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

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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 resume 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.

### 1. Introduction

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 patients in terminal stage, regardless of their age. The principles are to rehabilitate, readapt and reinsert (OECD 2013b)(Ministry of Health 2015).

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. Furthermore, LTC can also be provided in institutional settings to people with severe functional restrictions (Lipszyc, Sail, and Xavier 2012)(OECD 2013b). This thesis considers the provision of institutional services.

Nowadays, European countries face major demographic and social changes. New data indicates that population is growing old together with a rising prevalence of chronic diseases and with a significant increase on female employment. As a consequence, the demand for Long-Term Care (LTC) is growing (Barros, Machado, and Simões 2011). There has been a worldwide awareness on LTC planning leading to high pressures and huge challenges to policy-makers in Portugal and 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 (Barros et al. 2011)(OECD 2013b).

Policy makers are 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).

Mathematical programming models have been widely developed for supporting planning decisions in the healthcare sector in general.

In particular, literature in the area includes: 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)).

When it comes to consider the specificities of the LTC sector, only few models exist for that purpose (see in example Cardoso et al. (2015) and Lin et al. (2012)). Nevertheless, the interfaces and formats of these models are not adequate to interactively assist health policy makers that may lack the technical skills to use these types of models. Within this context, there is clearly the need to build decision support systems (DSS) that integrate these models with user-friendly interfaces and that allows its use by real health policy makers. Integrating mathematical programming models in these systems is not a common practice in the health care sector, but its relevance has been widely recognized in many different areas (in example Costa et al. (2014) and Relvas et al. (2011)). Within this setting, this thesis aims to fill this gap in the literature, by proposing a decision support system that integrates mathematical programing models with user-friendly interfaces to support planning decisions in the LTC sector.

In this line of thought, this study aims to develop a DSS - the *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 and provides a user-friendly interface that is designed as to enable the use of existing mathematical planning models by real health policy makers without requiring specific knowledge about the models.

Specific functionalities of the tool include: i) Inputting the data required to run the model; ii) Defining the objectives space, i.e., which objectives are to addressed when planning the LTC network, that can include a single objective or multiple objectives; iii) Defining the constraints space i.e. which constraints should be considered when planning the network; iv) Analysing the LTC network configurations that are obtained when different objectives and constrains are considered; v) Analysing model outputs, through web enabled mapping tools, graphs and a resume report

Within this context, this study contributes to the literature by providing a tool that supports LTC network planning that are not currently considered in the literature. The *LTCPlanner* also provides a solution that enables the use of mathematical models that by real decision makers that in other situation would not have the necessary technical skills to use.

The paper is organized as follows: Section 2 provides a literature review of mathematical models and DSS in the health care sector, followed by Section 3 presents a short description of the developed methodology and its implementation are presented. Section 4 presents the case study followed by section 5 where the main results are exhibited and discussed. Finally in section 6 the main conclusions are drawn.

## 2. Literature Review

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 to:

- Location and allocation of services while accounting for a wide variety of objectives (Teshebaeva and Jain 2007)(Shariff, Moin, and Omar 2012)(Mitropoulos et al. 2006);
- Scheduling medical personal (M'Hallah and Alkhabbaz 2013);
- Layout Planning (Arnolds and Nickel 2013);
- Hospital and services merging (Gunes and Yaman 2006);

Mathematical programming models can also be distinguished based on the number objectives accounted for, given that mathematical models can have a single or multiple objectives. The tendency in the past years is the development of multiple objectives(Mitropoulos et al. 2006)(Smith, Harper, and Potts 2012). But there is a challenge associated with the management of conflicting objectives, consequently, most of the studies on health care are single objectives (Stummer et al. 2004) (Rahman and Smith 2000).

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. Considering the health care sector in the past years the trend is to develop multi service models, but there is still little research on these (see Santibáñez, Bekiou, & Yip, (2009)) (Hulshof, Kortbeek, Boucherie, Hans, & Bakker, 2012).

The mathematical programming models can also be divided in Deterministic and Stochastic. The first is based on parameters values and initial conditions and the second has some degree of uncertainty (Williams 2013). 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 a great number of studies and models developed in the health sector fail to aid in real life use (Ritrovato et al. 2015). 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, Sridhar, and Herrick 1999).

DSS operate alongside with quantitative models and algorithms from various subjects 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(Shim et al. 2002)(Bhargava et al. 1999)(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)(Natali 2008)(Bhargava et al. 2007).

**ii.Model driven DSS** make use of formal representations of decision models (e.g., accounting and financial, representational and optimizing models) providing analytical support(Natali 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;

**iii.Knowledge driven** DSS advises and proposes alternatives based on statistical tools (Natali 2008)(Bhargava et al. 2007);

**iv.Communication driven DSS** is able to link multiple decision makers over space and time, making use of electronic communication technologies (Natali 2008) (Bhargava et al. 2007);

**v.Document driven DSS** make use of storage and processing technologies to deliver document retrieval and analysis (Natali 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 study.

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 (Natali 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 and Sharda 2007). Power & Sharda, (2007) 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 (Natali 2008).

In the health care sector there is still little studies regarding the development of DSS. For instance, Natali, (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 (Natali 2008).

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

A DSS was developed in Paul R. 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.

All in all, after a bibliographic research it is clear that even though some studies providing methods to aid healthcare planning is no evidence of any research on DSS in LTC. 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 when planning the different sectors including the health care one can argue that the these tools will also be a key component when planning LTC

## 3. Methods

This in this study a DSS – the *LTCPlanner* –was developed with the aim of supporting planning decisions in the LTC sector in particular aid decision makers and planners planning networks of institutional LTC services within the context of a NHS-based system, by providing detailed information on: i) Which services should be closed or opened; ii) How much bed capacity should be available in each unit; iii) How should LTC patients be allocated to existing services; iv)Which is the impact on key policy objectives and on costs.

The tool was developed so as to allow its use by non-expert on mathematical formulation users, and since these are familiar and have access to Microsoft Excel, the tool was developed in Excel's programming language Visual Basic for Applications (VBA) that is able to provides a real time, user-friendly, graphical user interface. VBA also enables the user to have minimum contact with the data, and the different programs that are used in the developed DSS (Natali 2008). The DSS also takes advantage of the program General Algebraic Modelling System (GAMS) – a high-level modelling system for mathematical programming problems – to model the mathematical programming model adapted from the study developed in Cardoso et al. (2016) To enhance information retrieval a web enabled mapping tool – Google maps – was used.

### 3.1. LTC Planner Modules

The *LTCPlanner* is composed by 5 modules: data gathering, data storage, data processing, outputs and decision making.

***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 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 user 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 1).

The Data Gathering module is divided in three major parameter capture windows: (a) Area; (b) Services; and (c) Objectives; that are used to introduce/update inputs. The Main Menu frame is used to navigate between this menus.

The Data Gathering Framework involves the following steps:

**(i)Select the *Area* form**: that is used to select the geographical area to analyse and gives the opportunity to introduce the annual budgets available for operations and investments if the user so wishes.

**(ii)Service information** where the user has to select the Services option. The Services menu is then displayed, with four sub sections, each related to each of the IC services: (b.1) Convalescence Care units (CC), (b.2) Medium-term and rehabilitation Care units (MTRC), (b.3) Long-term and Maintenance Care units (LTMC) and (b.4) Palliative Care units (PC). 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; A service is no longer providing care; The number of beds of a certain unit providing a certain type of service is different,

**(iii)Select the Objectives** window and select which context of planning is wanted to be considered in the LTC network (re)organization: equity improvements with a limited budget or minimization of costs, corresponding to:

i. Planning Context A: There is a minimum budget assigned to plan the LTC network that cannot be exceeded. The equity improvements are the most relevant objectives when (re)organizing the network;
ii. Planning Context B: There is no budget limit and the DM seizes to plan the network with a minimum cost. The minimization of cost is the most relevant objective. The user has to select the equities in which a minimum satisfactory value is wanted;

The Data Gathering procedure is similar when comparing this two scenarios. The main differences in this procedure are mainly when characterizing the equities chosen:

•Temporal Equity improvements: In path B (minimization of costs) it is provided the choice of selecting different temporal progressions for each equity selected whereas in planning context A this is not provided. In A the budgets assigned are annual therefore there is no advantage in selecting constraints in equity improvements during all the temporal resolution.

•Most relevant equity: In planning context A after selecting the relevant equities for the network planning the DM has to select which of the selected equities is the most relevant. In planning context B since the minimization of costs is the most relevant objective this is not asked.

The equities that can be selected in the different scenarios are: Equity of Access (EA), Geographical Equity (GE), Socioeconomic Equity (SE) and Equity of Utilization (EU). And for each the Present Situation, the Target and in case EA is selected Maximum distance have to be verified/changed.

When the user has finished inserting all the objectives-related information, the user has all the conditions to select the *Run* Button and start the modelling procedure

***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) and the outputs retrieved once the model is solved is stored. The user has no access to this component. 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 is an adapted version of the model proposed by (Cardoso et al. 2016)

This module uses data (either captured as input from the user or as parameters) process it to find optimal solutions and stores output results in the Data Storage module for user visualization and analysis. 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 user;

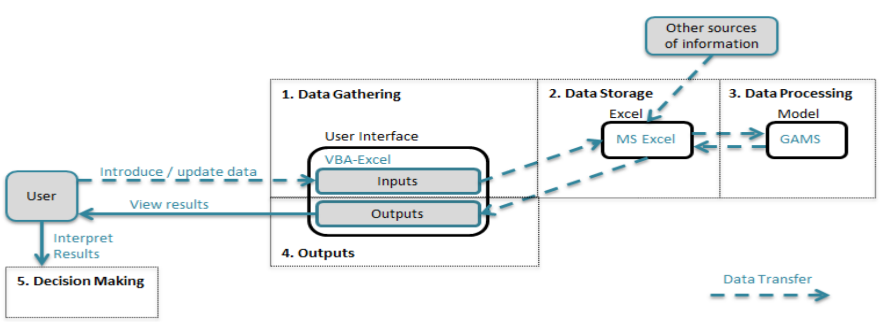


*Figure 1 – LTCPLanner architecture*

***Outputs***

VBA developed Graphical User Interface providing the user the user to visualize and analyse the results in the form of graphs and maps (based on google maps) that will aid in the Decision Making module; These graphs and maps reflect the results of the mathematical model in easily accessible for interpretation and analysis. The results window opens after the mathematical formulation procedure has ended and shows six sub-sections: i. Units, ii. N$^{re}$ of beds, iii. Budgets, iv. Demand Points, v. Objectives, vi. Maps and vii. Access. A Microsoft Word Document is automatically created with a summary of the results obtained.

***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 simulating 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).

To summarize, in the user interface module the user 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).

### 3.2. Mathematical Programming

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)).

The user is able to select which context of planning is wanted to be considered in the LTC network (re)organization: equity improvements with limited budget or achieving equity targets with minimum cost. Therefore, the objective function given by Equations (1-3) is constituted by two parcels that reflect the mentioned alternatives (equity objectives and minimization of costs).

#### 3.2.1. Objectives:

The equation (1) represents the global objective function that includes the maximization of equity improvements (*EqMax*) and minimization of costs (*CostMin*).

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 ($w^{EA}$, $w^{GE}$, $w^{SE}$ $w^{EU}$).

- $f^{EA}$ is the equity level obtained, regarding the average of total traveled time, by individuals accessing the institutional services.
- $f^{GE}$ is obtained level of equity concerning the unmet need in the geographical area with the highest levels of unmet need.
- $f^{SE}$ regards the levels of equity obtained for the unmet need for the lower income groups.
- $f^{EU}$ is the equity level obtained 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 reading used in (Cardoso et al. 2015), additional

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

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

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

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 equity objective and to the costs For the purpose of this thesis, the approach followed to define these weights is different from the one followed in Cardoso et al. (2016). When using the tool, the user 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 relevant 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 eq.(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.

### 3.2.2. Constraints:

The mathematical programming model used in this thesis comprises a set of constraints, whose detailed description can be found in Cardoso et al. (2016). Still, some additional constraints need to be defined so as to allow the integration of the model within the proposed tool, namely: I) cost constraints and II) 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. Under this context, it is imposed that each level of equity (at the end of the planning horizon) should not be higher than the target levels defined by the decision maker as the desired level of achievement for each type of equity. This is imposed by equation 7 (adapted for each equity). Where MT corresponds to the target value. Note that higher levels of equity represent worst levels of provision, and so minimum satisfactory values are imposed in these cases.

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

$$E^{EA}_{(t=|T|/2)} \geq SQ^{EA} - \left(SQ^{EA} - E^{EA}_{(t=|T|)}\right) \times GR^{EA} \quad (8)$$

$$E^{EA}_{(t=|T|/2)} \leq SQ^{EA} - \left(SQ^{EA} - E^{EA}_{(t=|T|)}\right) \times GR^{EA} \quad (9)$$

$$\begin{cases} E^{EA}_{t} - E^{EA}_{w} \leq (E^{EA}_{w} - E^{EA}_{c}) \times 1{,}2 \\ E^{EA}_{t} - E^{EA}_{w} \geq (E^{EA}_{w} - E^{EA}_{c}) \times 0{,}8 \end{cases} \forall\, w = t+1, c = w+1 \quad (10)$$

Furthermore, an additional set of constraints is also defined to model the improvements of each type of equity over time. 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, equation 8 should be used (applied similarly for each of the remaining equities). 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. On the other hand, if the user aims at achieving major improvements in the first half of the time period, equation 9 should be used. An additional possibility is also considered. In the case that a linear equity progression is selected, it should be imposed that the equity improvements between consecutive years should be approximately equal (Equation (10)).

## 4. Case study

The case study is applied to the Portuguese LTC network (RNCCI) in particular in the Great Lisbon region during the planning period between 2016 and 2020. The case study considered different scenarios, presented in table 1. Firstly, the user is presented with an opening window where the main objective of the tool is explained, here an where the DM is able to start the planning network by selecting the begin button.

The following window – *Main Menu* – is mainly an index that can be used to navigate between the input menus (*Area, Services and Objectives*). The first step is to select the *Area* button that will open the *Area* window where 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). Afterwards, the DM is able to change the values referring to the annual budgets assigned for operations and investments. If the user is willing to follow scenario B (minimizing costs) then this step can be ignored. In the *Services window* the DM is able to change/update the information related with the four types of services (convalescence care, medium and rehabilitation care, Long-term care and maintenance and palliative care). The *LTCPlanner* then displays a new window that is separated in four sub-menus, regarding the four types of services. In this window the user is able to:

i. Confirming or changing 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 user 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 user 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 user selects Create New Unit and a window is shown 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 have already provided some type of LTC services in network; Afterwards, the user selects the *Objectives* button from the Main Menu and a window is displayed where the user has to select the main objective for the network planning. The *LTCPlanner* provides two main options: minimization of costs or achieve the maximum equity improvements with a minimum budget. This information is resumed in Table 1 (scenario A and B). If the user aims to plan the LTC network within the (re)organizing context of having equity improvements with a minimum cost - assuming that the user wants to ensure the provision of LTC within the budgeted values selected.

The user has to select the button related to the option of planning the LTC network with a defined budget. A window is shown where the equities relevant to the network planning are selected. One or more equities can be selected. For each equity selected some information can be changed. After selecting all the equities wanted in the network (re)organization it is necessary to insert the equity that has more importance to the Decision Maker. If the scenario B is wanted the user has to select the option to plan the network with the objective of minimizing costs. Afterwards a window is shown where, the DM has to select the equities that will be used as constraints of the mathematical model.

One or more equities can be selected. For each equity selected the user has to select the graph that better shows the equity improvements growth then a new window opens to select the percentage of improvement (except from the linear progression). After the selection of the equities for the planning of the network the user is in condition to start the modelling procedure.

**5. Results and Discussion**

This tool provides information to evaluate: 1. the requirements on the units and services for each year regarding the four types of services; 2. if the available budget was totally used and costs incurred (see Figure 2); 3. the provision for each county; 4. The level of improvement for each type of equity (see Figure 3); 5. the geographical distribution of units per service, unit and year and 6. The geographical allocation of patients to units and services.

*Table1: The possible scenarios in LTCPlanner*

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

These last two types of results are provided in maps which enhance perception regarding the provision in geographical means and allows to see the RNCCI provision as a hole for each year and by type of service and illustrating how accessibility to the RNCCI is done. Furthermore, to the results on the geographical distribution of services and to the equity levels comparison an additional description on the main conclusions that can be taken from these results are presented (see Figure 3). Furthermore, the decision maker is able to select the year and the type of service to analyse. Results show that the Equity targets imposed for all equities' were all achieved in scenario B. And in scenario A the maximum level of expenditure corresponds to the annual budget assigned, which go along with the objectives assigned and are also reflected in the geographical (re)organization of the network. The results also 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.

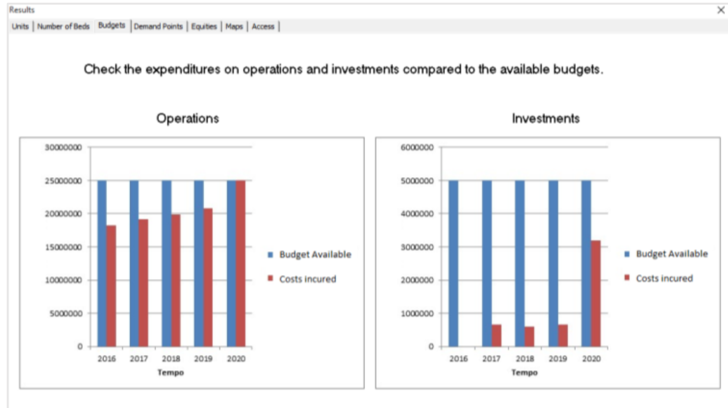


*Figure 2 - Results Windows showing the budget available and costs incurred while planning*

## 6. Conclusions:

The aim of this thesis is thus to develop a Decision Support System– *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. 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 that are thought to be important for network planers (maximization of equity of utilization, minimization of costs, modelling how each equity objective will improve over time).

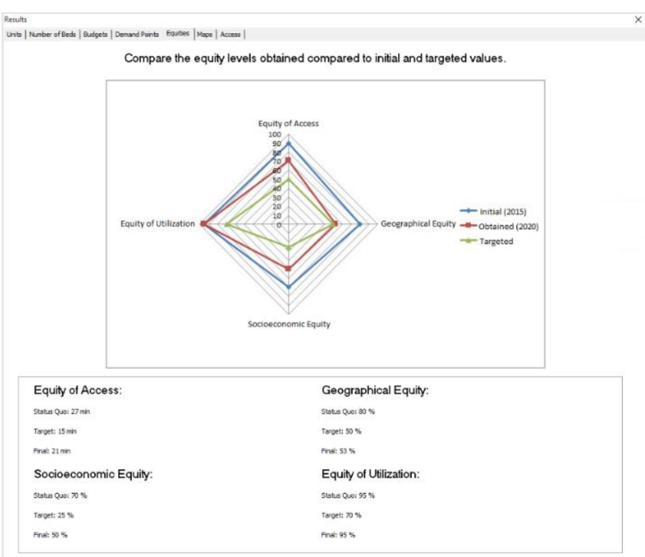


*Figure 3 – Results Windows showing the comparison between the levels of equity obtained after planning and the initial and target levels of equity*

In summary, the *LTCPlanner* was developed using the VBA language of Microsoft Excel, GAMS software and google maps, aiming to aid planning of LTC networks when accounting for equity objectives – Equity of Access, Geographical Equity, Socioeconomic Equity and Equity of Utilization – and cost considerations. This thesis thus contributes to the literature by: i) proposing an approach that supports planning decisions in the LTC sector; ii) proposing a DSS 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.

The main results show that the provision of LTC that nowadays is available 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 *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 models; ii. Can be used by real health policy makers with no specific knowhow on the mathematical models; iii. Provides user-friendly interface; iv. Useful as planning tool since aids in inputting data and analysing the results; v. 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 and the LTC sector; vi. The integration of GAMS software to implement the mathematical programming model allows the export of data do Excel;

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.

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