

In this section a set of scenarios are defined to illustrate the applicability of the tool. In particular, three scenarios were defined representing scenarios with potential interest for real DMs in the LTC sector in Portugal. Particularly, the *LTCPlanner* provides two main contexts of planning for (re)organizing the LTC network: maximization of equity improvements (Scenario A) and minimization of costs while achieving satisfactory levels of equity improvements (Scenario B). Furthermore, in this study two scenarios were also considered when considering the minimization of costs, as summarized in Table 10, with the main differences being the type of temporal progression of the equity improvements: improvements take place mainly in the first half of the planning horizon (Scenario B1) or in the second half of the planning horizon (Scenario B2).

In this line of thought, in Table 10 are summarized the implications on the mathematical model considering the three planning contexts that will be considered in this case study: The main objective;

the constraints; and the considerations regarding the equities (which equities were selected, temporal progression and percentage of equity improvements);

Table 10 – Scenarios explored when applying the LTCPlanner to the Portuguese context

Scenario		**Objective**	**Equity improvements**		
			Equities Selected	**Temporal progression**	**Percentage of equity improvements in the 1^{st} half of planning horizon**
A		Maximizing Equities Improvements	EA, GE.,SE and EU	-	-
B	**B1**	Minimizing Costs		Improvements take place mainly in the 1^{st} half of the planning horizon	75%
	B2			Improvements take place mainly in the 2^{nd} half of the planning horizon	25%

The following section analyses the differences between the scenarios explored through the application of this tool.

6.3. *LTCPlanner* Application

In order to explain how the *LTCPlanner* can be used, all the steps that need to be followed for the network planning process will be covered.

This sub-chapter is then divided in the following sections: Common Steps, Particular case of Scenario A and Particular case of Scenario B1 & B2. In the first section, the steps that are to be followed for all the scenarios and that are common between them are described. This section is followed by two sections where a detailed description of the steps to be taken when considering each particular scenario (A or B) is provided.

6.3.1. Common Steps

Firstly, the DM is presented with an opening window where the main objective of the tool is explained, here the DM selects *Begin* in order to start planning the network (Figure 11).

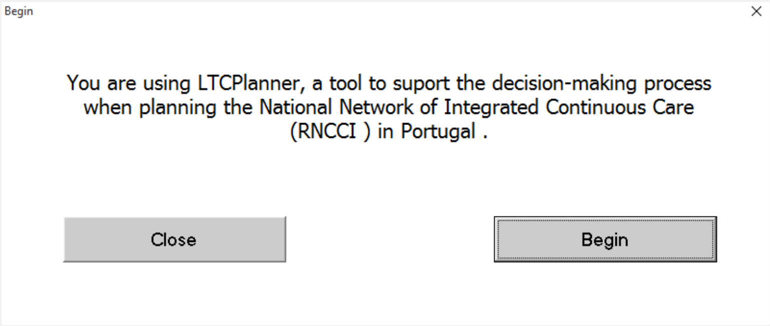


Figure 11 – Begin window

The following window – *Main Menu* (Figure 12) – is mainly an index that can be used to navigate between the input menus (*Area, Services and Objectives*). The DM is always able to return to the *Main Menu.*

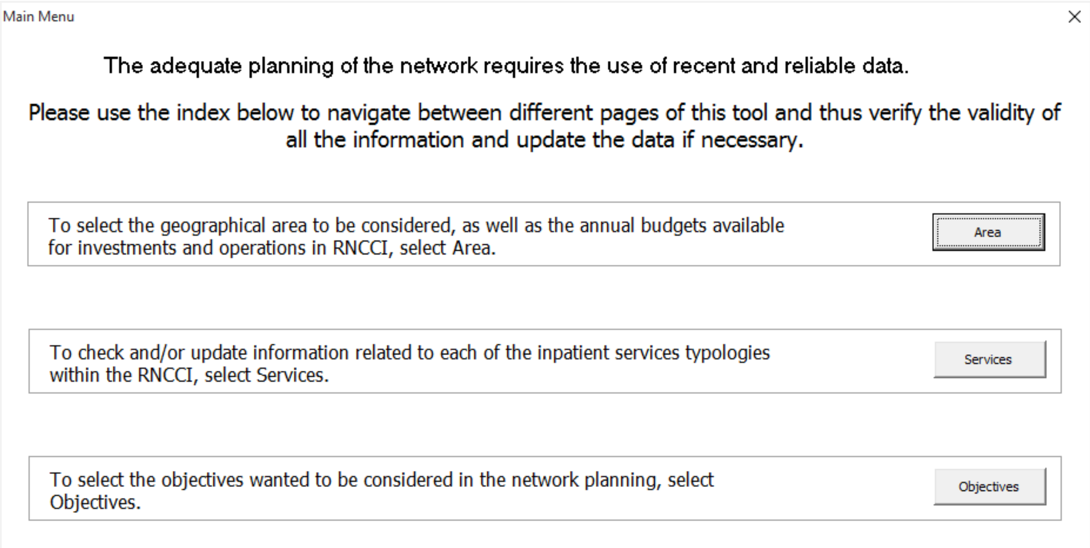


Figure 12 – Main Menu window

The first step to take once the main menu is shown is to select the area button that will open the *Area* window. Here the DM has to select one of the five Portuguese areas (Lisbon and Tagus Valley, *Centro, Algarve, Norte e Alentejo*) to plan the network. In this case study the area of Lisbon and Tagus Valley is selected (Figure 13). Afterwards the DM is able to change the values referring to the annual budgets assigned for operations and investments. If the DM is willing to follow scenario B (B1 or B2, for cost minimization) then this step can be ignored, since the main objective is to minimize expenditure and the annual budgets are not accounted in the model.

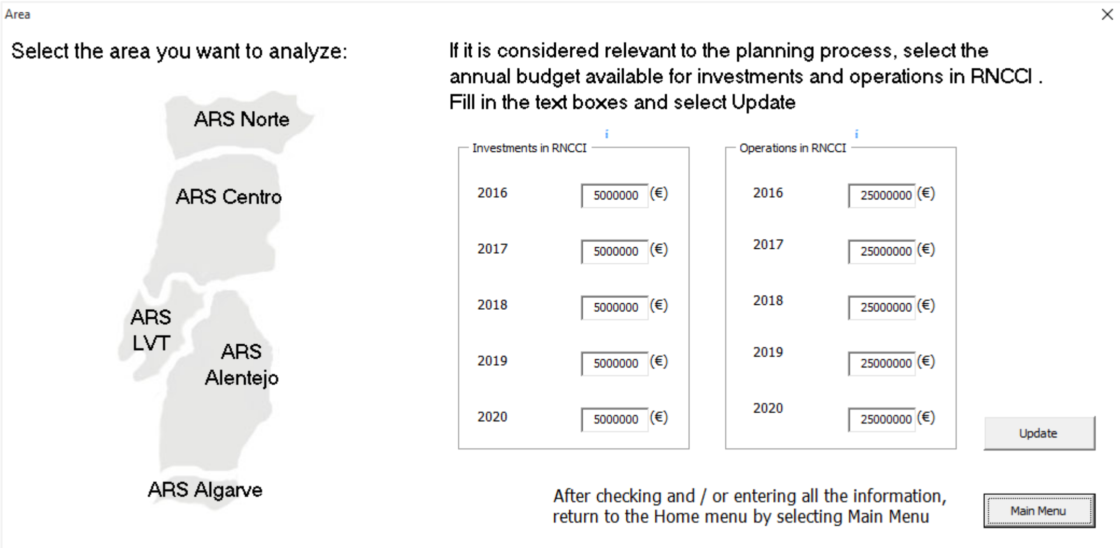


Figure 13 – Area window

After selecting the *Main Menu* button the DM is presented with the window shown in Figure 12 and need to Select *Services* so as to verify/change the information related with the four types of services (CC, MTRC, LTMC and PC). The *LTCPlanner* displays a new window that is separated in four sub-menus, regarding the four types of services (Figure 14 In this window, the DM can follow the following options for each type of LTC service:

i. Confirming or changing the LOS;

ii. Changing the number of beds available per service and unit by selecting the name of the unit and changing the number of beds. This is relevant because it allows the DM to deal with the following situations:

   a. In case an existing unit has more or less beds available than the value shown in the tool;

   b. In case one of the listed units was recently closed, and in that case the DM can set the N^{er} of beds to zero.

iii. Opening new units, in case there are units missing in the list of existing units. For that, the DM selects *Create* and the window shown in Figure 15 is opened where it is necessary to select the unit (in the example is selected *SCM Amadora*) and the number of beds. Here the *LTCPlanner* is only able to use units that already provides at least one type of LTC service in the LTC network. Once this information is inserted, it is necessary to press *Create* to return to the *Services* menu. When no more changes are necessary, the DM can return to the main menu to follow the *Objectives* menu.

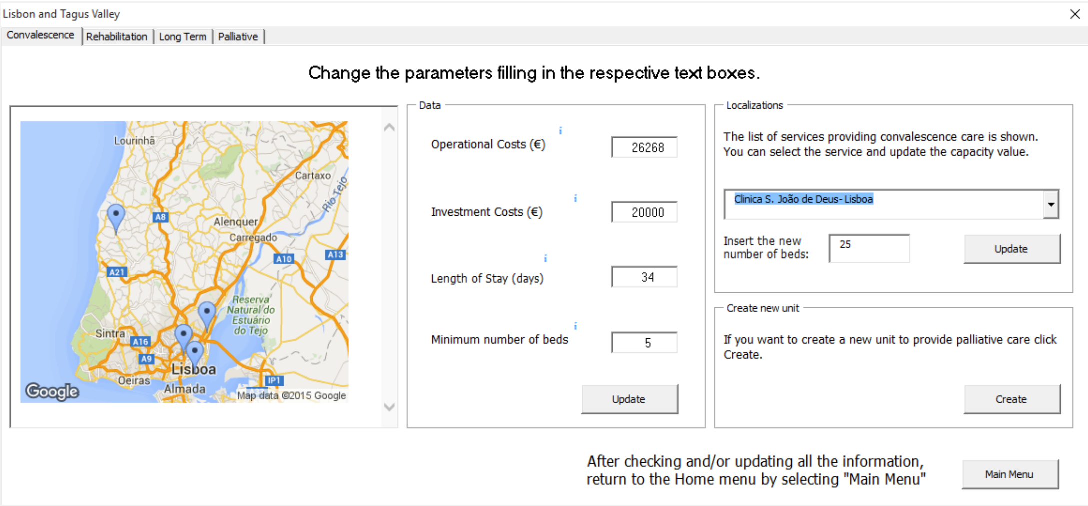


Figure 14 – Services window

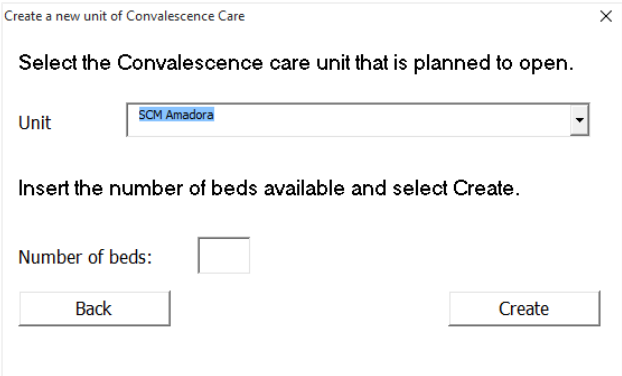


Figure 15 – Create new unit of convalescence care window

The DM selects the *Objectives* button from the Main Menu and a window is displayed (Figure 16). Here the DM has to select the main objective for the network planning i.e. the objectives that will be considered in the mathematical formulation. The actions to be pursued by the DM from this point onwards vary according to the scenarios in analysis. These details can be found in the following sections.

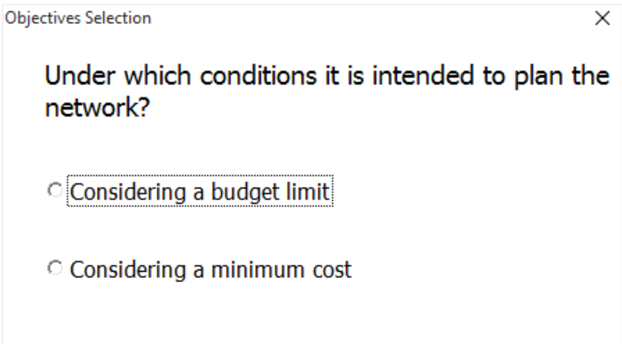


Figure 16 – Objectives Selection Menu

6.3.2. Particular case of Scenario A

Under this scenario, it is assumed that the DM aims to plan the LTC network so as to ensure the provision of LTC within the available budget and while maximizing equity-related objectives.

For this purpose, the DM has to select the button related to the option of planning the LTC network with a budget limit (see Figure 16). A window is afterwards shown (see Figure 17) where the objectives relevant to the network planning are selected, namely, EA, GE, SE and EU. One or more equities can be selected, but for the purpose of this scenario it is assumed that all the four types of equities are relevant for the DM. For each equity selected some information can be changed (more information in Figure 7).

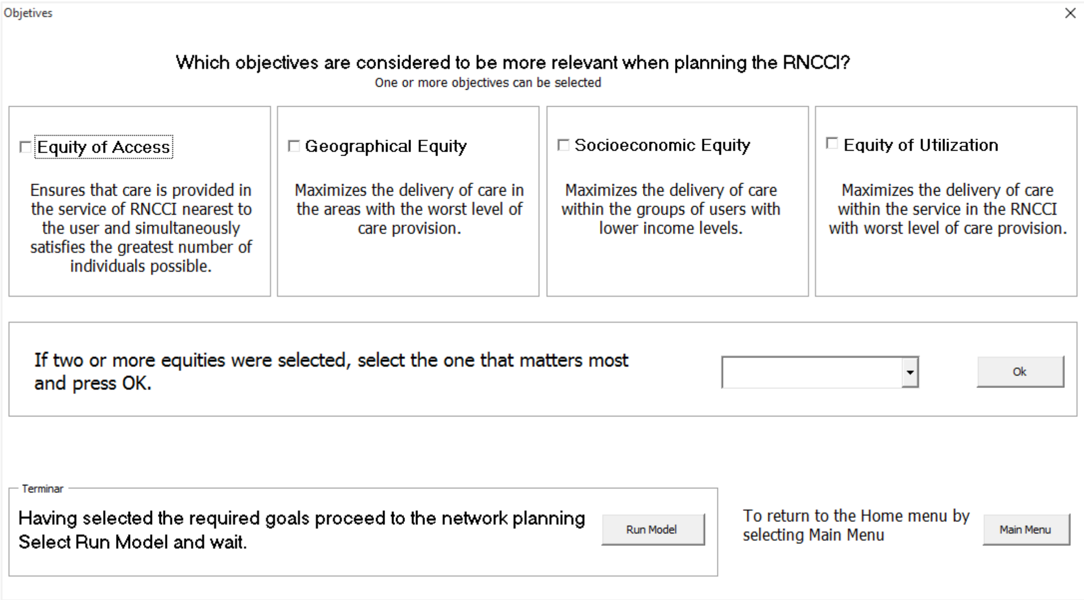


Figure 17 – Objectives window in scenario A

For instance, in Figure 18 the window to insert the information regarding the EA objective is shown, whereas Figure 19 reflects the window shown for the case of selecting the EU (the windows for the GE and SE are similar to Figure 19). As it can be seen from Figure 18 and Figure 19, the information that should be confirmed and/or updated by the DM includes the following

- Status Quo;
- Targets;
- Maximum distance than can be travelled by patients (for the case of Equity of Access).

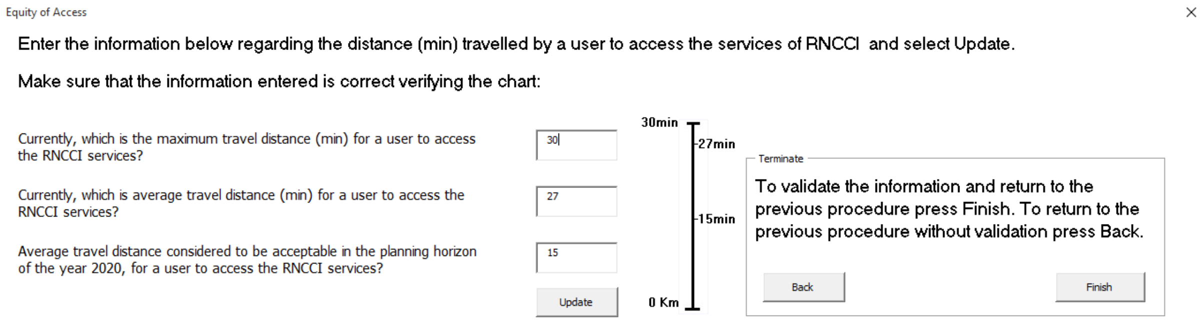


Figure 18 - Equity of Access menu when planning the network with a minimum budget

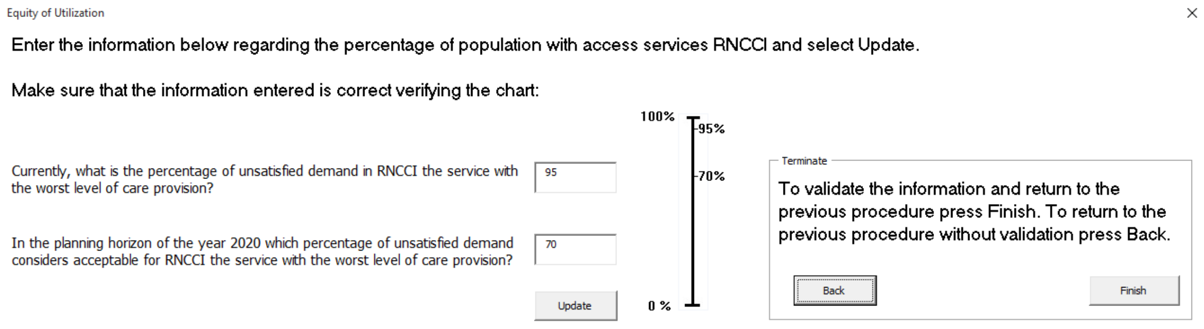


Figure 19 – Equity of utilization Menu when planning the network with a minimum budget

In this case study, all the equities were selected has objectives for the network planning. The targeted values assigned for each equity were as follows:

- EA: 50% (15 minutes), aiming to decrease the average time to access the network services by 15 minutes.
- GE: 50% meaning that the DM aims at reorganizing the LTC network so as to ensure that no more than half of the patients requiring LTC in the worst-off region will not receive the care they need.
- SE: 25%, meaning that the DM aims at reorganizing the LTC network so as to ensure that no more than one quarter of the lower-income patients requiring LTC will not receive the care they need.
- EU: 70%, meaning that the DM aims at reorganizing the LTC network so as to ensure that no more than 70% the patients requiring to receive the LTC with the lowest level of provision will not receive the care they need.

After selecting all the objectives that are relevant for the network (re)organization and after confirming and/or updating all the information related to each selected equity, it is necessary to insert information on which equity has more importance to the DM, when compared to the remaining objectives, and select *OK.* For the purpose of this scenario, the equity of access was select as the objective with more importance for the DM.

At this point, all the information is inserted. Figure 20 shows the *Objectives* window with all the previous information inserted. The DM is now in conditions to select *Run Model* button to start solving the model that will support decisions on how to plan the LTC network under the selected conditions.

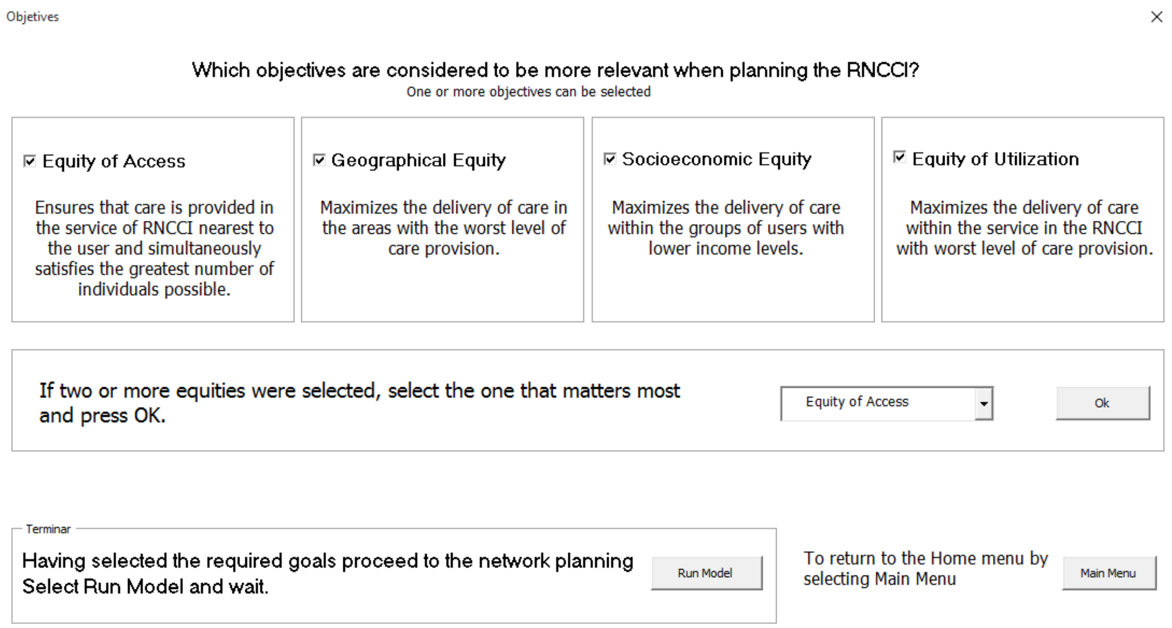


Figure 20 – Objectives window in scenario A before the running the mathematical model

6.3.3. Particular case of Scenario B1 & B2

Under these scenarios, it is assumed that the DM aims to achieve a certain level of LTC provision for the minimum cost. In particular, we are assuming that the DM wants to reorganize the LTC network so as to ensure the achievement of pre-defined targets for equity at a minimum cost.

In this study and regarding the minimization of costs two scenarios were also considered, as summarized in Table 10. The main differences being the type of temporal progression of the equity improvements considered (mainly in the first or the second half of the planning horizon).

For this purpose, the DM has to select in the window shown in Figure 16 the option to plan the network with the objective of minimizing costs. Afterwards, a window is shown (see Figure 21) where the DM has to select the equities concerns that are relevant from his/her point of view and that will be used as constraints of the mathematical model. One or more equities can be selected.

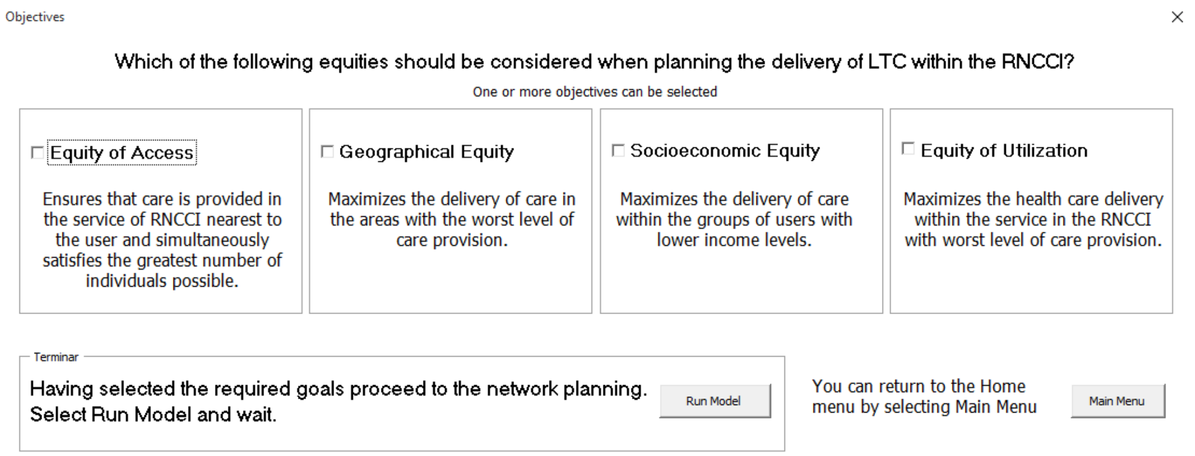


Figure 21 – Objectives window in scenario B

For instance, assuming that Equity of access is selected, its selection will open the window shown in Figure 22. The windows related to the GE and SE and EU are similar. As it can be seen in Figure 22, for each equity selected the DM has to confirm and/or update the following information (similarly to the procedure described for scenario A):

- The graph that better shows the equity improvements growth. A new window is afterwards opened (see Figure 23) to select the percentage of improvement that the DM wants to achieve in the 1st half of the planning period (except from the linear progression).
- Status Quo,
- Targets
- Maximum distance to be travelled by patients (for the case of EA)

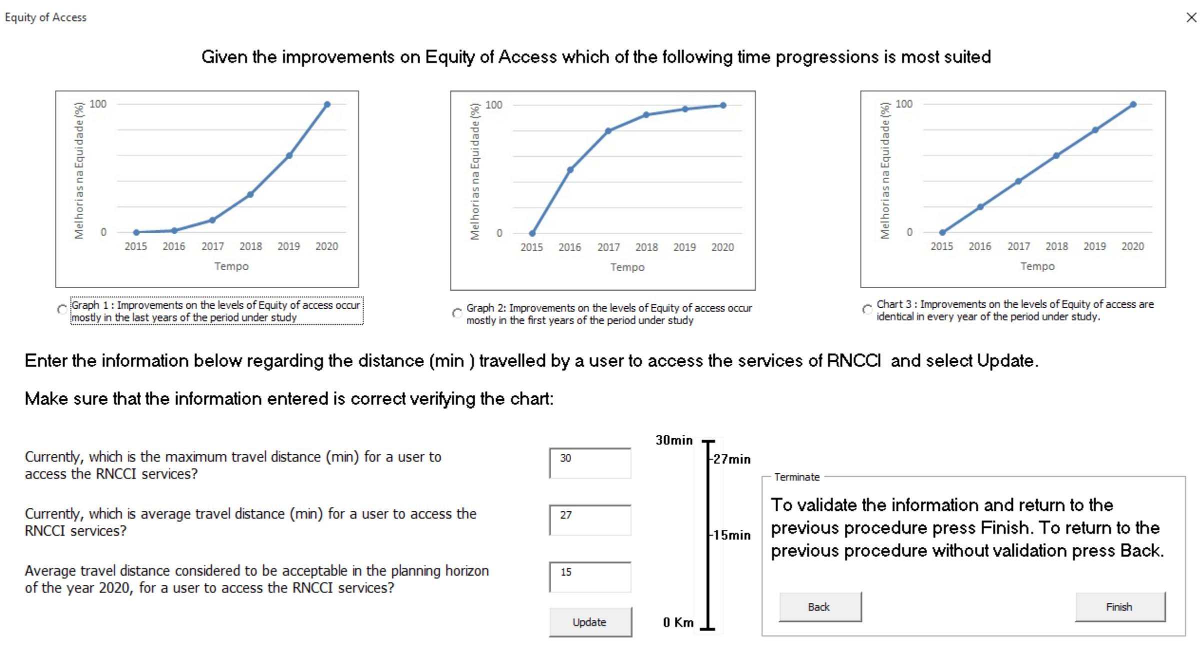


Figure 22 – Equity of Access menu when planning the network under planning context B

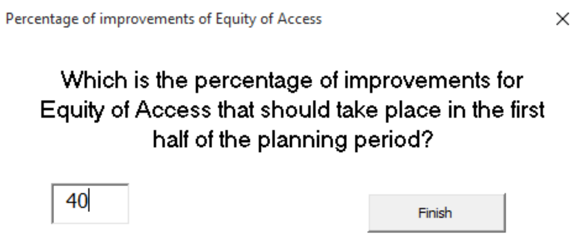


Figure 23 – Percentage of improvement window

Similarly to scenario A, under these scenarios, all the equities were selected, and the targeted values assigned for each equity were also 50% (15 minutes) for EA, 50% for GE, 25% to SE and finally 70% for EU. For comparison purposes, the *LTCPlanner* was used with two different temporal progressions regarding the equity improvements: (1) the percentage of improvements will take place mainly in the second half of the time period, with a percentage of improvements in the 1st half equal to 25%; (2) the percentage of improvements will take place mainly in the 1st half of the time period, with a percentage of improvements equal to75%. After the selection of all the equities for planning the LTC network, the DM is in condition to select the *Run* button.

6.4. Results

This section presents the results obtained through the application of the *LTCPlanner* so as to aid the reorganization of the RNCCI currently operating in the Great Lisbon region. As mentioned in chapter 5.1, this tool provides information regarding:

i. The number of beds per unit and type of service throughout the years (Figure 24);

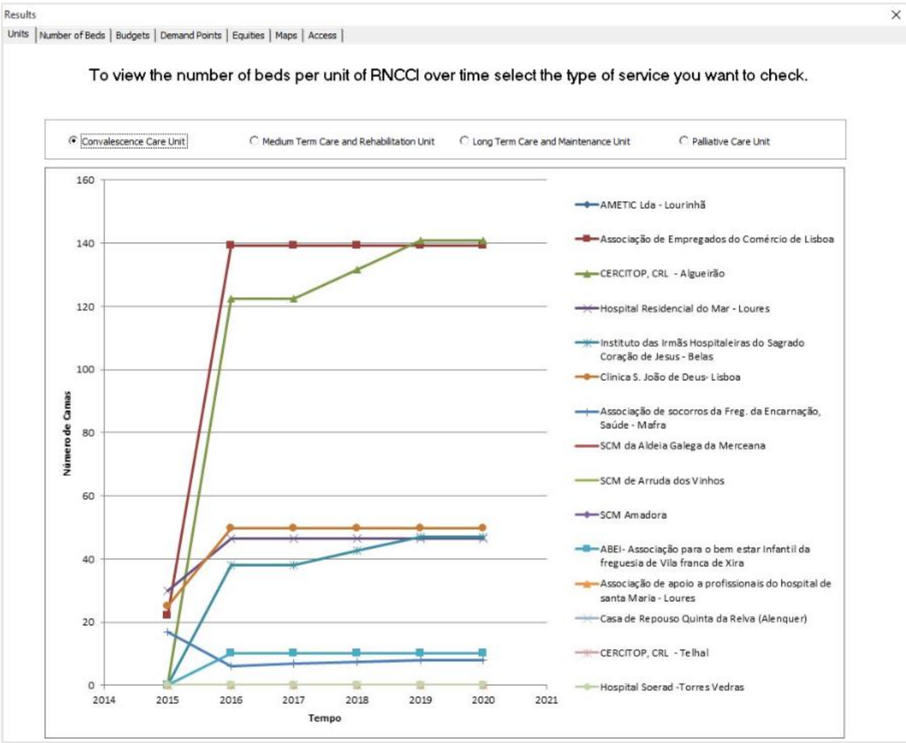


Figure 24 – Results window showing the number of beds per type of service and unit throughout the years

ii. The number of beds per type of service and unit in each year (Figure 25);

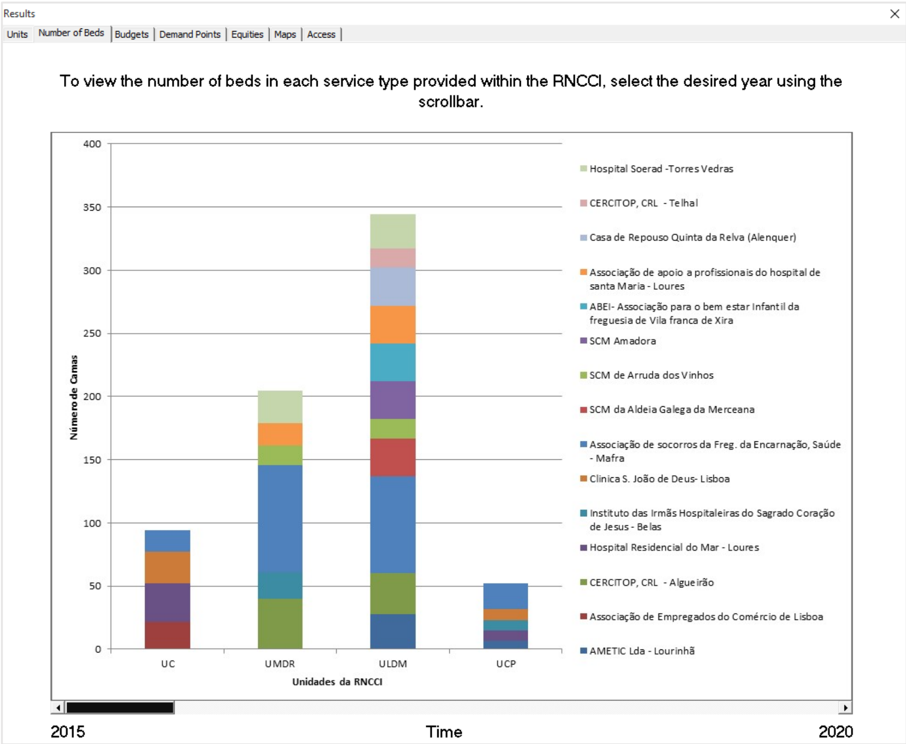


Figure 25 – Results Windows showing the number of beds per type of service, unit and year

iii. The annual budget available and costs that were incurred per year, thus allow analysing if the available budget was totally used or if additional amounts are needed to reorganize the network of care (Figure 26);

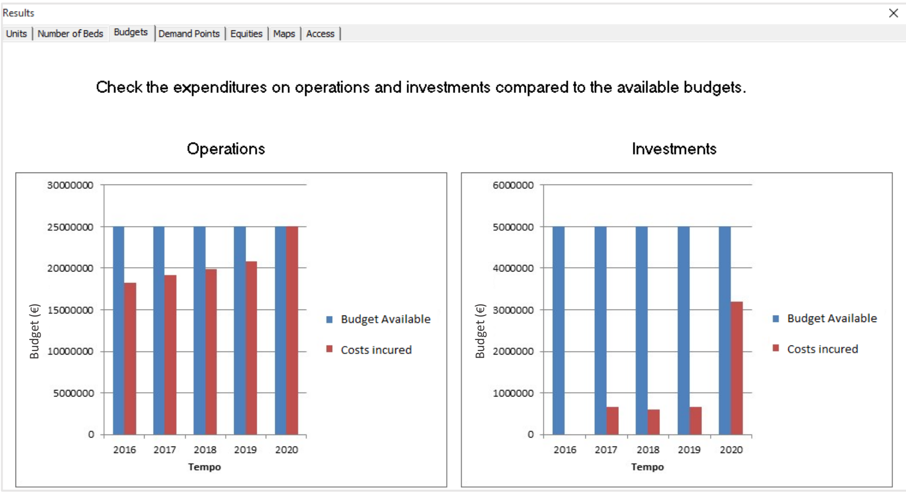


Figure 26 – Results Windows showing the budget available and costs incurred while planning

iv. The number of patients in different socioeconomic groups per demand point and year that are receiving LTC. Whenever the socioeconomic equity objective is selected, one should expect to have more LTC patients belonging to the lowest socioeconomic groups and receiving LTC (Figure 27);

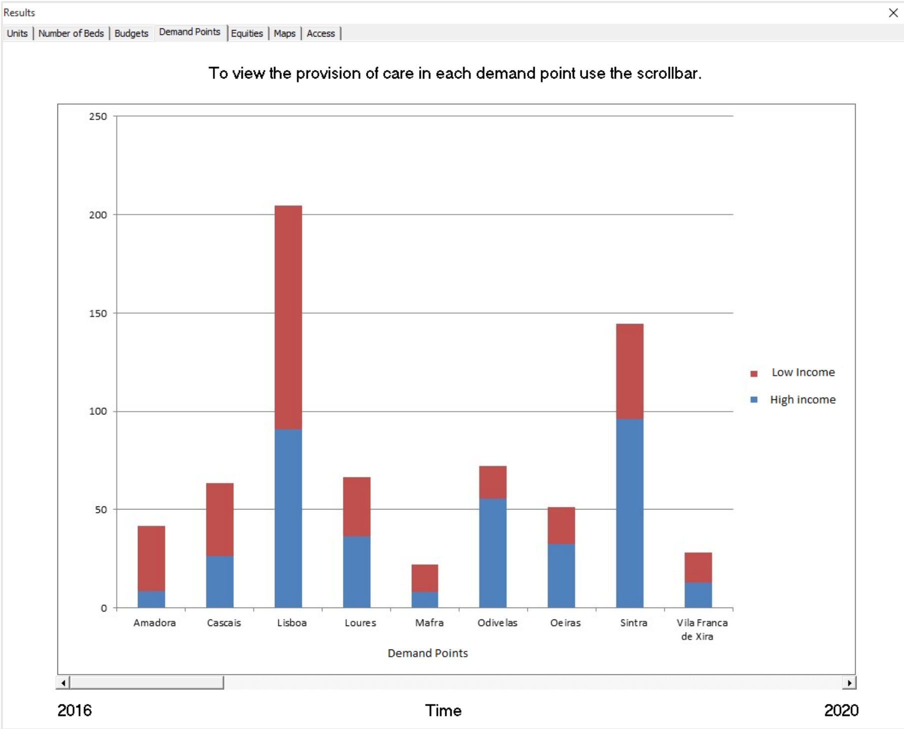


Figure 27 – Results Windows showing the number of patients in the different socioeconomic groups per demand point and year

v. The values of equity obtained after planning compared with the initial and targeted values of equity. This allows evaluating the level of improvement for each type of equity, as well as to analyse how far we are from the target values in case equity improvements are not enough to achieve equity targets (Figure 28);

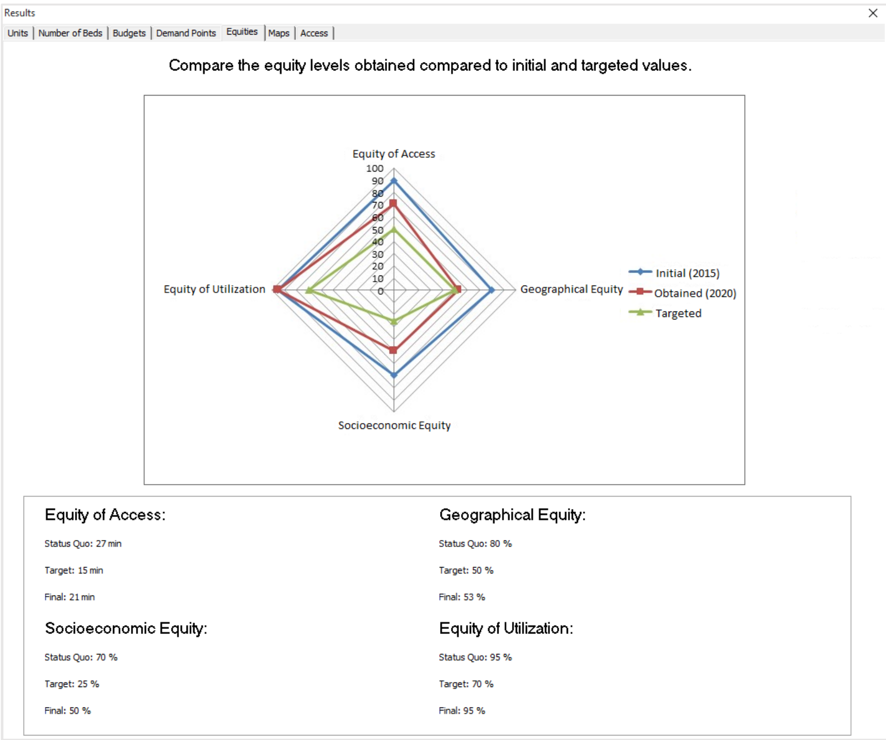


Figure 28 – Results Windows showing the comparison between the levels of equity obtained after planning and the initial and target levels of equity.

vi. The geographical distribution of services per year (Figure 29);

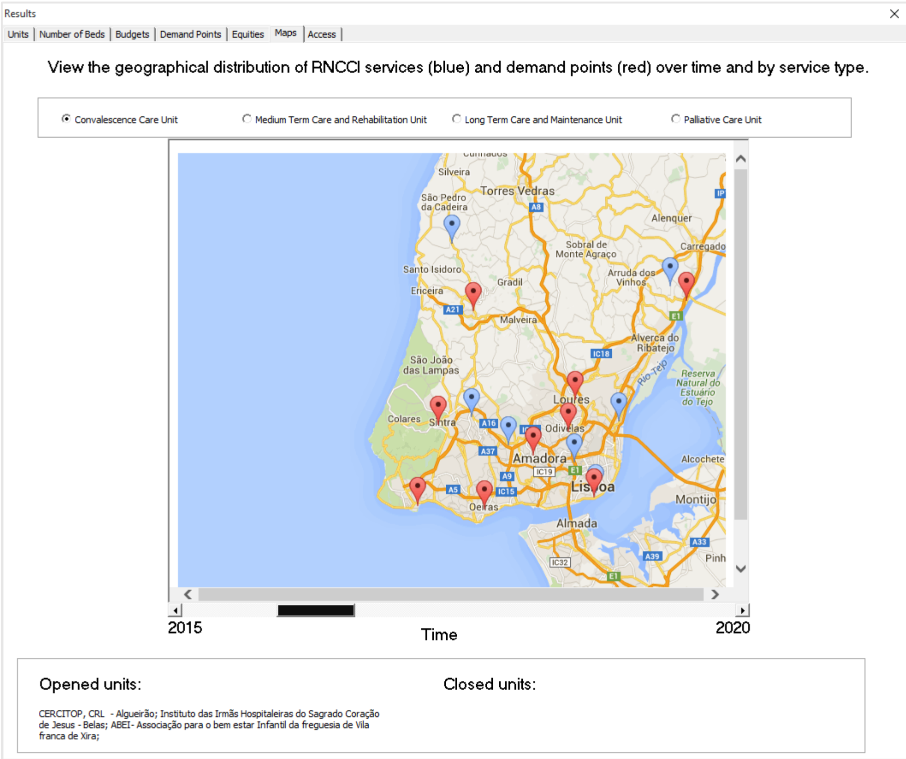


Figure 29 – Results Windows showing the geographical distribution of services per year

vii. The geographical allocation of patients to units and services per year (Figure 30).

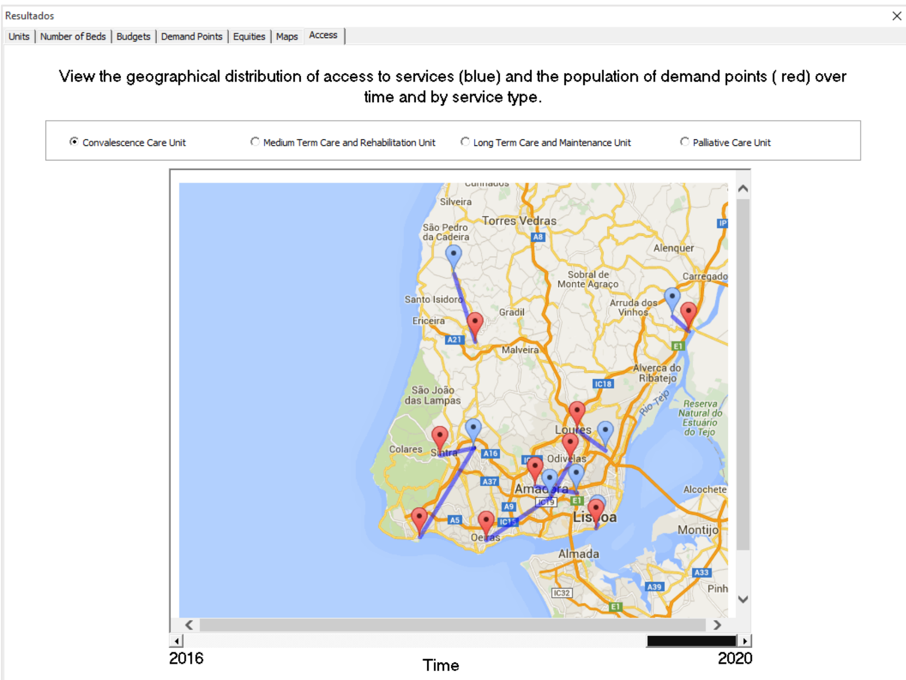


Figure 30 – Results Windows showing the. geographical allocation of patients to services

In Figure 24 and Figure 25, the DM is able to foresee the requirements on each service for each year regarding the four types of services. In Figure 29 and Figure 30, maps are provided to enhance perception regarding the geographical distribution of services and the allocation of patients to services, respectively. Figure 29 allows to see the RNCCI provision as a hole for each year and by type of service (i.e. the units providing the some type of service).

Furthermore, for the results on the geographical distribution of services (Figure 29) and for the spider diagram (Figure 28), an additional description on the main conclusions that can be taken from these results are presented. In particular, the initial levels of each equity (Status Quo; with blue coloured line), the targeted values (with a green line) and finally the final values obtained for each equity (with a red coloured line) are summarized in the bottom of the window shown in Figure 28. And in Figure 29one can also find a summary on which units have been closed or opened each year.

Also, as it can be seen in Figure 25, 27, 29 e 30, the DM is able to navigate through the Results obtained per year. For that purpose, the DM just needs to navigate with the scrollbar in the bottom of the page.

The *LTCPlanner* also provides a report that summarizes the information referred previously, in the format of a Microsoft Word document.

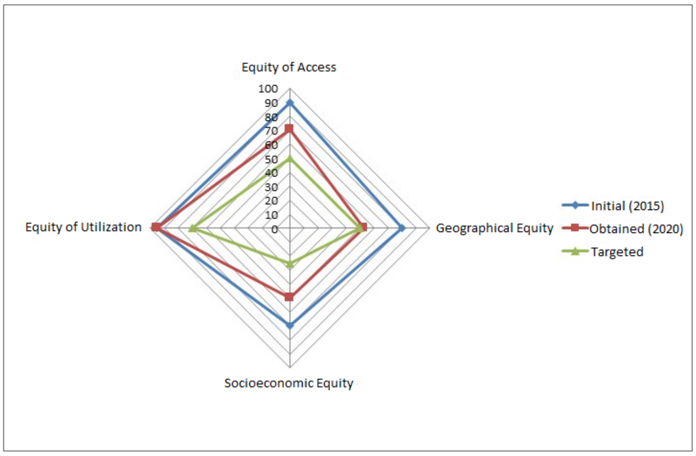
A more detailed analysis on the results obtained through the application of the LTCPlanner to the Portuguese context and for the different scenarios is presented in the following sections.

6.4.1. Scenario A

Scenario A aims to understand how should the current network of LTC evolve so that equity is maximized, given that a limited budget is available. For that, the model was run with the objective of improving the four equities (where EA represents the most important objective) and while considering a limited budget (details can be found in Table 10).

As it can be seen in Figure 31, EA improved from 90% (representing an average travelling time of 27 minutes) to 70% (21 minutes), leading to a decrease on the average time to access the network services. The value of GE and SE have also improved 27%.and 20%, respectively. This means that the improvements in GE lead to a decrease on the percentage of patients not receiving care in the worst-off region of 27% (from 80% to 53%). Considering the SE, this shows that the portion of low-income individuals with no access to LTC will decrease from 70% to 50%.The EU has not changed, meaning that the percentage of patients with no access to care regarding the service with the lowest level of provision will not be improved.

Although the equity objective with higher importance to the DM is EA, one can see that the improvements on other equities (GE and SE) is bigger than the improvements in EA. This is due to the fact that EA is influenced by features of the network that cannot be changed, such as the road network that will influences travelling times.



Equity of Access:

Status Quo: 27 min

Target: 15 min

Final: 21 min

Geographical Equity:

Status Quo: 80 %

Target: 50 %

Final: 53 %

Socioeconomic Equity:

Status Quo: 70 %

Target: 25 %

Final: 50 %

Equity of Utilization:

Status Quo: 95 %

Target: 70 %

Final: 95 %

Figure 31 – Comparison between the levels of equity obtained and the initial and targeted levels of equity under scenario A

In terms of expenditure, the expenses on operations and investments have increased linearly, reaching a maximum level in the last year, has it can be seen in Figure 32. The maximum level corresponds to the annual budget assigned. These results show that the available budget is not sufficient to (simultaneously) achieve the equity targets: EA assigned with 15 minutes, GE with 50%, SE with 25% and finally EU with 70%. This happens because the operational budget is limiting investments within the RNCCI. In fact, as it can be seen from Figure 32, it would be possible to invest extra money to further improve LTC provision, but it would require using more money for operating this extra capacity, and the operational budget is already totally used.

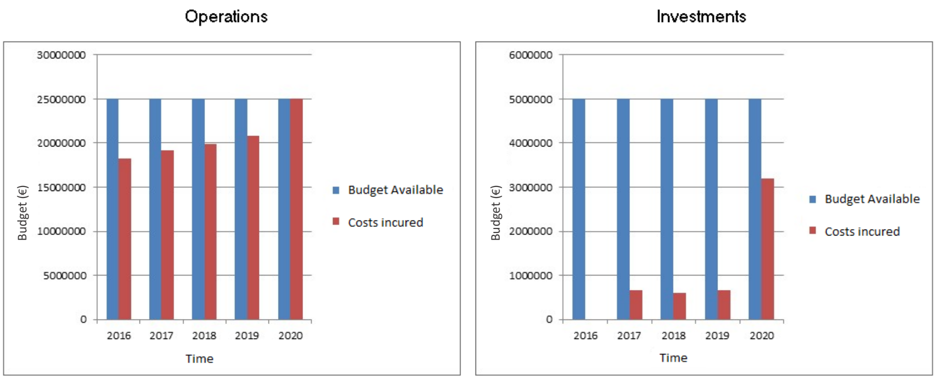


Figure 32 – Comparison between budget available and costs incurred for operation and investments in scenario A

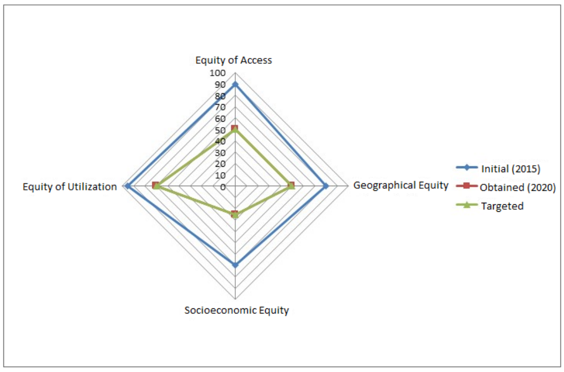
6.4.2. Scenario B1 & B2

Scenarios B1 and B2 are relevant when the DM wants to know how much it would cost to improve the provision of institutional LTC so as to achieve the target levels of equity. According to this, the model was run with the objective of minimizing costs while imposing the achievement of target levels of equity (details in Table 10). Two possible time progressions of equity improvements were also modelled: under scenario B1 it was imposed that most of the equity improvements would take place in the 1st half of the planning horizon, and under scenario B2 the rate assigned for the improvements are mainly in the 1st half of the time period with a percentage equal to75% (details in Table 10).

As it can be seen in Figure 33 and Figure 35, the targets imposed for all equities were entirely achieved. The EA value is of 50 % (15 minutes) leading to a decrease of 12 minutes on the average time to access the required services. The value of GE has improved 30%, meaning that the percentage of patients not receiving care in the worst region diminished from 80% to 50%. The SE has also improved, 48% in B1 and 45% in B2, therefore the portion of low-income individuals with no access to LTC decreases from 70% to 22% and 25% under scenarios B1 and B2, respectively. The EU has also improved: the percentage of patients with no access to care regarding the service with the lowest level of provision decreased from 95% to 70%.

In terms of expenditure, the expenses on operations and investments the main features and results of each scenario are:

i. Scenario B1: Investments are mostly made in the 1st half of the planning period (i.e., in the first three years). This can be verified in Figure 34 that present a peak of investments in 2018.
ii. Scenario B2: Investments are mainly focused in the 2nd half of the planning period, (i.e., in the last two years of the planning horizon), thus verified in Figure 36 where peaks of investments are only present in 2019 and 2020.



Equity of Access:
Status Quo: 27 min
Target: 15 min
Final: 15 min

Geographical Equity:
Status Quo: 80 %
Target: 50 %
Final: 50 %

Socioeconomic Equity:
Status Quo: 70 %
Target: 25 %
Final: 25 %

Equity of Utilization:
Status Quo: 95 %
Target: 70 %
Final: 70 %

Figure 33 – Comparison between the levels of equity obtained after planning and the initial and target levels of equity under scenario B1

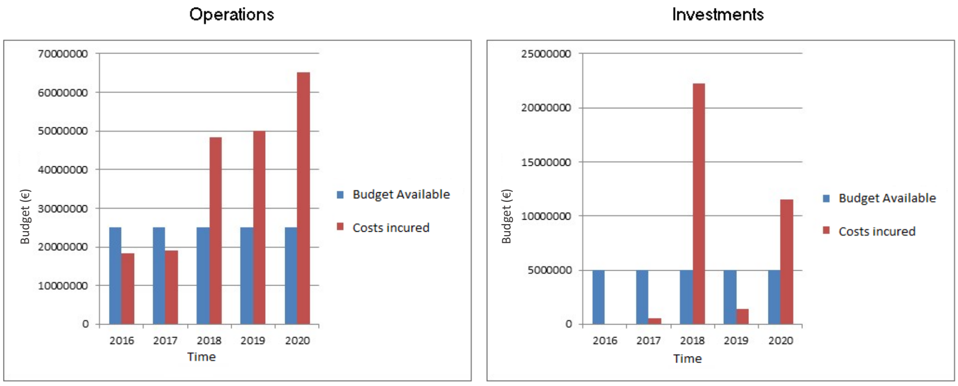
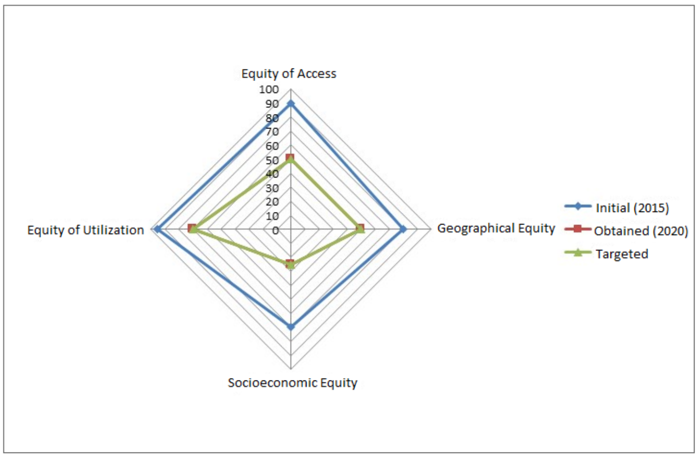


Figure 34 – Comparison between the budget available for operations and investments and costs incurred for operating and investing within the RNCCI under scenario B1



Equity of Access:	**Geographical Equity:**
Status Quo: 27 min	Status Quo: 80 %
Target: 15 min	Target: 50 %
Final: 15 min	Final: 50 %
Socioeconomic Equity:	**Equity of Utilization:**
Status Quo: 70 %	Status Quo: 95 %
Target: 25 %	Target: 70 %
Final: 25 %	Final: 70 %

Figure 35 – Comparison between the levels of equity obtained after planning and the initial and target levels of equity under scenario B2

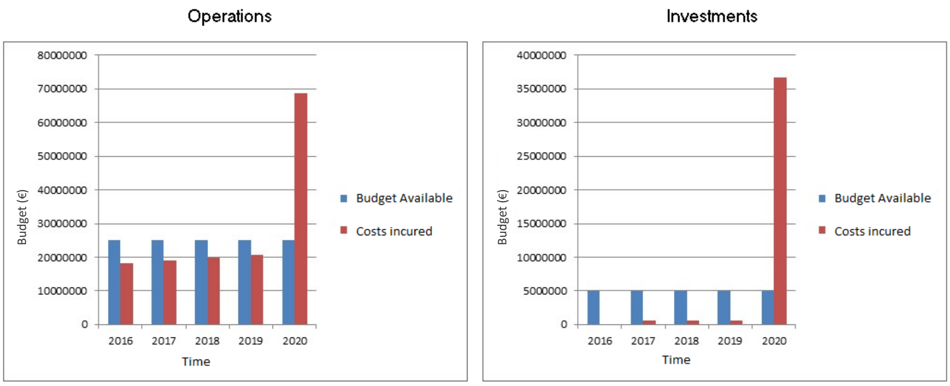


Figure 36 – Comparison between the budget available for operations and investments and costs incurred for operating and investing within the RNCCI under scenario B2

To compare the scenarios B1 and B2 in terms of the expenditure on operations and investments within the network, annual expenses per scenario are detailed in Table 11. As it can be seen in Table 11, total costs are higher under scenario B1. And this happens because investments in additional beds for the network take place earlier, and so there is need to operate that additional bed capacity for a longer period, and so higher costs are incurred under this situation.

Table 11 – Costs incurred for Operations and investments for scenario B1 and B2

Years	**Costs incurred (€) for scenario B1**		**Costs incurred (€) for scenario B2**	
	Operations	***Investments***	**Operations**	***Investments***
2016	18 256 260	0	18 256 260	0
2017	19 036 687.49	594 203.9662	19 021 495.43	582 636.9937
2018	49 485 832.36	23 183 451.25	48 280 847.67	22 277 563.76
2019	513 36 755.59	1 409 260.871	50 085 982.87	1 374 398.66
2020	66 997 944.09	11 924 157.53	65 239 641.02	11 537 732.72
Total	205 113 479.5	37 111 073.62	200 884 227	35 772 332.13
Global for each scenario	242 224 553.2		236 656 559.1	

Moreover, regarding the figures related to the budget available for operations and investments and to the operating and investment costs incurred under both scenarios, it can be verified that the expenditure is above the available budget. The total budget that is available for operating the LTC network over the 2015-2020 period is of 125 Million of euros, whereas for investing in the network is of 25 Million of euros. Comparing these values with the total expenditure presented in Table 11, one can argue that if the main purpose of the network planning is to ensure equity improvements to the desire levels of equity, the expenditure is way above the available budget, and therefore it is easy to conclude that the current provision of LTC is far from meeting the entire population's needs. These results go along with the objectives assigned and are also reflected in the geographical reorganization of the network.

Given the information retrieved from this tool, the DM is thus able to conclude, among other things, that the current provision of the RNCCI in the area of Great Lisbon is not adequate to the needs of its population, nor are the budgets assigned enough to provide care with the adequate levels of equities. Accordingly, taking into account the information that can be retrieved from the interpretation of the results provided by this tool, the DM is able to make more informed decisions when planning the RNCCI.

7. Discussion

According to the literature in the area, mathematical programming models have been widely used for planning networks of healthcare service in general, and LTC services in particular. Nevertheless, the formats and interfaces of these models are usually not appropriate to interactively assist policy makers and planners in their decision making process. For this reason, a Decision Support System that integrates a mathematical programming model that supports planning decisions in the LTC sector – the *LTCPlanner* – was developed to aid the planning of LTC networks within the context of a NHS-based countries. This tool makes use of a previously developed mathematical programming model, which for the purpose of this study was the model developed by Cardoso et al. (2016).

This section discusses the main advantages of the proposed tool, and also points out its main weaknesses. Afterwards, the results obtained through the application of the tool the Great Lisbon region for the 2016-2020 period are also discussed.

7.1. Limitations of the *LTCPlanner*

Nonetheless some limitations were encountered while developing the *LTCPlanner*. For instance, the utilization of VBA from Microsoft Excel has shown not to be the most appropriate language to develop this type of tools. The initial idea when developing the decision support system was to produce a tool that would diminish as far as possible the software installations and other computational means. Since Microsoft Excel is a commonly used tool that is able to deploy applications with no further effort done by the user, the VBA language seemed to be the best approach (Chongwatpol & Sharda, 2010) (Schuurman et al., 2008). Nevertheless, some limitations can be associated with this tool, namely, in terms of the interaction with other applications (for instance, the link with ArcGIS was not possible to be accomplished within the time frame of this thesis), in the deployment of contents (graphs and maps), and regarding the general features of layout and visual aspect.

Regarding the interaction with other applications, this turned out to be a real challenge, since there is little information regarding the interaction of VBA for Microsoft Excel with other tools, in particular with ArcGIS. ArcGIS is a Geographical information system that allows mapping and compiling geographical data (Esri Press, 2015). Since one of the main features of this DSS is to provide information regarding location-allocation decisions within the RNCCI, the visualisation of these results through maps is of great importance when interpreting the results. The ArcGIS software is a powerful tool that is able to provide this type of data, disconnected from the internet. But unfortunately it was not possible to integrate ArcGIS within the tool within the time frame of this thesis, since there was no way to automatically deploy and retrieve data from Excel/VBA to ArcGIS. Considering that mapping the RNCCI is one of the main features of these tools another path was taken. Instead of using ArcGIS, the Google Maps API was used. This tool allowed the deployment of maps but at the cost of having to be connected to the internet and with limited features (will been seen in detail).

In terms of the deployment of contents, the VBA from excel is very limited since it is only able to display objects in the format of images (jpeg) or web sites (url). As a result, the information regarding the results and maps had to be done through one of these solutions. For this, an approach was taken to display the graphs which consists on exporting the graphs as jpeg images to a file, and then importing them back and display them in the tool. This procedure lead to an increase on the time of deployment and also a decrease on the quality of the graphs. In terms of layout design, VBA form excel turned out to be limited and offered very little features and objects to provide a more user friendly interface, especially in terms of colours and type of letters.

Analysing now in more detail specific features of the tool, some additional limitations can be pointed out. Regarding the assumption about the weights assigned to each objective, they do not always reflect the real relative importance given by the DM – for the purpose of this thesis, a simple assumption of an arbitrary value to the weight of the most important objective was made. For instance, in the case study under scenario A, all the equities were selected but the most valued objective was EA and for this purpose the value assigned to EA was of 0.4 and to the remaining equities the value 0.2 was considered. This limitation would be surpassed by integrating the MACBETH approach within the tool, since this approach allows building weights together with DMs based on their judgements on the relative importance of different objectives (see the Conclusions section for more details).

Another point to consider is the fact that the *LTCPlanner* has not yet been tested in a real life environment. Although it has already been proven the applicability of DSS in the healthcare in Chapter 3, it is necessary to ensure the applicability of the *LTCPlanner* in a real life context, in particular in the area of LTC. The mathematical model was already tested in real life situation and has been proven that it provides valuable information when regarding the RNCCI planning (Cardoso et al., 2016). Nonetheless, it is still necessary to evaluate the applicability of the *LTCPlanner* regarding the accessibility, interpretation and layout. For instance, by confronting DMs without the technical background to work with mathematical programming models and related software, it will be possible to conclude if the tool is easy and simple to use by them.

Moreover it is still necessary to verify whether the new features added to the mathematical model proposed by Cardoso et al. (2016) (namely, the maximization of equity of utilization, the minimization of costs and additional constraints that allow modelling how each objective will improve over time) are relevant from the point of view of DMs aiming at planning networks of LTC, or even if there are any other features relevant for DMs in this sector.

Another limitation of this tool is related to the fact that it does not allow opening services in new locations where no institutional LTC services is already provided. Any new service that needs to be opened in a new location has to be updated manually in the spreadsheets. This means that during the input or update of the information regarding services there is no automatic way to insert a new service to be provided in a new unit if this new unit is not providing any type of service at the beginning of the planning procedure.

An additional issue that deserves to be discussed is related to the computational times required to run the mathematical programming model: the model takes 30 minutes to be solved, and even with that computational time it is not possible to achieve a zero gap (see Annex A). Real DMs may be expecting to have solutions within few seconds or minutes, but the strategic and tactical nature of these models make it acceptable to have these computational times.

7.2. Advantages of the *LTCPlanner*

The proposed tool integrates mathematical programming models that inform location-allocation decisions in the LTC sector with a user-friendly interface designed as so to enable its usage by real health policy makers with no need for specific knowhow about existing models. The built tool not only guides the DM in the process of introducing the data that is required to apply the mathematical planning model, but it also shows the results in user-friendly formats that can be easily understood by the DM. By using this tool, the DM do not need to interact directly with the mathematical programming model or the software in which it is implemented, and it does not require the DM to analyse the output files that are generated by mathematical programming models' software (in this case, GAMS) that are typically not easy to analyse by users with no experience in mathematical programming. The DM only needs to have expertise in the LTC area and on issues related to health care planning.

An additional advantage of the *LTCPlanner* is related to the fact that it is an Excel-based tool. For this reason, this tool is easily used by most of the potential users - DM responsible for the organization and planning of LTC provision, in the particular case of Portugal. Furthermore, the regional coordination teams (*Equipa Coordenadora Regional*) will not need to invest in additional and expensive software, since most users are familiar with excel.

The Google maps feature can also be seen as strong feature of the tool, since it enables the access to the most recent maps. Any changes made to the road structures that will affect distances travelled by patients will be automatically taken into account by the tool.

Moreover, it is relevant to note that the *LTCPlanner* can integrate other mathematical programming models aiming at locating services and allocating patients to services within a LTC network operating within a NHS-based system. In fact, the developed tool can be easily adapted to the specificities of other mathematical models. In particular, if there is need to consider a different location-allocation model that accounts for additional objectives (e.g., maximization of health gains), the tool can be easily adapted to accept those additional objectives. Similarly, additional constraints (e.g., minimum number of services per area) can also be considered in the tool.

Furthermore, although this thesis illustrates the application of the tool to the Great Lisbon area, it can be easily applied to the other regions in Portugal. This application simply requires the introduction of the information requested to the DM for the particular context under analysis, as well as information related to the LTC demand in those areas. This tool can also be applied to international contexts, given that a similar LTC structure exists as well as a NHS-based system is in place. As an example, one could apply the proposed tool to the UK system so as to support the reorganization of their residential and nursing care network.

It is important to refer that the LTCPlanner was also developed in Portuguese as to ease its usage among Portuguese decision makers and LTC network planners.

In terms of complexity, this tool accounts for many different concerns with relevance for health policy makers and that affects planning decisions in the LTC sector (e.g., budget constraints, minimization of costs, maximization of equity, etc.).

7.3. Discussion of Results

The results obtained through the application of the *LTCPlanner* to the Portuguese context show that the current provision of the RNCCI in the area of Great Lisbon is not adequate to the needs of its population, nor are the budgets assigned enough to provide care with adequate levels of equities. This because:

i. According to the results obtained under scenario A, the available budget is not enough to achieve the equity targets, meaning that it is also not enough to fully satisfy LTC demand.
ii. Also, according to the results obtained under scenarios B1 and B2 and as shown in Figures 34 and 36, the costs associated with improving the delivery of LTC so as to achieve the targets imposed for each type of equity are way above the budget currently available for improving the provision of LTC. Accordingly, in case a total satisfaction of demand is imposed, these costs would be even greater.

Also, when one compares investment and operational budgets available under scenario A, one can conclude that the available budget is not sufficient to (simultaneously) achieve the equity targets since the operational budget is limiting investments within the RNCCI. In fact, one could obtain greater equity improvements while using the available budget by simply allowing the redistribution of funds from the investment budget to the operational budget.

An additional conclusion that can be taken is related to the impact of forcing equity improvements to take place in a specific period of the planning horizon. In fact, results obtained under scenarios B1 and B2 have clearly shown that forcing equity improvements to take place at the first years of the planning period will have impact on the total costs to be incurred when planning the network – this because forcing the achievement of equity improvements in the first years will imply making earlier investments in the network, and all the beds in which one have invested in the first years will need to be operated for the coming years; and as soon as we invest in the network, the greater will be the operating costs.

Taking into account the information retrieved from the application of this tool, the DM is able to make more informed decisions when planning the RNCCI.

8. Conclusions and Future Research

This chapter presents the main conclusions of the thesis and proposals for future research.

8.1. Conclusions

There has been a worldwide awareness on the planning of LTC and this is now seen as a policy priority in many European countries. This is mainly due to major demographic and social changes - population ageing, rising prevalence of chronic diseases and a significant increase on female employment (Barros et al., 2011) (OECD, 2013b). Moreover, the LTC supply is also influenced by budget constraints which also leads to an increased importance of an adequate LTC planning, which has potential to impact in the health care system as a whole.

Within this context, mathematical programming models have been developed to aid in these tasks , but their formats and interfaces are not appropriate to interactively assist policy makers (Brailsford & Vissers, 2011) (Ritrovato et al., 2015). Decision Support Systems appear as a solution to this issue, by allowing the integration of mathematical programming models with user-friendly interfaces, thus enabling the use of these models by users without specific knowledge on these models. Nevertheless, most of these systems have been developed in areas other than health care and LTC, such as the oil industry, supply chains and facility location in a wide variety of sectors (see for instance Relvas et al. (2011), Costa et al. (2014), Aboudi et al. (1989) and Ibn-Mohammed et al. (2014)). In fact, in the health care sector, this type of systems are now starting to appear, particularly integrated with simulation approaches (Kadri et al. (2014) and De Angelis et al.(2003)). Within this context, one can argue that these types of systems have potential to be developed for supporting planning decisions in the health care sector in general, and in the LTC sector in particular.

The aim of this thesis is thus to develop a Decision Support System– the *LTCPlanner* – that integrates mathematical programming models with user-friendly interfaces so as to aid real health policy makers and health care planners in the management and planning of LTC networks within the context of a NHS-based countries. In particular, this tool will support the following planning decisions: i) which services should be closed or opened over time; ii) how much bed capacity should be available in each service; iii) how should LTC patients be allocated to existing services; and iv) which is the impact of these planning decisions on key policy objectives and on costs. The proposed tool thus integrates the mathematical programming model developed in Cardoso et al. (2016) with a user-friendly interface that is designed to enable its use by real health policy makers without requiring specific knowledge and technical skills about existing models. This model was adapted so as to incorporate additional features proposed by Cardoso et al. (2015) and also new features that are thought to be important for network planers. Within these changes, new objectives were introduced, namely, maximization of equity of utilization and minimization of costs (both based on Cardoso et al. (2015)) and additional constraints that allow modelling how each equity objective will improve over time. This last feature is believed to be relevant since it allows controlling when investments are made.

In summary, the *LTCPlanner* was developed using the VBA language of Microsoft Excel, GAMS software and google maps, aiming to aid the planning of LTC networks when accounting for several equity objectives – Equity of Access, Geographical Equity, Socioeconomic Equity and Equity of Utilization – and cost considerations. These objectives aim to address other health policies such as the equitable distribution of resources and access to care regardless of socioeconomic conditions, and location (Ministry of Health 1990).

This thesis thus contributes to the literature by: i) proposing an approach that supports planning decisions in the LTC sector; ii) proposing a Decision Support System that enables non-expert users on mathematical programming languages to make use of mathematical models to plan the LTC network without ever needing to interact with them; iii) exploring the joint analysis of competing and classical equity objectives; and iv) introducing a feature that allows modelling the equities improvements over time, thus giving the opportunity for DMs deciding when to invest in the LTC sector.

Although still not applied with real decision makers, the *LTCPlanner* has shown the potential to be used by real health policy makers with no need for specific knowhow about existing models by guiding them through all the necessary steps to model the LTC network, from the introduction of data until the interpretation of planning results, and by providing notes regarding concepts and other notions that may raise doubts, for instance information regarding the concepts of budgets available of operations and investments.

The main results show that the current provision of LTC within the RNCCI in the Great Lisbon region is far from meeting the entire population's needs, nor are the available budgets enough to provide a full provision of care. This is proven by the fact that to obtain the desired levels of equity the expenditure is way above the budget available.

The main limitations encountered while developing the *LTCPlanner* were:

i. The programming language used – the VBA from Microsoft Excel – that has shown not to be most appropriate language to develop this type of tools;
ii. The difficulty in interacting with other applications, in particular ArcGIS;
iii. The fact that this DSS is still untested with real planners in the LTC sector.

The main advantages encountered while developing *LTCPlanner* were:

i. Integrates mathematical programming models with user-friendly interfaces, thus allowing its use by real health policy makers with no specific knowhow on the mathematical models;
ii. Integrates a web enabled mapping tool – google maps – that allows the visualization of the network provision as a hole;
iii. Useful as a planning tool since aids in inputting data and analysing the results;
iv. No need to invest in additional and expensive software since most users are familiar with excel;

v. Is able to plan the network considering different planning contexts with relevance for health policy makers in the LTC sector.

8.2. Future Research

At the end of this thesis, it is worth pursuing several research topics. The programming language used to build the interfaces should be different so as to enable the interaction with other programs (such as with ArcGIS), deploy of contents (graphs and maps) and provide a more user friendly interface, for instance Java language.

Given the recognized importance of key information built with MACBETH regarding the preferences of the DM on the various objectives, integrating MACBETH with our tool should be regarded in the future agenda. This would imply implementing a protocol of questioning to capture the judgments of DMs, and then these judgments could be used to build the scale of weights. Figure 37 illustrates a possible architecture of the *LTCPlanner* if this new feature is considered. In this suggestion, the user interface interacts with the MACBETH software so as to enable the weighting of the criteria selected (in this case, equity objectives).

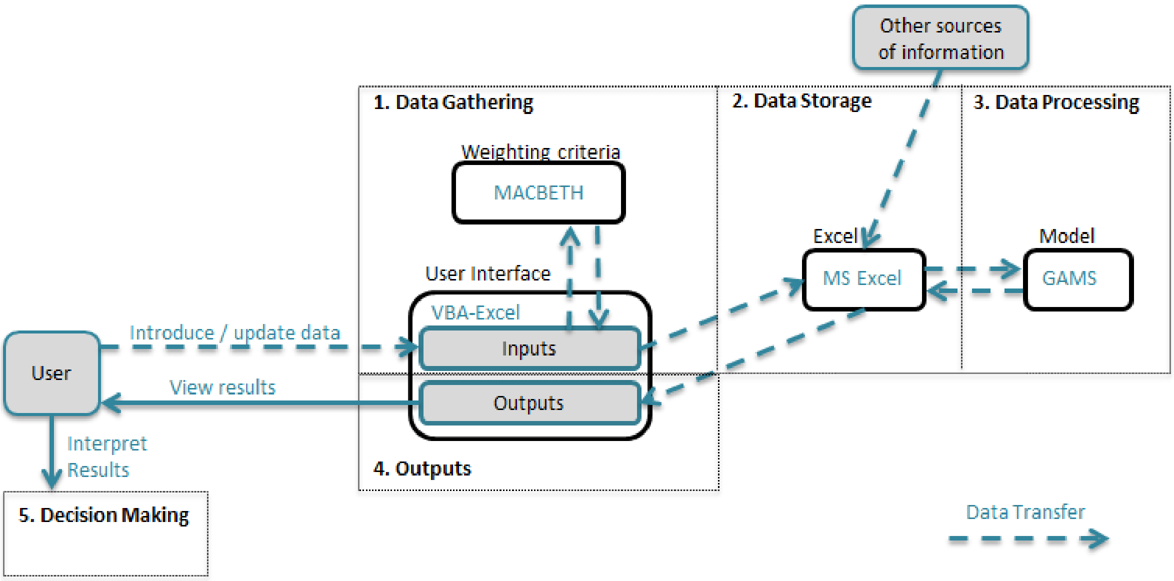


Figure 37 – LTCPlanner architecture after the integration with MACBETH

Furthermore, adapting the tool to allow the integration of stochastic mathematical programming models with the interfaces. This adaptation may require the introduction of additional data by the user, such as information on scenarios and associated probabilities of occurrence, as well as the redesign of the outputs menu, since it would require the comparison of results for different scenarios (for instance, network organization for different scenarios). The main drawback with this integration is that these stochastic models are usually associated with higher computational times, and this may not be well accepted by LTC planners.

Also, extending the tool so as to allow the planning of the complete range of LTC services, that includes not only institutional care services, but also home-based and ambulatory care services, should also be considered as further work. Accounting for all the types of services will then allow for a more detailed analysis of the system, thus allowing to explore the interaction between these different typologies – for instance, it would enable the analysis of the impact on the network of care of substituting typically expensive institutional care services by cheaper home-based care services.

Moreover, it is necessary to ensure the applicability of the *LTCPlanner* in real life context, in particular in the area of LTC regarding the accessibility, interpretation and verify whether the new features added to the mathematical model (maximization of equity of utilization, minimization of costs and additional constraints that allow modelling how each objective will improve over time) are relevant to the network planning. Furthermore, it should also be analysed which other features would be valuable according to the views of real DMs.

It is also necessary to extend the application of the *LTCPlanner* to the all the regions in Portugal (*Norte, Centro, Alentejo*, Lisbon and Tagus Valley, *Algarve*) and to the LTC sector within other a NHS-based system countries.

All in all, this thesis addresses the gap that exists in the area of LTC planning, given that few studies exist proposing methods to support planning decisions in this area, and based on the reviewed literature no easy-to use tool exist for aiding real planners in the LTC sector. The usefulness and applicability of the tool is shown through its application to the LTC sector in the Great Lisbon region in Portugal and under different planning contexts.

References

Aboudi, R., Hallefjord, Å., Helgesen, C., Helming, R., Jørnsten, K., Pettersen, A. S., … Spence, P. (1989). A mathematical programming model for the development of petroleum fields and transport systems. *European Journal of Operational Research*, *43*(1), 13–25. http://doi.org/10.1016/0377-2217(89)90405-0

Ahmed, M. a., & Alkhamis, T. M. (2009). Simulation optimization for an emergency department healthcare unit in Kuwait. *European Journal of Operational Research*, *198*(3), 936–942. http://doi.org/10.1016/j.ejor.2008.10.025

Algarve Health Region. (2004). Plano Director Regional da Saúde da Algarve [Regional plan for health in Algarve].

Arnolds, I. V., & Nickel, S. (2013). Multi-period layout planning for hospital wards. *Socio-Economic Planning Sciences*, *47*(3), 220–237. http://doi.org/10.1016/j.seps.2013.02.001

Baker, M. R. (2000). *Making Sense of the NHS White Papers*. Radcliffe Publishing.

Bana e Costa, C. A., De Corte, J.-M., & Vansnick, Je.-C. (2012). MACBETH. *International Journal of Information Technology & Decision Making*, *11*(02), 359–387. http://doi.org/10.1142/S0219622012400068

Barjis, J., Kolfschoten, G., & Maritz, J. (2013). A sustainable and affordable support system for rural healthcare delivery. *Decision Support Systems*, *56*(1), 223–233. http://doi.org/10.1016/j.dss.2013.06.005

Barros, P. P., Machado, S. R., & Simões, J. D. A. (2011). *Portugal: Health system review. Health Systems in Transition* (Vol. 13).

Berner, E. S. (2007). *Clinical Decision Support Systems: Theory and Practice*.

Bhargava, H. K., Power, D. J., & Sun, D. (2007). Progress in Web-based decision support technologies. *Decision Support Systems*, *43*(4), 1083–1095. http://doi.org/10.1016/j.dss.2005.07.002

Bhargava, H. K., Sridhar, S., & Herrick, C. (1999). Beyond spreadsheets: Tools for building decision support systems. *Computer*, *32*(3), 31–39. http://doi.org/10.1109/2.751326

Brailsford, S., & Vissers, J. (2011). OR in healthcare: A European perspective. *European Journal of Operational Research*, *212*(2), 223–234. http://doi.org/10.1016/j.ejor.2010.10.026

Burstein, F., & Holsapple, C. W. (2008). *Handbook on Decision Support Systems 1: Basic Themes*. Springer Science & Business Media.

Cardoso, T., Oliveira, M. D., Barbosa-Póvoa, A., & Nickel, S. (2012). Modeling the demand for long-term care services under uncertain information. *Health Care Management Science*, *15*(4), 385–412. http://doi.org/10.1007/s10729-012-9204-0

Cardoso, T., Oliveira, M. D., Barbosa-Póvoa, A., & Nickel, S. (2015). An integrated approach for planning a long-term care network with uncertainty, strategic policy and equity considerations. *European Journal of Operational Research*, *247*(1), 321–334. http://doi.org/10.1016/j.ejor.2015.05.074

Cardoso, T., Oliveira, M. D., Barbosa-Póvoa, A., & Nickel, S. (2016). Moving Towards an Equitable Long-Term Care Network : A Multi- Objective and Multi-Period Planning Approach. *Omega*, *58*, 69–85. http://doi.org/10.1016/j.omega.2015.04.005

Central Administration of the Health System. (2012). Relatório de monitorização do desenvolvimento e da atividade da Rede Nacional de Cuidados Continuados Integrados (RNCCI) 1o Semestre de 2012 [Implementing and Monitoring the National Network of Long-Term Care 1st Semester 2012 - Report]. *Cuidados Continuados - Saúde E Apoio Social*, 1–10.

Central Administration of the Health System. (2013). Implementação e Monitorização da Rede Nacional de Cuidados Continuados Integrados - Relatório Final [Implementing and Monitoring the National Network of Long-Term Care - Final Report].

Central Administration of the Health System. (2014). Relatório de Monitorização do Desenvolvimento e da Actividade da Rede Nacional de Cuidados Continuados Integrados (RNCCI) 1º Semestre de 2014 [Implementing and Monitoring the National Network of Long-Term Care 1st Semester 2014 - Report]. *Cuidados Continuados -Saúde E Apoio Social*.

Central Administration of the Health System. (2015). Monitorização da Rede Nacional de Cuidados Continuados Integrados (RNCCI) 2014 [Monitoring the National Network of Long-Term Care 2014].

Chongwatpol, J., & Sharda, R. (2010). SNAP: A DSS to analyze network service pricing for state networks. *Decision Support Systems*, *50*(1), 347–359. http://doi.org/10.1016/j.dss.2010.05.009

Colombo, F., Llena-Nozal, A., Mercier, J., & Tjaden, F. (2011). *Help wanted? Providing and paying for long term care, OECD Health policy studies*. *OECD Health policy studies*. OECD Publishing.

Costa, P., Gomes, M. I., Carvalho, A., & Barbosa-Póvoa, A. (2014). Decision Support Tool for Strategic Planning in Supply Chains. *24th European Symposium on Computer Aided Process Engineering*, *Volume 33*, 895–900. http://doi.org/http://dx.doi.org/10.1016/B978-0-444-63456-6.50150-2

Davari, S., Fazel Zarandi, M. H., & Hemmati, A. (2011). Maximal covering location problem (MCLP) with fuzzy travel times. *Expert Systems with Applications*, *38*(12), 14535–14541. http://doi.org/10.1016/j.eswa.2011.05.031

De Angelis, V., Felici, G., & Impelluso, P. (2003). Integrating simulation and optimisation in health care centre management. *European Journal of Operational Research*, *150*(1), 101–114. http://doi.org/10.1016/S0377-2217(02)00791-9

Esri Press. (2015). The ArcGIS Book.

Gayialis, S. P., & Tatsiopoulos, I. P. (2004). Design of an IT-driven decision support system for vehicle routing and scheduling. *European Journal of Operational Research*, *152*(2), 382–398. http://doi.org/10.1016/S0377-2217(03)00031-6

Greene, V. L., Ondrich, J., & Laditka, S. (1998). Can home care services achieve cost savings in long-term care for older people? *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *53*(4), S228–S238.

Gunes, E. D., & Yaman, H. (2006). Health Network Mergers and Hospital Re-Planning.

Harper, P. ., & Shahani, A. . (2003). A decision support system for the care of HIV and AIDS patients in India. *European Journal of Operational Research*, *147*(1), 187–197. http://doi.org/10.1016/S0377-2217(02)00270-9

Harper, P. R. (2002). A Framework for Operational Modelling of Hospital Resources. *Health Care Management Science*, *5*(3), 165–173. http://doi.org/10.1023/A:1019767900627

Harper, P. R., Shahani, a. K., Gallagher, J. E., & Bowie, C. (2005). Planning health services with explicit geographical considerations: A stochastic location-allocation approach. *Omega*, *33*(2), 141–152. http://doi.org/10.1016/j.omega.2004.03.011

Health Regulatory Authority. (2011). Estudo do Acesso dos Utentes aos Cuidados de Saúde [A study on the access of patients to Health Care]. Retrieved from https://www.ers.pt/uploads/writer_file/document/144/Relatorio_Cuidados_Continuados.pdf

Hulshof, P. J. H., Kortbeek, N., Boucherie, R. J., Hans, E. W., & Bakker, P. J. M. (2012). Taxonomic classification of planning decisions in health care: a structured review of the state of the art in OR/MS. *Health Systems*.

Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., & Acquaye, A. (2014). Integrating economic considerations with operational and embodied emissions into a decision support system for the optimal ranking of building retrofit options. *Building and Environment*, *72*, 82–101. http://doi.org/10.1016/j.buildenv.2013.10.018

Instituto da Segurança Social, I. P. (2014). *Guia Prático Rede Nacional de Cuidados Continuados Integrados [National Network of Long-Term Care - A pratical Guide]*.

Kadri, F., Chaabane, S., & Tahon, C. (2014). A simulation-based decision support system to prevent and predict strain situations in emergency department systems. *Simulation Modelling Practice and Theory*, *42*, 32–52. http://doi.org/10.1016/j.simpat.2013.12.004

Katok, E., & Ott, D. (2000). Using mixed-integer programming to reduce label changes in the coors aluminum can plant. *Interfaces*, *30*(2), 1–12. http://doi.org/10.1287/inte.30.2.1.11679

Kim, D.-G., & Kim, Y.-D. (2010). A branch and bound algorithm for determining locations of long-term care facilities. *European Journal of Operational Research*, *206*(1), 168–177. http://doi.org/10.1016/j.ejor.2010.02.001

Lin, F., Kong, N., & Lawley, M. (2012). Community-Based Operations Research. In M. P. Johnson (Ed.), (Vol. 167). New York, NY: Springer New York. http://doi.org/10.1007/978-1-4614-0806-2

Lipszyc, B., Sail, E., & Xavier, A. (2012). *Long-term care: Need, use and expenditure in the EU-27*. Retrieved from omic_paper/2012/pdf/ecp469_en.pdf

M’Hallah, R., & Alkhabbaz, A. (2013). Scheduling of nurses: A case study of a Kuwaiti health care unit. *Operations Research for Health Care*, *2*(1-2), 1–19. http://doi.org/10.1016/j.orhc.2013.03.003

Mestre, A. M., Oliveira, M. D., & Barbosa-Póvoa, A. (2011). Organizing hospitals into networks: a hierarchical and multiservice model to define location, supply and referrals in planned hospital systems. *OR Spectrum*, *34*(2), 319–348. http://doi.org/10.1007/s00291-011-0272-1

Ministry of Health. (1990). Decreto de Lei nº48/90 Lei de bases da Saúde [Fundamental Principles of health]. Diário da Republica.

Ministry of Health. (2006). Decreto de leiº 101/2006: Cria a Rede Nacional de Cuidados Integrados[Mission for Long-Term Care]. Diario da República. I Série -A, nº109 de 6 de Junho.

Ministry of Health. (2012). Cria rede Nacional de cuidados paliativos[create the National paliative care network]. Diário Diário da República, 1.a série—N.o 172—5 de setembro de 2012.

Ministry of Health. (2013). Decreto de Lei n º 331/2013: Cria normas regulamentares à repartição dos resultados jogos sociais atribuídos ao Ministério da Saúde [Creates regulations the allocation of social gaming results attributed to the Ministry of Health]. Diário da República, .

Ministry of Health. (2014a). Cuidados Continuados Integrados em Portugal Continental [Long-term Care in Portugal's mainland].

Ministry of Health. (2014b). Define as condições de instalação e funcionamento das unidades de internamento e de ambulatório da RNCCI [Defines the functioning and installation condition of RNCCI units of inpatient and ambulatory care], Diário da República, 1ª Série - Nº174-10 Setembr.

Ministry of Health. (2015a). Equipa Coordenadora Regional - Cuidados Continuados Integrados [Regional Coordinator Team - Long-term Care]. Retrieved September 20, 2015, from http://www.arslvt.min-saude.pt/pages/215

Ministry of Health. (2015b). Onde Estamos - [Where we are]. Retrieved August 22, 2015, from http://www.acss.min-saude.pt/DepartamentoseUnidades/DepartamentoGest%C3%A3oRedeServi%C3%A7RecursosemSa%C3%BAde/CuidadosContinuadosIntegrados/OndeEstamos/tabid/1152/language/pt-PT/Default.aspx

Ministry of Health. (2015c). Portal da Saúde - História do Serviço Nacional de Saúde [Health portal - The history of the National Health Sector]. Retrieved August 22, 2015, from http://www.portaldasaude.pt/portal/conteudos/a+saude+em+portugal/servico+nacional+de+saude/historia+do+sns/historiadosns.htm

Ministry of Health. (2015d). Rede Nacional de Cuidados Continuados Integrados [National network of Continuing and Integrated Care]. Retrieved August 22, 2015, from http://www.arslvt.min-saude.pt/pages/217

Ministry of Health. (2015e). Referenciação para RNCCI [RNCCI referral]. Retrieved August 22, 2015, from http://www.acss.min-saude.pt/DepartamentoseUnidades/DepartamentoGest%C3%A3oRedeServi%C3%A7RecursosemSa%C3%BAde/CuidadosContinuadosIntegrados/Referencia%C3%A7%C3%A3oparaRNCCI/tabid/1151/language/pt-PT/Default.aspx

Ministry of labour and Social Solidarity. (2011). Plano de Implementação da RNCCI e Orçamento RNCI 2011[RNCCI implementation plan and 2001 budget].

Mission Unit for Integrated Continuing Care. (2009). Modelo de referenciação de utentes- Rede Nacional de Cuidados Continuados [Patients referral model- National Network of Continuing Care].

Mitropoulos, P., Mitropoulos, I., Giannikos, I., & Sissouras, A. (2006). A biobjective model for the locational planning of hospitals and health centers. *Health Care Management Science*, *9*(2), 171–179. http://doi.org/10.1007/s10729-006-7664-9

Natali, J. M. (2008). *Mixed Integer Programming Approaches for the Analysis and Synthesis of Biological Systems and Processes*. ProQuest.

OECD. (2011). Help Wanted? Providing and Paying for Long-Term Care, Portugal.

OECD. (2013a). A Good Life in Old Age? | OECD READ edition.

OECD. (2013b). Health at a Glance 2013 OECD Indicators.

OECD. (2015). Demography - Elderly population - OECD Data. Retrieved August 22, 2015, from https://data.oecd.org/pop/elderly-population.htm

Oxendine, V., Meyer, A., Reid, P. V, Adams, A., & Sabol, V. (2014). Evaluating Diabetes Outcomes and Costs Within an Clinical Decision Support System, *32*(3), 113–120.

Pordata. (2015). PORDATA - Esperança de vida aos 65 anos: total e por sexo (base: triénio a partir de 2001) - Portugal. Retrieved August 22, 2015, from http://www.pordata.pt/Portugal/Esperan%C3%A7a+de+vida+aos+65+anos+total+e+por+sexo+(base+tri%C3%A9nio+a+partir+de+2001)-419

Portuguese Observatory on Health Systems. (2011). Relatório de Primavera 2011 [2011 Spring Report].

Power, D. J. (2002). *Decision Support Systems: Concepts and Resources for Managers*. Greenwood Publishing Group.

Power, D. J., & Sharda, R. (2007). Model-driven decision support systems: Concepts and research directions. *Decision Support Systems*, *43*(3), 1044–1061. http://doi.org/10.1016/j.dss.2005.05.030

Rahman, S., & Smith, D. K. (2000). Use of location-allocation models in health service development planning in developing nations. *European Journal of Operational Research*, *123*(3), 437–452. http://doi.org/10.1016/S0377-2217(99)00289-1

Rais, A., & Viana, A. (2011). Operations Research in Healthcare: a survey. *International Transactions in Operational Research*, *18*(1), 1–31. http://doi.org/10.1111/j.1475-3995.2010.00767.x

Relvas, S., Barbosa-Póvoa, A. P. F. D., Matos, H. A., & Pinto, P. (2011). Decision Support System for Multiproduct Pipeline and Inventory Management Systems, *29*, 910–914. http://doi.org/10.1016/B978-0-444-53711-9.50182-6

Ritrovato, M. ., Faggiano, F. C. ., Tedesco, G. ., & Derrico, P. . (2015). Decision-Oriented Health Technology Assessment: One Step Forward in Supporting the Decision-Making Process in Hospitals. *Value in Health*, 1–7. http://doi.org/10.1016/j.jval.2015.02.002

Santibáñez, P., Bekiou, G., & Yip, K. (2009). Fraser Health Uses Mathematical Programming to Plan Its Inpatient Hospital Network. *Interfaces*.

Schuurman, N., Leight, M., & Berube, M. (2008). A Web-based graphical user interface for evidence-based decision making for health care allocations in rural areas. *International Journal of Health Geographics*, *7*, 49. http://doi.org/10.1186/1476-072X-7-49

Shariff, S. S. R., Moin, N. H., & Omar, M. (2012). Location allocation modeling for healthcare facility planning in Malaysia. *Computers and Industrial Engineering*, *62*(4), 1000–1010. http://doi.org/10.1016/j.cie.2011.12.026

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. (2002). Past, present, and future of decision support technology. *Decision Support Systems*, *33*(2), 111–126. http://doi.org/10.1016/S0167-9236(01)00139-7

Smith, H. K., Harper, P. R., & Potts, C. N. (2012). Bicriteria efficiency/equity hierarchical location models for public service application. *Journal of the Operational Research Society*, *64*(4), 500–512. http://doi.org/10.1057/jors.2012.68

Stummer, C., Doerner, K., Focke, A., & Heidenberger, K. (2004). Determining Location and Size of Medical Departments in a Hospital Network: A Multiobjective Decision Support Approach. *Health Care Management Science*, *7*(1), 63–71. http://doi.org/10.1023/B:HCMS.0000005399.23600.69

Syam, S. S., & Côté, M. J. (2010). A location-allocation model for service providers with application to not-for-profit health care organizations. *Omega*, *38*(3-4), 157–166. http://doi.org/10.1016/j.omega.2009.08.001

Teshebaeva, K. O., & Jain, S. (2007). Optimization of health facility locations in Osh City, Kyrgzstan. *Applied GIS*, 1–11.

Tillman, Fred. (2009). Excel Spreadsheet tools for analyzing Groundwater level records and displaying information in ArcMap, 68. Retrieved from C:\Biblioteca\Academico\Hidrolog?a\SIG\[USGS] Excel spreadsheet tool for analyzing GW levels and information in ArcMap.PDF

Velten, K. (2009). *Mathematical Modeling and Simulation: Introduction for Scientists and Engineers*. John Wiley & Sons.

Williams, H. P. (2013). *Model Building in Mathematical Programming* (5th ed).

Annex A

Table 12 – Computational Results obtained when applying the LTCPlanner for all cases under analysis.

Scenarios	Total variables	Integer variables	Total constraints	Iterations	CPU (s)	Gap (%)
A			91 123	1 320 124		1.2
B1	48093	900	91 143	685 552	1800	0.9
B2				795 342		0.8