ISCTE Business School
Instituto Universitário de Lisboa

PLANNING THE DELIVERY OF HOME-BASED LONG-TERM CARE: A MATHEMATICAL PROGRAMMING-BASED TOOL TO SUPPORT ROUTES' PLANNING

Daniel Henrique Gomes Espadinha

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Supervisor
Profª. Teresa Sofia Sardinha Cardoso de Gomes Grilo, Profª. Auxiliar,
ISCTE Business School, Departamento de Marketing, Operações e Gestão Geral

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Abstract

The adequate planning of home-based long-term care (HBLTC) is essential in the current European setting where long-term care (LTC) demand is increasing rapidly, and where home-based care represents a potential cost-saving alternative from traditional inpatient care. Particularly, this planning should involve proper route planning to ensure visits of health professionals to patients' homes. Nevertheless, literature in the specific area of HBLTC planning is still scarce.

Accordingly, this paper proposes a tool based on a mathematical programming model – the LTC^{routes} – for supporting the daily planning of routes to visit LTC patients' homes in National Health Service-based countries. The model allows exploring the impact of considering different objectives relevant in this sector, including the minimization of costs and the maximization of service level. Patients' preferences, traffic conditions and budget constraints are also considered in the proposed model.

To illustrate the applicability of the model, a case study based on the National Network of LTC in Portugal (RNCCI) is analysed.

Keywords: Health care planning; long-term care; home-based care; route planning; mathematical programming models

JEL Classification System:

L91 – Transportation: General

R410 – Transportation: Demand, Supply and Congestion; Travel Time; Safety and Accidents; Transportation Noise

Resumo

O planeamento adequado de cuidados continuados ao domicílio é essencial na conjuntura atual Europeia em que a procura de cuidados continuados está a aumentar rapidamente, e em que os cuidados ao domicílio representam uma alternativa com potencial de poupança de custos relativamente ao tradicional internamento hospitalar. Particularmente, é necessário haver um planeamento adequado das rotas dos profissionais de saúde às casas dos pacientes. No entanto, a literatura na área específica de planeamento de cuidados continuados ao domicílio ainda é escassa.

Nesse sentido, este artigo propõe uma ferramenta baseada num modelo de programação matemática - o LTC^{routes} - para apoiar o planeamento diário das rotas para visitar as casas dos pacientes com necessidade de cuidados continuados em países com Serviço Nacional de Saúde. O modelo desenvolvido permite explorar o impacto de considerar diferentes objetivos relevantes neste setor, incluindo a minimização de custos e a maximização do nível de serviço. As preferências dos pacientes, condições de trânsito e restrições de orçamento também são consideradas no modelo proposto.

Para ilustrar a aplicabilidade do modelo, é analisado um caso de estudo baseado na Rede Nacional de Cuidados Continuados Integrados (RNCCI) em Portugal.

Palavras-chave: Planeamento de cuidados de saúde, cuidados continuados; cuidados ao domicílio; planeamento de rotas; modelos de programação matemática

JEL Classification System:

L91 – Transportation: General

R410 – Transportation: Demand, Supply and Congestion; Travel Time; Safety and Accidents; Transportation Noise

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Abreviations

GAMS – General Algebraic Modelling System

HBLTC – Home-Based Long-Term Care

HHC – Home Health Care

HHCVRP – Home Health Care Vehicle Routing Problem

LM – Logistics Management

LTC – Long-Term Care

NHS – National Health Service

PHCC – Primary Health Care Centers

RNCCI – Rede Nacional de Cuidados Continuados Integrados

TM – Transport Management

VRP – Vehicle Routing Problem

1. Introduction

This first chapter introduces the research problem of this dissertation, highlights the main objectives of this work as well as its contribution to the existing literature and finally defines the structure that this paper will follow.

1.1. Problem Statement

Home Health Care (HHC) delivery is an important component of health care systems, having the potential to reduce costs of health care provision and free capacity in overcrowded acute care settings such as hospitals (Milburn, 2012). Nevertheless, this potential is found not only for general acute care services, but also in the Long-Term Care (LTC) sector.

However, the HHC sector, and the LTC sector in particular, are facing a challenge that need to be tackled as quick as possible: demand is doubling but health care resources are scarce (Milburn, 2012; WHO, 2000).

A major factor for this growth in demand for LTC is the ageing of the population in the most economically developed countries, propelled by an increase in life expectancy, as well as a decrease in the fertility rates of the younger generations (Fikar and Hirsch, 2017; Simões J *et al.*, 2017). According to the OECD, the average life expectancy at birth for the OECD34 is of 80,5 years. In Portugal, the average value stands at 80,8 years (OECD, 2015). For Portugal, and for many other European countries that are facing this growth of their older population, the pressure to provide social as well as medical care is increasing. And when both social and medical care come into play, long-term care plays a key role in the area.

LTC is aimed for the older people but also for the chronically ill and other groups with special needs, such as people with mental and physical disabilities or dependencies (Simões J *et al.*, 2017). This type of care can be provided in both formal and informal settings (Knapp and Somani, 2009). In fact, although informal delivery of LTC by families traditionally represents a cornerstone of LTC delivery, the development and strengthening of formal Home-Based LTC (hereafter-called HBLTC) by health professionals currently represents a policy priority across European countries. This is not only due to the expected growing demand for LTC (WHO, 2000; Milburn, 2012), but also to the decreasing reliance on informal care provided by families, due to the increase in female employment and migration of the younger members to urban centers (Simões *et al*., 2017). Fikar and Hirsch (2017) also noted another reason that is likely to lead to a substantial increase in demand for HHC services, which is the preference by patients who need continued nursing care to stay at their own home.

The health sector is well known for the high costs involved, and there is a vast number of papers that focus on strategies that can help cutting these costs down by optimizing procedures and other practices (see, for instance, Kaplan and Porter, 2011). In Europe, between 1% and 5% of the total public health budget is spent on HHC services (Fikar and Hirsch, 2017). In a Portuguese Health System review, Simões *et al*. (2017) describe the public provision of residential care as lacking sufficient resources to face the current needs in long-term care due to the factors mentioned above that result in an increase of patients with incapacitating chronic diseases. To face this reality, the National Network of Long-Term Care (RNCCI, *Rede Nacional de Cuidados Continuados Integrados*), was created in Portugal by the Decree-Law 101/2006 within the scope of the Ministry of Health and the Ministry of Labour and Social Solidarity (Ministry of Health, 2006). This network ensures not only the provision of inpatient care and ambulatory care, but also of home health care through multi-disciplinary teams that deliver long-term care and social support. The work of the RNCCI, which includes its HHC provision, is based in communitarian services and covers many institutions that work together under the network such as hospitals and ACES, local and district social security services, the Solidarity Network (with a strong contribution from private providers, such as *Misericórdias*) and municipalities. While the network has registered a continuous growth in number of inpatient beds, domiciliary teams and areas of action, it still faces a problem of lack of resources to answer effectively to the rapidly increase of the demand for home-based long-term care.

Within this context, and considering the current pressures to reduce health care spending across European countries, such as is the case of Portugal, there is clearly the need to plan the adequate provision of HBLTC (Genet *et al*., 2013; Gutiérrez and Vidal, 2013). In fact, when considering European countries where health care services are provided within a National Health Service (NHS), such as it is the case of Portugal (Ministry of Health, 1990), home-based care services poise an appealing cost shift and potential cost-saving alternative from traditional inpatient care.

This adequate planning implies, among other issues, the planning of routes for HBLTC provision. This planning is typically performed manually, resulting in high organizational efforts and potentially non-optimal routes – and this may result in higher costs incurred in the care delivery process, as well as on poor service levels.

According to Fikar and Hirsch (2017), a review on HHC routing and scheduling models revealed that mathematical programming models represent a key method when the aim is to support the planning of routes, with the most frequent approach being extensions of the Vehicle Routing Problem (VRP). Still, when considering the particular case of route planning of HBLTC services, no related-study was found.

Within this context, the main purpose of this master thesis is to propose a general tool based on a mathematical programming model that can be used to support the planning of routes to patients' home in NHS-based countries, so as to respond to the growing demand of HBLTC – this model will be hereafter called LTC^{routes}. The particular case of home health care provided within the scope of the National Network of LTC (Rede Nacional de Cuidados Continuados Integrados, RNCCI) in Portugal is used as case study to illustrate the usefulness of the proposed approach. The LTC^{routes} aims at informing the practitioners on the optimal routes to visit their patients' homes on a daily basis. The model allows exploring the impact of considering different objectives relevant in this sector, such as the minimization of costs (measured in different ways, including travelling time and number of vehicles required to perform the routes) and the maximization of service level (measured by the percentage of patients visited). Patients' preferences, traffic conditions and budget constraints are also imposed to explore the impact on planning decisions.

Even if this is just a basic solution of a first improvement to the current situation, it shows how we can use the knowledge acquired in this Master and apply it to a practical situation that can help our community.

1.2. Objectives & Research Questions

The research question under analysis in this master thesis is as follows: "How can we support the planning of the daily routes performed within the scope of HBLTC services provided within NHS-based countries, while accounting for cost and demand-related issues?"

Particularly, a mathematical programming model is developed, which aims to meet the following general objectives:

- Propose a tool that can be used to support route planning decisions of HBLTC delivery on a daily basis;
- Develop a mathematical model to solve the problem in question, by selecting the most adequate approach based on the reviewed literature;
- Explore the impact of accounting for different objectives relevant in this sector, such as the minimization of the costs (measured in different ways) and the maximization of service level;
- Propose a planning model that allows accounting for constraints such as patients' preferences and traffic conditions;
- Propose a generic approach that can be used to plan HHC delivery in general, and that can be applied to other regions of Portugal or other countries with a NHS.
- Assess the possible benefits of using the developed model in a real-life scenario, using the RNCCI as a case study.

In order to achieve the general objectives herein proposed, the following specific objectives:

1. How to plan and define daily routes of HBLTC services in countries with a NHS?
2. How to plan and define daily routes if the objective is to minimize travel time, while satisfying all demand?
3. How to plan and define daily routes if the objective is to minimize costs (vehicles/teams needed), while satisfying all demand?
4. How to plan and define daily routes if there is a budget constraint?

Most studies found about the HHC routing problem don’t take into consideration situations where the demand cannot be fully satisfied due to budget constraints, or the influence of traffic in the time travelled in different shifts, so these specificities were included in the proposed model, thus filling a gap in the literature. In addition to contributing to scientific literature in the area, this thesis also contributes to the daily practice within the RNCCI in Portugal, by providing a tool based on a mathematical programming model that can help their health professionals in the daily planning of their HHC services – these professionals currently perform this planning manually, and using the proposed model this planning can be performed more easily and quickly.

1.3. Structure

This dissertation is composed by seven chapters, including this **first chapter** where the research problem is introduced.

In the **second chapter**, a literature review is conducted, presenting an exploration of what has already been discussed by other authors about the subject in question. It starts by introducing the general concept of Transportation Management and most studied problems, in specific the Vehicle Routing Problem and its variants, and explores the most relevant solution methods already developed for solving this kind of problems. Then the application of this subject to Home Health Care and Long-term Care is focused to explore what has already been published and conclude the contribute that this dissertation brings to the already existing literature.

The **third chapter**, entitled methodology, summarizes the thought process followed to solve the problem approached by this dissertation.

Chapter four explains the model developed to answer the research question, fulfilling the objectives proposed.

Subsequently, the case study in which this work is based on is presented in the **chapter five**. It introduces the Portuguese national network of long-term care (RNCCI), its current structure and objectives. Then it focuses on the specific data (geographic zone, point of demand and other) as well as the assumptions that will be considered when running the model that was developed for this dissertation.

Deriving, **chapter six** presents the results obtained by running the proposed model for different objectives and exploring different scenarios regarding the satisfaction of the current demand, the possibility to absorb extra demand from the inpatient care sector and the impact of different levels of investment on the distance travelled and customer satisfaction rate.

Lastly, the **seventh chapter** is devoted to conclusions and the proposal of future research.

2. Literature Review

A vast literature exists on HHC logistics management in an effort to create tools to help health decision-makers making planning decisions related to their HHC processes.

This literature review starts with a brief identification of Transport Management (TM) as one of the key elements of Logistics Management (LM), as well as the increasing interest of this subject in professional services like in the Heath Care sector, namely Home Health Care services. From the many problems dealt with by TM, the Vehicle Routing Problem (VRP) will be presented in detail since it is one of the most known and studied transportation problems and also the this is for the method in which the thesis will be focused on. The different variations of the classic VRP and solution methods developed will be presented, firstly in a general way and then within the scope of HHC.

By the end of this literature review, the model chosen for the specific case of the RNCCI in Portugal will be presented and justified according to the data exposed throughout this review, comparing the suggested model with some of the studies analysed.

The search protocol at the basis of this review consisted mainly in searching online databases such as b-on, Science Direct and Google Scholars by using combinations of the keywords: Home Health Care, Logistics Management and Routing.

2.1. Logistics Management

The Council of Supply Chain Management Professionals (CSCMP) defines Logistics management (LM) as "*that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements*" (CSCMP, 2017).

Islam *et al* (2013) mentions five key elements of Logistics management that must be considered for an efficient and effective logistics system: i) transport management, ii) warehousing management, iii) inventory management, iv) packaging, and v) information processing. Even though each of these activities deals with specific logistic problems, see Figure 2.1, there needs to be an integrated approach where all these elements are considered to achieve a balanced service level. Due to this complexity and many fields that influence the competitiveness of a company, the advantages of optimizing all LM activities has been vastly and recurrently addressed in the literature.

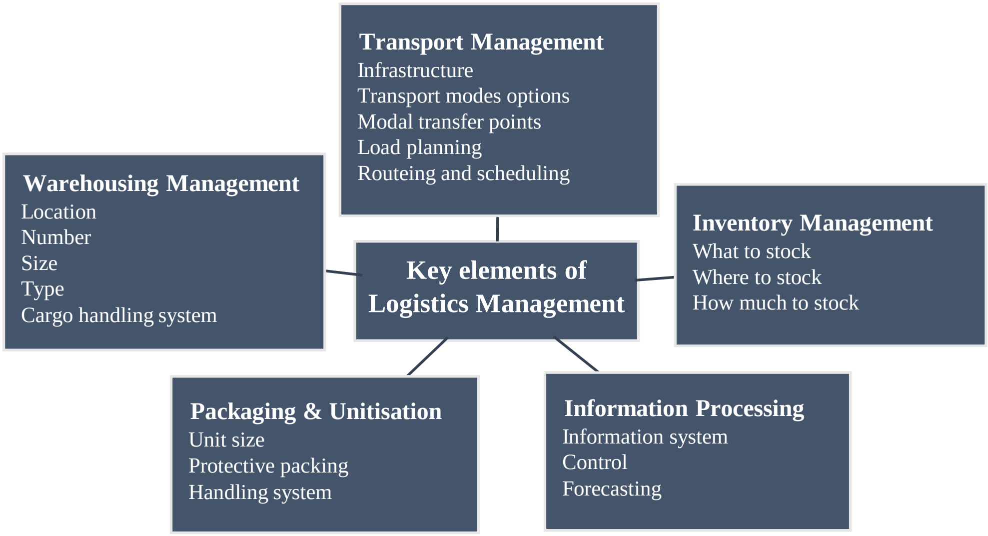

Figure 2.1 – Key elements of logistics management (adapted from Islam et al, 2013)

The application of LM practices has always had more expression within the industry sector, as opposed to the service sector, which includes the health care sector that is the subject of this dissertation.

Christopher and Towill (2001) noted that manufacturing companies are continually paying attention to their customer demand to gain competitive advantage, showing that they have well found out that it is the supply chain (SC) that competes, not the company solely.

However, according to de Vries and Huijsman (2011), the health care sector is behind the industry sector when it comes to implementing LM practices. There has also been a lack of academic research in this field though this gap has been continuously filled in the last decade.

Within the health care sector, Home Health Care services have recently gained relevance due to the increasing demand that the current system is not prepared to satisfy. Thus, there is a need to create tools to help decision-makers optimize their HHC processes.

Gutiérrez and Vidal (2013) provides a framework, see Figure 2.2, that presents three different dimensions from which HHC logistics management can be viewed: i) the planning horizon, ii) management decisions, and iii) services processes. Regarding the planning horizon, and depending on whether one is dealing with strategic, tactical or operational decisions, the time horizon may be long (years), medium (months or weeks) or short (days), respectively. Concerning the second dimension, different groups of management decisions may need to be accounted for: network design, transportation management, staff management and inventory management. Finally, the third dimension describes the services processes at the medical, patient and support services levels.

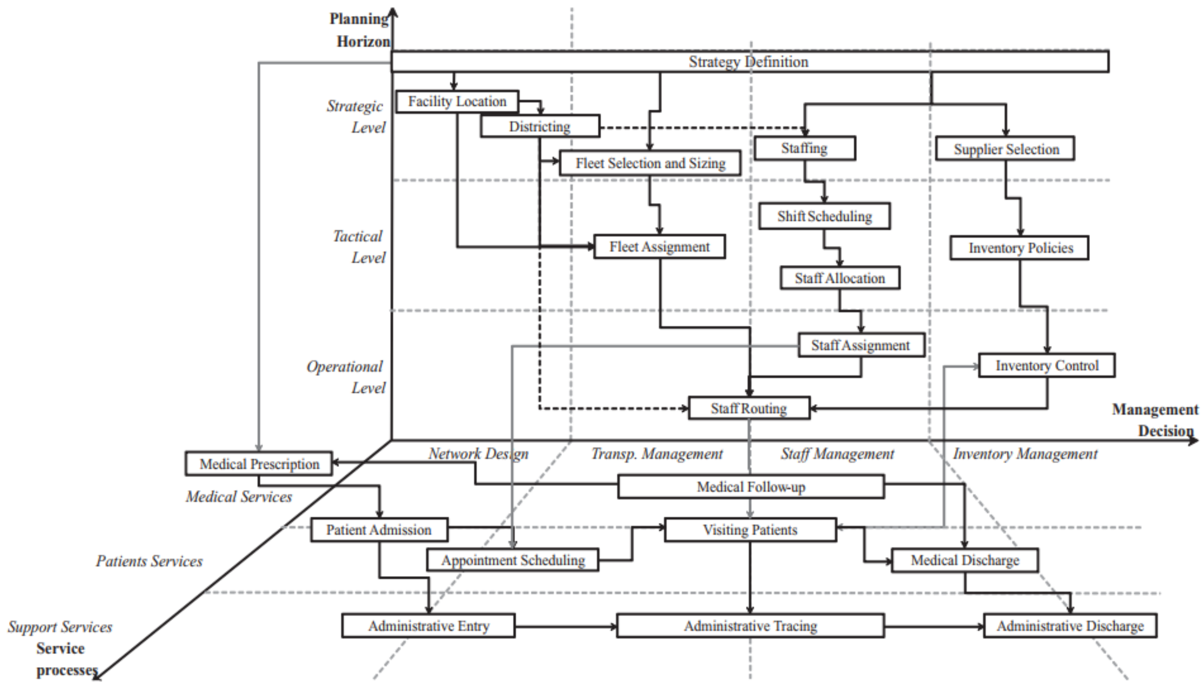

Figure 2.2 – Home Health Care Logistics Framework (Gutiérrez and Vidal, 2013)

Within this setting, this paper is focused on a specific challenge related to transportation management, namely, the HBLTC routing problem. Accordingly, a tool is proposed to support the planning of HBLTC routes on an operational level, thus providing information on how to plan the routes to patients' homes on a daily basis.

2.2. **Transportation Management**

Generally, transport is a major component of most logistics services, and according to Ballou *et al*. (2002) transport management alone is responsible for absorbing between one to two thirds of the total logistic costs of a company. One of the most relevant results of transport-planning decisions is the definition of routes and their respective visit sequence, which is no more than the solution of a routing problem.

Routing problems have been extensively studied in the literature as one of the main problems of a company's supply chain management, with the goal of developing efficient techniques for optimization in transportation due to its economic importance (Cacchiani *et al*., 2014).

In early literature, routing problems were first introduced with the Traveling Salesman Problem (TSP), although according to Dantzig *et al*. (1954) there is no concrete date for when this problem was first studied. The TSP is commonly described as the problem of a salesman (i.e., one vehicle) seeking to travel the minimum distance possible, visiting all cities (customers) once and only once, during one day (Laporte, 1992).

In 1964, Clarke and Wright generalized the "Truck Dispatching Problem" of Dantzig and Ramser (1959) to a linear optimization problem: how to serve a set of customers, geographically dispersed around the central depot using a fleet of trucks with varying capacities. This problem became known as the Vehicle Routing Problem (VRP), one of the most studied and well-known optimization problems. Simply putting, the VRP can be viewed as an extension of the TSP in which multiple vehicles are considered available instead of only one.

The routing problem tackled by this study will be treated as a VRP, since in Home Health Care, generally, more than one vehicle travels around the network to satisfy the customer demand, i.e. treat the patients at their homes. However, regardless of the nature of the business, there are many factors and constrains to consider when solving a routing problem (Carvalho, 2010a; Islam *et al*, 2013):

i) Modes of transport (such as road, rail, waterways, air, pipeline, multimodal or intermodal);
ii) Transport infrastructure;
iii) Geographical condition;
iv) Type of delivery (such as overnight express, normal, long distance);
v) Characteristics of the fleet (number, capacity, performance and filling speed);
vi) Load planning (in the cargo unit);
vii) Characteristics of the points to visit (location and customer specifications and preferences);
viii) Routing and Scheduling.

In HHC, the mode of transport is normally road transport, be it via vehicle, bicycle, public transportation or by foot. Thus, from the factors mentioned above, some of the most important to consider are: i) the transport infrastructures, i.e. the features of the road network (distance between nodes, that influences the variable costs of fuel, and road conditions, that can influence the travel time); ii) the characteristics of the fleet, namely, the number of vehicles available in each nursing and health care centre (the depots); iii) and the characteristics of the points to visit, that include the customer location (influences the travel time), the type of customer (influences the service time of the visit) and the customer preferences, for example, in terms of the period of the day for the visit.

Collecting data and using the appropriate analytical tools, is very important if a company wants to optimise its daily operations for transportation in terms of quality of service and costs. If a company establishes the visit sequence to their customers daily, then the company faces a more dynamic routing. However, by collecting data and having more information in advance, a company can do a better and more constant planning of its routes, for example for the whole week or month (a more static routing).

All these factors need to be accounted for when approaching a routing problem. As mentioned before, the HHC route planning, the topic in study, can be treated as a VRP. The classical form of a VRP, its most studied variations and solution methods will be addressed in more detail in the next section.

2.3. **Vehicle Routing Problem**

In the field of Supply Chain Management, one of the biggest challenges that managers face is defining a strategy to optimize the delivery of products by suppliers to clients, while respecting some constraints (Surekha e Sumathi, 2011). This challenge is generally recognized as a Vehicle Routing Problem and it is one of the most well-known and studied topics in the field of Operations Research (Braekers *et al.*, 2016).

The VRP is a combinatorial optimization problem that "…*consists of designing least cost delivery routes through a set of geographically scattered customers, subject to a number of side constraints*" (Laporte *et al.*, 2013). All routes begin and end at a depot node after all customers are visited and their demand satisfied; and each customer cannot be visited more than one time per route, over a given planning horizon (Reed *et al.*, 2014). Also, in a VRP, multiple vehicles can be traveling around a network, in which case the number of vehicles is either an input value or a decision variable (Cordeau *et al.*, 2005).

A VRP aims to find a set of n routes, while fulfilling the achievement of one or a set of objectives. The most widely considered objectives are as follows: (Toth *et al.*, 2002):

- Minimization of the global transportation cost, dependent on the global distance travelled (or on the global travel time) and on the fixed costs associated with the used vehicles;
- Minimization of the number of vehicles required to serve all the customers;
- Balancing of the routes, for travel time and vehicle load (decrease variation);
- Minimization of the penalties associated with partial service of the customers.

Besides the objective of a VRP, there is another element that brings complexity to this topic – the constraints that can vary widely depending on the setting of each specific problem (for example vehicle capacity, time windows, route length, precedence relations amongst clients, etc.). In fact, Laporte (2007) states the diversity of the constraints as the reason for the unavailability a single universally accepted definition of the VRP.

Due to the considerable variability of conditions in different real-life scenarios, the objectives and constraints encountered in practice are remarkably diverse, generating a wide variety of VRP variants.

Over the past decades, the VRP and its variants have grown ever more popular in the academic literature; and Braekers *et al*. (2016) sees a trend toward VRP variants that include real-life constraints and assumptions, following more realistic models and solution approaches more applicable in practice.

2.3.1. VRP Variants

The classical VRP, also known as the Capacitated VRP (CVRP), designs optimal delivery routes where each vehicle only travels one route, each vehicle has the same characteristics and there is only one central depot (Braekers *et al*. 2016). The client's geographic position and the demands are known beforehand and the vehicles have a homogeneous finite capacity. The objective is to minimize the total cost (reducing the number of routes, their length or travel time), serving all customers.

However, as noted before, due to the variety of constraints and complexity encountered in real-life problems, this classical VRP has been extended in many ways by introducing additional real-life aspects or characteristics, resulting in several variants of the basic problem (Braekers *et al*. 2016).

A system may include more than one depot, a homogeneous or heterogeneous fleet of vehicles, or consider variables such as time windows during which the customer has to or can be served, the capacity of the vehicle, maximum duration of driving periods, or even budgets. The higher the number of restrictions imposed by the problem, the greater the approach to reality (Ferrucci, 2013). From the existing literature, it is possible to identify some of the VRP types most commonly applied in real-life. The most relevant variants are:

- Multi-Depot Vehicle Routing Problem (MDVRP)
- Open Vehicle Routing Problem (OVRP)
- Periodic Vehicle Routing Problem (PVRP)
- Vehicle Routing Problem with Time Windows (VRPTW)
- Dynamic and Stochastic Vehicle Routing Problems

Multi-Depot Vehicle Routing Problem (MDVRP)

This variant of the VRP considers the existence of more than one depot per system, unlike the CVRP. The client's location and demand are still known beforehand, and it considers an homogenous fleet, however there is more than one depot node, with each vehicle starting and ending at the same depot. Because there are additional depots, it has to be determined which one serves which customers, i.e., prior to the routing problem, there is a grouping phase (Ho *et al*., 2008). Generally, and similar to the CVRP, the main objective of the MDVRP is to reduce the total distance of the routes, in addition to the number of routes/vehicles needed.

Open Vehicle Routing Problem (OVRP)

The Open Vehicle Routing Problem differs from the CVRP by not requiring the final node of the route to be the same as the departing one, i.e. as soon as the final client has been visited, the route is allowed to end without the vehicle returning to the depot. According to Li *et al*. (2007), the main objective is to minimize the total distance (or time) travelled as well as the number of vehicles necessary. The OVRP are commonly related to subcontract situations (for example, newspaper and magazines delivery) where the subcontractors resorts to their own vehicle.

Periodic Vehicle Routing Problem (PVRP)

This problem, in addition to the typical client's characteristics, takes into account several planning days, unlike the CVRP, with customers that require service on multiple days during the planning period (Carotenuto *et al*., 2015). The main objective is the minimization of the distance travelled during the time horizon, and in order to find the set of minimum routes for each day, the PVRP aims to determine the appropriate day combination for each customer (Cacchiani *et al*., 2014).

Vehicle Routing Problem with Time Windows (VRPTW)

According to Xu et. al (2015), the VRPTW continues to be one of the most difficult problems in combinatorial optimization. The particularity of the VRPTW is that customer nodes are visited in a pre-specified time window. In this problem, each customer is associated with a time interval during which deliveries can be made to a specific customer; its limits are the earliest allowed arrival time, and the latest allowed arrival time (Berov, 2016). The objective is to design routes that allow the available vehicles to serve all clients while minimizing the cost, respecting the constraints associated to the capacity, travel time of the vehicles and time windows of the clients (Tan *et al*, 2001).

Time Window (TW) constraints can be implemented as either a hard or a soft constraint. As such, the VRPTW type can be subdivided into VRPSTW (soft TW constraints) and VRPHTW (hard TW constraints). The most commonly employed are the Hard constraints are most commonly used and assure that the customer is visited within the time interval defined by the TW. Violations of the constraint are not permitted, which means that vehicles are allowed to wait with no cost if they arrive early and they are prohibited to serve if they arrive late. On the other hand, soft constraints can be violated at the cost of a penalty added to the objective function (Taş, *et al*., 2014).

Dynamic and Stochastic Vehicle Routing Problems

All the above VRP variants have in common a static demand, i.e. known demand, allowing the routes to be planned in such a way that the vehicle always has enough capacity to satisfy all customers' demands.

However, demand is not always a known factor and thus, the Stochastic VRP (SVRP) introduces randomness into combinatorial problems as a way of describing new real problems in which most of the information and data cannot be known beforehand (Juan *et al*., 2011). It can be seen as any VRP presenting one or more stochastic parameters, which means that future events are random variables characterized by a known probability distribution (Ritzinger *et al*, 2013).

In turn, Dynamic Vehicle Routing Problems (DVRP) acknowledges that not all the information is known from the beginning (for example, the arrival of new orders, service time or travel time changes) and enables the inclusion of information in real-time. DVRP are rising in the recent literature since the technological development, especially associated to information and communication, has dramatically increase and facilitate the collection of real-life information and the exact monitoring of vehicles, creating the conditions for real-time decision support in vehicle routing (Ritzinger *et al*, 2013).

Due to the complexity of real-life problems and the number of constrains needed to consider, many combinations between the ones already mentioned arise in the literature. However, increasing the number of constraints, to approximate the problem to the real-life situation, brings complexity of the solution method needed to achieve the optimized solution.

2.3.2. **Solution Methods**

Vehicle Routing Problems are NP-hard problems, which become exponentially more complex to solve with the size of the problem (Laporte, 2007). The current trend, mentioned before, to approach reality, hinders problem solving, mainly for two reasons: i) complexity and limitations of computation; and ii) large number of problem constraints (as closer a problem is to reality, the more constraints have to be considered). Throughout literature, essentially two types of solution methods have been proposed for the VRP: exact algorithms and heuristic algorithms. In some cases where hybrid methods are used, combining both exact algorithms and heuristics, the term matheuristics can be used (Fikar and Hirsh, 2017).

Exact Algorithms

Exact methods guarantee that the optimal solution is achieved, but only if the method is given enough time and space. The literature has proposed several exact algorithms to solve the VRP, based on integer linear programming (ILP), dynamic programming, and branch-and-bound. However, Laporte (2007) focus only on three families of ILP based branch-and-cut algorithms, stating that only these have been proven to be a workable methodology.

Despite yielding the most optimal results, the efficiency of exact methods relies on two variables: problem size and computational time. They require a significant mathematical programming machinery and their ability to solve real-life size instances is limited (Laporte, 2007). When trying to solve larger instances with this kind of methods, the time taken to find an optimum solution be so long that it becomes inapplicable (Martí *et al*., 2011). For this reason, exact methods are mainly used to solve small instances (Laporte *et al*., 2013).

Heuristic Algorithms

Heuristic methods only attempt to find a good solution – not an optimum one. They are frequently used when the process speed to solve a problem is as important as the quality of the solution obtained. In addition to the need to find a good solution in a reasonable time, Martí *et al*. (2011) also highlighted that heuristic methods are more flexible than the exact ones, allowing to add constrains difficult to model. In Laporte (2007) two classes of heuristics are considered: the classical heuristics and the metaheuristics.

Classical Heuristics

Laporte (2007) explains that the term “classical” refers to the fact that the improvement steps of these heuristics always proceed from one solution to a better one in its neighbourhood, until no further gain can be achieved. They are broadly classified into three categories: i) constructive heuristics; ii) two-phase heuristics or iii) improvement heuristics.

Constructive heuristics gradually build a feasible solution focused on solution cost, starting from scratch. The Savings Algorithm is an example of this kind of heuristic developed by Clarke and Wright, in 1964 that considers that there is a cost reduction whenever two customers can be served in the same route, instead of serving the two separately when going directly to each of them from the depot (Carvalho *et al*., 2010b).

Two-phase heuristics divide a VRP solution process into (i) clustering and (ii) routing. The first aims at organizing a partition of customers into subsets, each corresponding to a route; while the second determines the visit sequence for each route. A popular cluster first – route second heuristic is the Sweep Algorithm, developed by Gillet and Miller in 1974, in which clusters of nodes are obtained by rotating a ray centred at the depot. The route for each cluster is then designed by solving a TSP (Laporte *et al*, 2000).

Route improvement heuristics for the VRP are often used to improve initial solutions generated by other heuristics, using local search algorithms – starting from a given solution, this method applies simple modifications, such as arc exchanges or customer movements, in order to achieve a better solution and reduce cost (Cordeau et. al, 2007). Improvement algorithms applied to obtain VRP solutions are essentially of two types. Intra-route methods optimize each solution's route separately by means of a TSP improvement heuristic, whereas Inter-route heuristics are based on moving vertices from one to another route.

Metaheuristics

The other class of heuristics is known as metaheuristics which, in contrast with the first class, permits the consideration of non-improving or even infeasible intermediate solutions. The importance of these latter heuristics has been growing for about two and a half decades. Metaheuristics perform a more thorough search of the solution space and are less likely to end with a local optimum (as opposed to classical heuristics). They are more complex to develop but compensate by outperforming classical methods in terms of solution quality, and sometimes in terms of computing time.

2.4. VRP in Home-Based Long-Term Care

To the authors knowledge, no study exists proposing planning models to solve the HBLTC routing problem, but several studies exist dealing with routing problems in the health care sector in general. For this reason, the focus of this review will be on studies proposing methods to solve HHC routing problems, since these methods have potential to be applied for the particular case of the LTC sector.

2.4.1. Home Health Care as a Vehicle Routing Problem

The framework presented by Gutiérrez and Vidal (2013), see figure 2.2, show how HHC planners face complex and challenging planning problems on different decision levels, including routing decisions. And according to Fikar and Hirsch (2017), mathematical programming models represent the most widely used approach to deal with routing problems in HHC settings, with VRP playing a key role in this area, particularly, Home Health Care Vehicle Routing Problems (HHCVRP). HHCVRP formulations differ in several dimensions. Particularly, one can find:

- i) single- or multi-period models,
- ii) deterministic or stochastic models,
- iii) mono- or multi-objective models.

Single- or Multi-Period Models

Fikar and Hirsch (2017) concluded that most of the research papers is focused on single-period models, where only a single working day is considered for planning purposes (see, for instance, Bredström and Rönnqvist (2008) and Rasmussen *et al*. (2012)).

However, the planning period can range from a single day to multiple weeks, months or even years (see, for instance, Bachouch *et al*. (2011)). In Multi-Period HHC problems, patients might request multiple services spread over different days of a week or month, which requires HHC planners to consider factors such as working time regulations and continuity of care.

Deterministic or Stochastic Models

Since not all data is known in advance and uncertainty in demand is a reality faced by many HBLTC providers, stochastic models play a central role when planning in real-world situations (see, for instance, Birge and Louveaux (1997) for a comprehensive review on stochastic planning in general; and Rodriguez *et al*. (2015) for stochastic HHC planning).

Still, most literature in the area is based on deterministic models that ignore the impact of uncertainty on planning decisions (Fikar and Hirsch (2017)); Lanzarone and Matta (2014) notice that the variability in patients' demand is neglected in the literature and propose an exact model that deals with uncertainty in demands and service times. In their solution, the authors consider continuity of care while minimizing overtimes incurred by caregivers, and present an alternative policy for patient assignment that has been shown to reduce overtime and increase workload balance.

Mono- or Multi-Objective Models

Regarding the number of objectives, many existing studies opt to consider only one single objective (see, for instance, Akjiratikarl *et al*. (2007) and Bachouch *et al*. (2011)).

Nevertheless, multiple and conflicting objectives may need to be pursued – e.g., Braekers *et al*. (2016) present one of the few multi-objective approaches in the area, by proposing a bi-objective model focused on the minimization of total costs and minimization of client inconvenience. And when multiple objectives are accounted for, different approaches may be followed (Cohon, 1978):

- One can identify compromise solutions, the so-called Pareto optimal or non-dominated solutions;
- Alternatively, one can identify the best non-dominated solution through the aggregation of this multiplicity of objectives into an overall objective function using a set of weights.

This review is thus focused on single-period and deterministic models, since the aim of this paper is the proposal of a tool for supporting daily route planning of HBLTC services while ignoring the impact of uncertainty. Also, acknowledging the relevance of accounting for multiple objectives, this paper explores the impact of different objectives but through the use of a mono-objective model, i.e., different versions of the objective function are considered depending on the planning circumstances – in fact, a wide variety of objectives may need to be accounted for, as described below. And concerning the constraints that should be considered when the aim is to ensure an adequate planning of HHC routes, a set of key constraints may be worth to be considered, as also described in detail below.

2.4.2. Main Objectives in HHCVRP

A key objective found in VRP studies is usually the minimization of travelling costs (either in monetary terms or in distances travelled) (see, for instance, Trautsamwieser and Hirsch (2011)). However, in HHC settings, rather than minimizing traveling distances, most studies propose the minimization of the travel time spent by caregivers traveling to patients' homes, or, alternatively, the travel cost associated with moving between patients' homes, since working times are often considered as the main cost factor (Fikar and Hirsch, 2017). Focusing on working times allows accounting for both overtime and waiting times - in fact, many studies propose models aiming at minimizing the time that caregivers have to wait before starting a visit, or aiming at minimizing the overtime needed to perform all the visits assigned to health professionals.

According to Fikar and Hirsch (2017) other objectives include i) maximizing the preferences of patients (for a specific caregiver or visit time window), ii) minimizing the number of nurses needed, iii) maximizing the number of tasks performed, and iv) maximizing fairness, i.e., balancing the workload amongst the staff.

Still, although relevant in contexts of budgetary cuts in health where it is not possible to fully satisfy health care demand (Baker 2000), no study was found considering service level-related objectives to study the maximum of served patients when facing a budget constraint.

2.4.3. **Main Constraints in HHCVRP**

Bertels and Fahler (2006) present six categories of key factors that influence the delivery of HHC and that should be considered when planning HHC routes, namely: i) preferences of patients (such as gender of the nurse, maintaining the nurse in multiple visits or the time windows for visits); ii) preferences of nurses (such as shifts, days off or type of patients), iii) legal aspects (such as working time or service duration); iv) qualifications/experience (such as nurse experience or languages spoken); and v) ergonomics (such as cooperative services or light/heavy patients).

Also, according to Fikar and Hirsch (2017), the most common constraints include the time windows to visit the patients, followed by the patients' skills requirements and working time regulations. On the other hand, although having the potential to significantly impact travelling times (especially in big city centers), traffic conditions are not commonly accounted for in existing literature.

2.4.4. **Main Solution Methods in HHCVRP**

Based on the review of existing literature on Single-Period HHCVRP done by Fikar and Hirsh (2017) most of the works develops metaheuristics solution procedures. Exact solution methods are used for smaller instances, with mainly Branch and Price algorithms being implemented (Rasmussen *et al*., 2012). Some studies also use mathematical problem formulations to benchmark the solution methods with optimization software (Braekers *et al*., 2016; Bredström and Rönnqvist, 2008; Trautsamwieser et. al., 2011). Matheuristics, the combination of exact solution methods and metaheuristics, are also used by multiple authors to take advantage of both methods.

2.5. **Conclusions**

This literature review permitted a better understanding of one of the most studied problems in transportation management – the VRP – more specifically in the context of HHC. As shown, the complexity of the real-life HHC setting makes it that each paper can approach a VRP from a different angle, focusing on different constraints, and thus, originating a wide variety of problem formulations.

Table 2.1 summarizes key studies and features that are relevant to be considered when developing planning models to deal with the HHC routing problem. It can be concluded that no study exists considering service level-related objectives (accounting for the reality that it is not always possible to fully satisfy health care demand) together with cost objectives, which is essential for countries facing budgetary cuts in health (such as happens in several European countries, including in Portugal).

Also, traffic conditions are not typically considered in existing studies, and no study considers the specificities of the LTC sector. Furthermore, patients' preferences are especially relevant in HBLTC, representing a key aspect that should be considered in planning models in this sector.

Accordingly, it can be concluded that there is space to develop research devoted to the development of planning models based on mathematical programming so as to support the route planning of HBLTC, and so the LTC^{routes} fills this gap in the literature.

Table 2.1 – Key features analysed in home health care routing problems, and in the long-term care sector in particular

	Multiple objectives		**Preferences**	**Traffic conditions**	**LTC**
	Travel time/cost	**Service level**			
Bredström and Rönnqvist (2008)	√				
Bachouch *et al*. (2011)	√				
Trautsamwieser and Hirsch. (2011)	√				
Braekers *et al*. (2016)	√		√		
LTC^{Routes}	√	√	√	√	√

Up to the authors' knowledge, the model proposed by Braekers *et al*. (2016) is the one more closely related to the model proposed in this study (the LTC^{routes} model), but it still does not account for service level-related objectives and traffic conditions, and it is also applied to an health care context other than LTC.

3. Methodology

The current chapter outlines the methodology followed in the development of this work. Figure 3.1 schematizes the sequence of phases on which this work was built on.

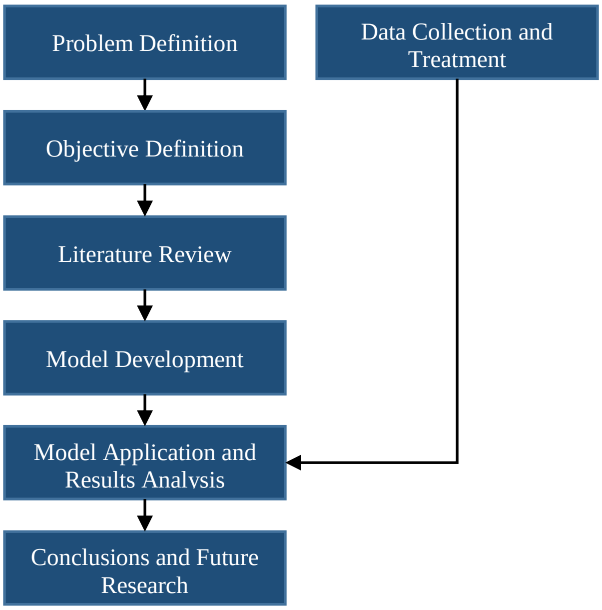

Figure 3.1 - Scheme of the methodology implemented

The majority of costs in the health system are related to long-term care of patients with chronic conditions (Simões J *et al.*, 2017) and the development of the home health care system for long-term care has the potential to reduce the system-wide costs of delivering this type of care. This dissertation aims to tackle one of the basic problems inherent to home health care, which a vehicle routing problem, and present one model as a possible starting solution for this problem in the specific case of HBLTC.

The scope of this paper is the the Portuguese national network responsible for long-term care, *Rede Nacional de Cuidados Continuados Integrados* (RNCCI), so data on the network was collected to comprehend the current operating structure and available resources.

Based on the information gathered, the main research question this work intends to answer was formulated, as presented before: *"How can we support the planning of the daily routes performed within the scope of HBLTC services provided within NHS-based countries, while accounting for cost and demand-related issues?"*

Subsequently, to understand the main solution considered for the problem in question, literature on transportation and routing, in general and for the HHC in specific, was reviewed. In a broad sense, the basis of a VRP in HHC consists in trying to assign caregivers to a set of heterogeneous patients, spread across the geographical area of operations of a care centre. However, there is a wide variety of factors that can impact the way caregivers are assigned like, for example, the time windows preferred by the patients, specific nurses' skill or regulatory contexts that meaningfully vary amongst countries. For all these reasons, the formulations of VRPs applied to HHC vary considerably regarding constrains, objectives to optimize and the solution method used (Fikar and Hirch, 2017).

Based on the literature reviewed and the main purpose of this thesis, a decision was made to develop an exact mathematical model, the LTC^{routes}, based in integer linear programming to solve the presented problem. To obtain the results, i.e. the optimal visit sequence for each of the defined objectives, the model was implemented in the software GAMS (General Algebraic Modelling System). The results obtained will then be presented to show the potential of the model as a tool to support decision making within the RNCCI.

Lastly the conclusions of the work will be presented focusing on the relevant results, practical uses of the model and gaps that can be further developed in future research.

4. Mathematical formulation of the model

The model proposed in this paper – the LTC^{routes} – aims at supporting the planning of routes within the HBLTC sector in any country with a NHS. Relying on the previous context, this planning should follow different objectives, and it should consider several key constraints inherent to this context.

The notation used for the model formulation is presented below, together with the mathematical formulation of the objectives and key constraints of the model.

4.1. Notation

4.1.1. Indices and Sets

The model integrates two types of entities: the nodes (*J*) and the vehicles (*V*), that represent the HBLTC teams. The teams are defined by a set $v \in V=\{1,\ldots,v\}$, representing the v existing vehicles/teams. In turn, the nodes set has several subsets associated to it, namely a subset for the depots, in this case the PHCC from where the team depart and arrive *(Jo)*, and a subset for the municipalities that represent the patients' homes *(Jm)*.

To allow the traffic constraint to be considered, a set $w \in W=\{1,\ldots,w\}$ was created, representing the *w* periods of the day. This will allow for the definition of time multipliers for each period of the day to increase the time travelled according to the traffic condition of each period.

Lastly, a set for the type of patients P was needed to account for the different service times of HBLTC patients and the ones requiring inpatient care but receiving home-based care as a substitute service.

Table 4.1 – Indices and Sets' definition

$v \in V$	Vehicles
$j, i \in J = Jo \cup Jm$	Nodes representing primary health care centers (PHCC) ($jo, io \in Jo \subseteq J$) and municipalities ($jm, im \in Jm \subseteq J$), with municipalities representing patients' homes
$w \in W$	Periods of the day
$p \in P$	Patient type

4.1.2. **Parameters**

Table 4.2 – Parameters' definition

M_v	Maximum daily work time for each vehicle *v*, in minutes
N	Number of vehicles available
K_w	Duration, in minutes, of each period of the day *w*
D_p	Duration, in minutes, of the visit to a patient belonging to type *p*
$N_{p,j}$	Total demand of patients belonging to type *p* on node *j*
N_{jm}	Total number of municipality nodes
$T_{i,j}$	Travel time, in minutes, from node *i* to node *j*
$TRAFFIC_w$	Impact of traffic on each period *w* of the day
$PREF_{jm,p,w}$	Preference of a patient belonging to type *p* in municipality *jm* to be visited during the period of the day *w*

4.1.3. **Variables**

In a VRP problem such as the one that is being addressed in this paper, a variable that concerns the sequence in which the nodes are visited needs to be defined. That variable is $x_{i,j,v,w}$, a binary variable that takes the value 1 if a vehicle travels between nodes in a specific period of the day.

Also, since the demand per municipality is aggregated into one node, a variable $s_{i,j,v,p,w}$ was defined to determine how many patients were served when a vehicle travel to a certain node.

Besides these two main variables, some other were needed for specific constraints and objectives as will be explained in the following chapters. These auxiliary variables are described in Table 4.3.

Table 4.3 – Variables' definition

$x_{i,j,v,w}$	Binary variable that equals 1 if vehicle *v* travels between nodes *i* and *j* during the period of the day *w*; and zero otherwise
k_v	Binary variable that equals 1 if vehicle *v* is used; and zero otherwise
y_v	Maximum time, in minutes, that a vehicle *v* can be used per day
$s_{i,j,v,p,w}$	Number of patients belonging to type *p* served in node *j* by vehicle *v*, with this vehicle traveling from node *i*, during the period of the day *w*
u_{jm}	Variable to be used for eliminating subtours involving each municipality *jm*, as suggested by Miller *et al*. (1960)
z_1	Time traveled minimization variable
z_2	Vehicle minimization variable
z_3	Service level maximization variable

4.2. **Objective functions**

Depending on the planning circumstances, the objectives to be considered may differ.

As noted before, minimizing costs play a key role in this sector, and such cost can be measured in monetary terms, distance or time traveled. In this study, a key objective to be considered is the minimization of traveling costs, with costs being measured in two different ways:

i) Minimizing costs in terms of time traveled (Equation 1) – this will have as consequence an increase in the number of patients served per vehicle. It should be noted that the time used for providing care at patients' home is not considered in Equation 1, because this time is considered to be the same across patients, and so this will not have an impact on planning decisions.

$$Min\ z_1 = \sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{v \in V} \sum_{w \in W} T_{i,j} \times TRAFFIC_w \times x_{i,j,v,w} \tag{1}$$

ii) Minimizing costs in monetary terms, by minimizing the number of vehicles required to visit patients' home (Equation 2; with the number of vehicles being used as a proxy for investment costs) – this is important from a management and investment planning point-of-view, since it gives information on the resources needed to satisfy HBLTC demand.

$$Min\ z_2 = \sum_{v \in V} k_v \tag{2}$$

Furthermore, and still within the context of budgetary cuts in health, it may be relevant to maximize the demand to be satisfied with the available resources. This objective will be hereafter mentioned as service level-related objective (Equation 3).

$$Max\ z_3 = \sum_{i \in I} \sum_{j \in J} \sum_{v \in V} \sum_{p \in P} \sum_{w \in W} s_{i,j,v,p,w} \tag{3}$$

4.3. Constraints

A set of constraints is considered in the model, and are described below.

Routes-related constraints

Equation 4 ensures that a vehicle that enters a node j (either a municipality or a PHCC) must also leave from it, ensuring the continuity of the route.

$$\sum_{\substack{i \in I \\ i \neq j}} x_{i,j,v,w} - \sum_{\substack{i \in I \\ i \neq j}} x_{j,i,v,w} = 0 \quad \forall j \in J, v \in V, w \in W \tag{4}$$

Equation 5 eliminates the routes between the same node.

$$x_{j,j,v,w} = 0 \quad \forall j \in J, v \in V, w \in W \tag{5}$$

Equation 6 prevents subtours between municipalities, as suggested by Miller *et al.* (1960).

$$u_{jm} - u_{im} + N_{jm} \times x_{jm,im,v,w} \leq N_{jm} - 1 \quad \forall jm \in Jm, im \in Im, v \in V, w \in W, jm \neq im \tag{6}$$

Equation 7 prevents vehicles from traveling between PHCC. And this because after leaving a PHCC a vehicle must visit at least one of the municipalities.

$$x_{jo,io,v,w} = 0 \quad \forall jo \in Jo, io \in Io, v \in V, w \in W, jo \neq io \tag{7}$$

Equation 8 ensures that each vehicle departs from only one PHCC, i.e., each vehicle has a stationary PHCC.

$$\sum_{jo \in Jo} \sum_{j \in J} \sum_{w \in W} x_{jo,j,v,w} \leq 1 \quad \forall v \in V \tag{8}$$

Service level-related constraints

Equation 9 simply imposes that the satisfied demand can never surpass the total demand.

$$\sum_{i \in I} \sum_{v \in V} \sum_{w \in W} s_{i,j,v,p,w} \leq N_{p,j} \quad \forall j \in J, p \in P \tag{9}$$

Nevertheless, if the aim is to impose full demand satisfaction, Equation 9 is transformed in Equation (10).

$$\sum_{i \in I} \sum_{v \in V} \sum_{w \in W} s_{i,j,v,p,w} = N_{p,j} \quad \forall j \in J, p \in P \tag{10}$$

Equation 11 ensures that patients are served only if the respective municipality is visited by a vehicle.

$$s_{i,j,v,p,w} \leq N_{p,j} \times x_{i,j,v,w} \qquad \forall\, i \in I, j \in J, p \in P, v \in V, w \in W \tag{11}$$

Patients' preference-related constraints

Equation 12 guarantees that the preference of the patients to be visited at a specific period of the day is respected.

$$\sum_{\substack{i \in I \\ i \neq j}} \sum_{v \in V} s_{i,jm,v,p,w} \geq PREF_{jm,p,w} \qquad \forall\, jm \in Jm, p \in P, w \in W \tag{12}$$

Vehicle-related constraints

Equation 13 defines the maximum visit time per vehicle, and ensures that each vehicle has time enough to travel between nodes, to serve their patients and to return to the PHCC within the regulated daily work time.

$$y_v = M_v - \sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{w \in W} T_{i,j} \times TRAFFIC_w \times x_{i,j,v,w} \qquad \forall\, v \in V \tag{13}$$

Equation 14 defines the maximum visit time per vehicle.

$$\sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{p \in P} \sum_{w \in W} s_{i,j,v,p,w} \times D_p \leq y_v \qquad \forall\, v \in V \tag{14}$$

Equation 15 ensures that each vehicle cannot be used for a number of hours higher than the regulated daily work time – and this include the time used for travelling (first term) and the time devoted for care provision (second term). Similarly, Equation 16 ensures that the time available per period of the day w cannot be exceeded.

$$\sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{w \in W} T_{i,j} \times TRAFFIC_w \times x_{i,j,v,w} + \sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{p \in P} \sum_{w \in W} s_{i,j,v,p,w} \times D_p \leq M_v \qquad \forall\, v \in V \tag{15}$$

$$\sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} T_{i,j} \times TRAFFIC_w \times x_{i,j,v,w} + \sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{p \in P} s_{i,j,v,p,w} \times D_p \leq K_w \qquad \forall\, v \in V, w \in W \tag{16}$$

Equation 17 defines maximum number of vehicles that can be used.

$$\sum_{v \in V} k_v \leq N \tag{17}$$

According to Equation 18, if no visit is performed using a given vehicle v, that vehicle is not used.

$$k_v \leq \sum_{i \in I} \sum_{\substack{j \in J \\ j \neq i}} \sum_{w \in W} x_{i,j,v,w} \qquad \forall\ v \in V \tag{18}$$

And Equation 19 imposes the use of each vehicle, even if it is required for only one visit.

$$k_v \geq x_{i,j,v,w} \qquad \forall\ i \in I, j \in J, v \in V, w \in W \tag{19}$$

Non-negativity and binary variables

Non-negativity conditions are given by Equations (20-21).

$$y_v \geq 0 \qquad \forall\ v \in V \tag{20}$$

$$s_{i,j,v,p,w} \geq 0 \qquad \forall\ i \in I, j \in J, p \in P, v \in V, w \in W \tag{21}$$

Binary variables are given by Equations (22-23).

$$x_{i,j,v,w} \in \{0,1\} \qquad \forall\ i \in I, j \in J, v \in V, w \in W \tag{22}$$

$$k_v \in \{0,1\} \qquad \forall\ v \in V \tag{23}$$

5. Case study

This chapter will focus on the Portuguese national network of long-term care, the RNCCI, and particularly their focus in home health care as a growing solution for long-term care. For this, the general definition and relation between long-term care and home health care will be presented, followed by the explanation of the RNCCI, internal organization and fields of action. The current problems and future objectives that the network has publicly defined are shown, establishing a bridge between them and the idea to develop this work. In the end, the dataset used to study the model in the later chapters is presented.

5.1. Long-term Care and Home Health Care in Portugal

In a review of the Portuguese Health System, Simões J *et al*., (2017) define long-term care as being aimed at older people but also at the chronically ill or patients with special needs, such as mental and physical disabilities or dependencies. It is also noted how the involvement of the public sector in this type of care has been neglected until recently, leaving it to the private sector, social hospitals like the *Misericórdias* and other non-governmental organizations. Even though the Portuguese NHS has paid some of the care provided by the latter two, the state provision of long-term care services is scarce.

The first line of long-term care in Portugal still relies on the traditional informal care delivered by the family at home, particularly in rural areas. However, this is no longer a possible reality for many Portuguese families due to the increase in female employment and migration of the younger members to urban centres. Moreover, Portugal, as well as many other European countries, is also facing the growth of its older population, thus the pressure to provide social as well as medical HBLTC is increasing.

Currently, one of the ways that HHC provision is expanding in Portugal is through the Integrated Support Plan for the Elderly in which the state is intervening by facilitating vocational training opportunities in areas such as domiciliary care and informal health care as part of a job-creation scheme (Simões J *et al.*, 2017).

The formal delivery of LTC by private nursing homes is very expensive and the majority of the population does not have the resources to pay for them, so an alternative solution of care through HHC services provided by the public sector as an increasing interest. Another reason that is likely to lead to a substantial increase in demand for HHC services is the preference by patients who need continued nursing care to stay at their own home.

Despite recent developments there is still a very limited public provision of services in continuing and home care and thus the development and strengthening of formal Home-Based LTC by health professionals currently represents a policy priority across European countries. In the specific case of Portugal, given the population's need for public sector involvement in long-term care to face these problems, since 2006, there is a dedicated network of long-term care providers – the RNCCI (Rede Nacional de Cuidados Continuados Integrados).

5.2. **RNCCI**

The RNCCI (Rede Nacional de Cuidados Continuados) was created by the Decree-Law 101/2006 within the scope of the Ministry of Health and the Ministry of Labour and Social Solidarity (Ministry of Health, 2006) to face the lack of resources to answer effectively to the rapidly increase of the demand for home-based long-term care, result of an increase in the number of people with incapacitating chronic diseases. This network ensures not only the provision of inpatient care and ambulatory care, but also of home health care through multi-disciplinary teams that deliver long-term care and social support. The work of the RNCCI, which includes its HHC provision, is based in communitarian services and covers many institutions that work together under the network such as hospitals and ACES, local and district social security services, the Solidarity Network (with a strong contribution from private providers, such as *Misericórdias*) and municipalities.

The network of long-term care crosses the whole of the NHS, and links with the social sector. Its mission is to provide health care and social support to every patient in a situation of dependency, embodying the principles of continuum of care and promotion of autonomy. The long-term care services provided by the network vary according to the need of each patient but guarantee "maintenance and stimulation activities, daily nursing care, medical care, prescription and administration of pharmaceutical products, psychosocial support, periodic psychiatric control, physiotherapy and occupational therapy, sociocultural animation, hygiene, comfort, nutrition and support in activities of daily life" (Simões J *et al.*, 2017).

The number of beds for inpatient care of patients with the need for LTC has been continuously increasing since the creation of the RNCCI, see Table 5.1, from 1902 beds in 2007 to 7759 beds in 2015, representing an increase of 308% in 8 years. These numbers show how much the

Portuguese health system was in need of adequate LTC, but to face the continuous growth in demand, new solutions need to be studied since there is a limit to how much inpatient beds can be created in the network and this solution represents a great cost to the NHS.

Table 5.1- Evolution of the number of beds in the RNCCI between 2007 and 2015 (Simões J *et al*., 2017)

	2007	2008	2009	2010	2011	2012	2013	2014	2015[a]
No. of long-term care beds	1 902	2 870	3 938	4 625	5 595	5 911	6 642	7 160	7 759
Recovery	452	530	625	682	906	867	860	860	764
Rehabilitation and medium term	663	922	1 253	1 497	1 747	1 820	1 895	2 021	2 306
Long-term care	732	1 325	1 942	2 286	2 752	3 031	3 692	4 094	4 411
Palliative care	55	93	118	160	190	193	195	185	278

In Simões J *et al*., (2017) it is pointed out that the majority of costs in the health system are related to caring for people with long-term chronic conditions and that in order to achieve financial sustainability there needs to be a focus in reducing the incidence of these diseases and developing new models of health care provision to deal with the increasing demand, and consequentially of cost, of LTC in the Portuguese health care system.

In line with this concern, the RNCCI is aware that the main issue is the current lack of adequate provision of continuous care, and thus has made public some goals that the network is currently pursuing such as: reducing the number of unnecessary inpatient and acute care patients that could be followed by continuous care; reducing the number of re-entries in the hospital by older people; providing better services of LTC and rehabilitation post treatment; and developing a more flexible model of organizing and planning its resources based on the regional health systems necessities.

Looking into the benefits of professional delivery of HHC, this type of care shows the potential to complement the delivery of long-term care that the RNCCI is aiming at. Home-Based Long-Term Care services can be used to solve all these problems presented before, by guaranteeing the continuous care of patients in their home after their hospitalization, thus reducing their re-entry in institutional care. Furthermore, in specific cases it might be possible to bypass the inpatient care by treating the patients solely with HHC.

Using HBLTC to help the RNCCI improve its delivery of continuous care to the Portuguese population is thus an interesting thesis to study, reason why this paper decided to focus on evaluating the benefits that can rise from the adequate planning of HBLTC starting form a generic model for route planning that can later be iterated into a more complex model to incorporate all of the different variables that the RNCCI faces regarding long-term care.

5.3. Problem Size and Data used

The RNCCI as a network covers the entire Portuguese territory, being divided into five different geographic regions of action – *Administrações Regionais de Saúd*e (ARS) – *Norte*, *Centro*, *Lisboa e Vale do Tejo*, *Alentejo* and *Algarve*.

The focus of this paper was in a sub-region of the *ARS Lisboa e Vale do Tejo* (ARSLVT), namely the region of *Lisboa Ocidental*. Since the LTC^{routes} model that was developed is based on the exact method of mathematical programming, it faces two obstacles, as mentioned in the literature review, problem size and computational time. Given its dimension, considering the data from the whole network would increase the problem size to a dimension that made the model inapplicable. Though it would be interesting to evaluate the network as a whole, starting by solving a small instance of the problem using the LTC^{routes} model to plan the routes for HBLTC in the RNCCI serves the purpose of showing the potential benefits of the model as a generic tool with the potential to be iterated and optimized by future works to gradually become a key tool to help the network deliver long-term care in Portugal.

The region of *Lisboa Ocidental* is comprised by 5 municipalities (*Ajuda*; *Alcântara*; *Santa Maria de Belém*; *Santo Condestável*; *São Francisco Xavier*), and there are three Primary Health Care Centers (PHCC) that can provide HBLTC within the scope of the RNCCI in this area (*Ajuda PHCC*; *Alcântara PHCC*; *Santo Condestável PHCC*).

The main dataset used for applying the model was i) the total demand of LTC for both home-based care and inpatient care per municipality in Lisboa e Vale do Tejo, see Table 5.2 (Cardoso *et al*., 2012); and ii) the travel times between nodes, calculated using Google Maps.

Table 5.2 – Demand for LTC for both home-based care and inpatient care in *Lisboa Ocidental* (Cardoso *et al*., 2012)

	Home-Based Care demand (patients/year)	Inpatient Care demand (patients/year)
Ajuda	85	171
Alcântara	76	153
Santa Maria de Belém	47	93
Santo Condestável	83	167
São Francisco Xavier	44	88

5.4. Assumptions considered in the model application

To guarantee that the model could run, some assumptions were considered to fill in some gaps in the data available. By using these assumptions, it is possible to study the benefits of the developed LTC^{routes} model and evaluate its viability as a planning tool to be used in real-life by the RNCCI, in which case the assumed values would simply be substituted by the real values of the network.

5.4.1. Patient Nodes

As seen in the Table 5.2 the data for the demand available is the total number of patients, and not their specific location. Thus there was the need to consider a central point where the demand of each municipality is concentrated and that served as the patient node to then calculate the distance between the different PHCC and these nodes, see Table 5.3. The central points considered were the parish councils of each municipality.

Table 5.3 – Travel times between nodes, calculated using Google Maps (*Lisboa Ocidental*)

	Node (1)	*Node (2)*	*Node (3)*	*Node (4)*	*Node (5)*	*Node (6)*	*Node (7)*	*Node (8)*
(1) Ajuda PHCC				2	5	5	13	5
(2) Alcântara PHCC				4	1	6	9	6
(3) Santo Condestável PHCC				11	9	12	5	12
(4) Ajuda	2	5	10		6	3	10	2
(5) Alcântara	6	2	9	6		6	8	8
(6) Santa Maria de Belém	4	6	11	3	6		12	2
(7) Santo Condestável	12	11	4	10	10	12		12
(8) São Francisco Xavier	5	7	11	3	8	3	11	

5.4.2. Patient Types and Service Duration

Two types of patients are considered, HBLTC patients and patients requiring inpatient care but receiving home-based care as a substitute service.

HBLTC patients are visited once per week, allowing for the daily plan proposed in the model and Home-based care can work 7 days per week, as it is the case in the RNCCI in Portugal, meaning that by dividing the total HBLTC demand per the seven days of the week the model is considering a daily plan that if replied for every day guarantees the full satisfaction of the existing demand. The average duration of a visit per HBLTC patient is 25 minutes.

On the other hand, patients requiring inpatient care, but receiving home-based care as a substitute service need to be visited every day – these patients require care on a daily basis in institutional settings, that’s why substituting inpatient care by home-based care imply daily visits. The medium duration of each visit for these patients is 50 minutes.

5.4.3. **Work Regulations and Traffic Constraints**

Primary Health Care Centers are opened from 8:00 a.m. to 8:00 p.m. The means of traveling between nodes is in a vehicle (car/ambulance) that is subject to traffic. The work day is divided in 4 periods: i) morning (8:00-11:00), ii) lunch period (11:00-14:00), iii) afternoon (14:00-17:00), and iv) evening (17:00-20:00) – the morning and evening periods are the ones with more traffic in Lisbon, thus justifying the need to distinguish between these 4 periods. Also each team/vehicle can only work 8 hours/day (480 min/day).

5.4.4. **Patient Preferences**

Also, for illustrative purposes, the preference of patients is considered as follows: 20% prefer to be served in the morning; 40% prefer the lunch period; 10% prefer the afternoon; and 30% prefer the evening. And it is considered that preferences are respected for half of the patients. Also, traffic conditions characterizing the different periods of the day were taken into account when determining the time needed to perform each route.

6. Model Application to the Case Study

In this section the LTC^{routes} model is applied to real-life scenarios using data from one of the Portuguese regions served by the RNCCI, to illustrate how its usefulness to support the planning of routes within the HBLTC sector. Specifically, the model is applied in the context of *Lisboa Ocidental*, in *Lisboa e Vale do Tejo*, one of the regions covered by the National Network of LTC (RNCCI) in Portugal, as mentioned in the previous chapter.

6.1. Scenarios studied

Considering the three objective functions defined in the previous chapter, as well as the solution methodology that is being followed, it was considered that the analysis of the results should be carried out in three different scenarios. These scenarios are characterized mainly by the objective function that is under scrutiny, but in two of these scenarios, two sub-scenarios are considered for each being differentiated by the type of demand that is being considered. In total, five scenarios will be studied in this chapter.

For each scenario, a solution is obtained and analysed, as well as compared among each other so that the functionalities of the model can be more accurately understood and validated. A schematic of the different scenarios under analysis in this paper can be found in Figure 6.1.

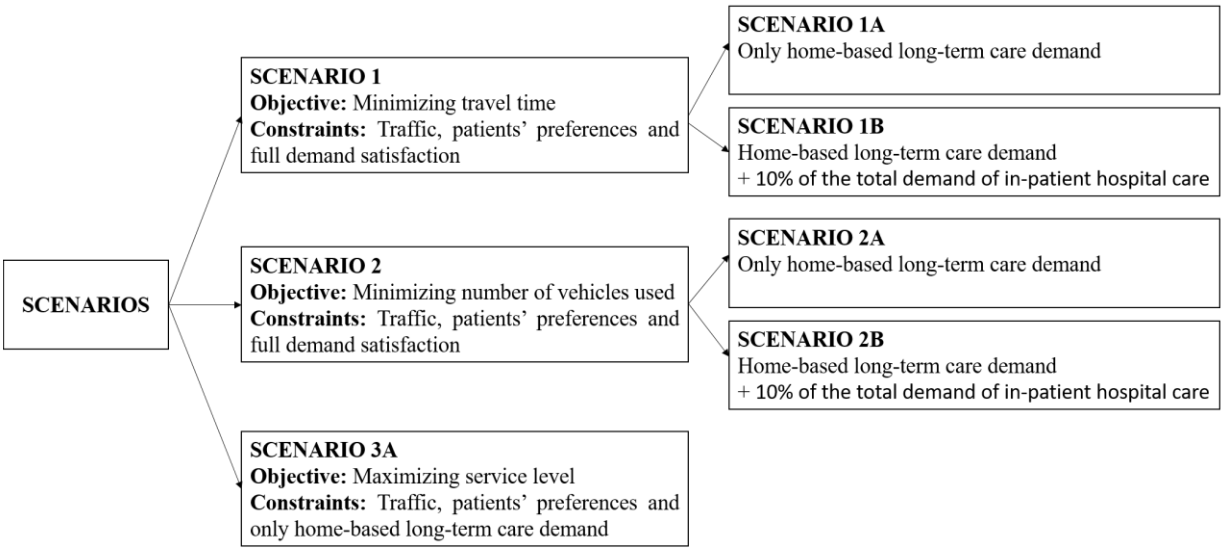

Figure 6.1 - Scenarios' under study

Scenario 1 (1A and 1B)

The first scenario (Scenario 1) refers to a situation where one wants to plan the daily routes of HBLTC without any budget constraint, i.e., the question to be answered is *"How can we plan daily routes so as to fully satisfy daily demand, and this while using the minimum possible time?"*. In this case the objective would be to minimize the travel time (Equation 1), while accounting for traffic conditions and patients' preferences. This scenario is chosen for analysis since minimizing travel time is a common objective found in the literature.

Two versions of this scenario are explored: i) Scenario 1A and ii) Scenario 1B.

i) In Scenario 1A, one wants to plan daily routes while ensuring the full satisfaction of home-based care demand (Equation 10). This is the most likely scenario to be used on a daily basis by the network to guarantee that every patient that is already receiving HHC has access to continuous care and doesn't need to go back to institutional inpatient care without being necessary for lack of home care.

ii) As for Scenario 1B, an extra amount of home-based care demand is considered, namely, 10% of the total inpatient demand should be also satisfied through home-based care. Transferring institutionalized patients to home-based care settings is considered for two reasons. Not only patients prefer to stay at home close to their relatives, but also the Portuguese state can save money with this transference because home-based care is a cheaper alternative when compared to institutional care (one should be aware that home-base care can be provided as a substitute service of inpatient care, whenever it is not possible to institutionalize patients).

To note that in both scenarios the number of vehicles/teams v considered available, i.e. the dimension of the set V, was a big enough number to guarantee enough vehicles/teams available to satisfy the constraint presented on the Equation 10, the total satisfaction of the demand as the scenario asks.

Scenario 2 (2A and 2B)

On the other hand, Scenario 2 is analysed to explore the amount of resources needed to fully satisfy HBLTC. Particularly, one wants to explore how many vehicles are needed to fully satisfy the demand in each municipality. The objective under study in this scenario is be the minimization of vehicles used (Equation 2) answering the question *"How can we plan daily routes so as to fully satisfy daily demand, and this while using the minimum possible vehicles/teams?"*.

One should be aware that the number of vehicles used can be used as a proxy for costs, and so by minimizing the number of vehicles we are minimizing costs, which is also a key objective to be considered in this sector as mentioned throughout this paper (particularly, in NHS-based countries with severe health care budget constraints).

The same two versions explored under Scenario 1 are explored under Scenario 2: i) Scenario 2A and ii) Scenario 2B. By doing so, a comparison of both scenarios under conflicting objectives can be analysed in the results chapter, showcasing the potential of this model as a support to the decision-making process of routing and investing in more or less teams for the network.

Just like in scenario 1, the number of vehicles/teams v considered available, was a big enough number to guarantee the satisfaction of the constraint presented on the Equation 10, i.e. the total satisfaction of the demand.

Scenario 3A

Finally, Scenario 3A considers the current context of budgetary cuts in health where it is not possible to fully satisfy health care demand, and thus intends to answer the question *"How much of the total demand is it possible to satisfy under a limited budget?"*.

In this case the objective would be to maximize the number of served patients (Equation 3), while accounting for the number of vehicles/teams available, traffic and preferences constraints. This is a key scenario for any NHS-based country with budget constraints that limit the number of patients to be served, such as happens in Portugal.

Contrarily to the previous scenarios, the number of vehicles/teams v considered available will equal the specific bubget constraint being considered. Also, Equation 10 is substituted by Equation 9 since it is not expected to achieve the total satisfaction of the demand.

6.2. Results and Discussion

Results obtained under each scenario are described below. These results were obtained with the General Algebraic Modelling System (GAMS) 25.0 using CPLEX (an optimization software) on a computer with a processor AMD Ryzen 7-1700, 3GHz with 16GB RAM.

6.2.1. Scenario 1 (1A and 1B)

According to Scenario 1A, the minimum daily travel time needed to fully satisfy the current demand for home-based LTC in *Lisboa Ocidental* is 100,4 minutes. While this value by itself is not the most relevant indicator to help in decision-making, by calculating it, the model creates the daily routes to satisfy all the demand considered. In Table 6.1 it is possible to see the 12 daily routes that should be performed per day so as to fully satisfy this demand – 3 distinct routes, each travelled by 4 different vehicles. One should be aware that each route needs to be performed by several vehicles, because one single vehicle is not enough to visit all the patients in the area until the end of the day.

Table 6.1 – Daily routes obtained under Scenario 1A

Routes		**No. of vehicles per route**
Route 1	*Ajuda PHCC → Ajuda → São Francisco Xavier → → Santa Maria de Belém → Ajuda PHCC*	4
Route 2	*Alcântara PHCC → Alcântara → Alcântara PHCC*	4
Route 3	*Santo Condestável PHCC → Santo Condestável → Santo Condestável PHCC*	4

According to Scenario 1B, so as to absorb 10% of the inpatient demand through HBLTC, besides satisfying all the existing home-based demand, the minimum daily travel time increases to 131,9 minutes. Table 6.2 shows the 14 daily routes that needed to guarantee the satisfaction of the extra demand – 6 distinct routes, each travelled by different vehicles.

Table 6.2 – Daily routes obtained under Scenario 1B

Routes		No. of vehicles per route
Route 1	*Ajuda PHCC → Ajuda → Ajuda PHCC*	3
Route 2	*Ajuda PHCC → Ajuda → São Francisco Xavier → → Santa Maria de Belém → Ajuda PHCC*	1
Route 3	*Ajuda PHCC → São Francisco Xavier → Santa Maria de Belém → Ajuda PHCC*	2
Route 4	*Alcântara PHCC → Alcântara → Alcântara PHCC*	3
Route 5	*Alcântara PHCC → Alcântara → Ajuda → São Francisco Xavier → → Santa Maria de Belém → Alcântara PHCC*	1
Route 6	*Santo Condestável PHCC → Santo Condestável → Santo Condestável PHCC*	4

6.2.2. Scenario 2 (2A and 2B)

To fully satisfy the existing demand for HBLTC in *Lisboa Ocidental*, and according to Scenario 2A, all the three PHCC need to operate with 6 vehicles between them (with these vehicles being used to perform 6 distinct routes). Accordingly, this number of vehicles is far less than the number of vehicles obtained under Scenario 1. Regarding the total travel time of this scenario, this lower number of vehicles is possible by allowing for longer (and, consequently, more expensive) routes.

On another hand, according to Scenario 2B, the added 10% of inpatient demand results in a higher number of vehicles needed – in particular, 12 different vehicles are needed to fully satisfy the imposed demand.

6.2.3. Scenario 3A

Under Scenario 3A, and considering that only 5 vehicles were to be available for the 3 PHCC, 28% of the HBLTC demand would remain unsatisfied, meaning that those patients would need to be referenced to other ACES of the RNCCI and/or wait for a vacancy in the network.

6.2.4. **Comparative analysis**

Table 6.3 summarizes the results obtained under each of the five scenarios under study.

Table 6.3 – Key results obtained under the different scenarios studied

Scenario	Total travel time [minutes]	No. vehicles needed	% Satisfied HBLTC Demand	No. of different daily routes planned
Scenario 1A	100,4	12	100	3
Scenario 1B	131,9	14	100	6
Scenario 2A	196,4	6	100	6
Scenario 2B	259,0	12	100	12
Scenario 3A	257,7	5	72	5

The comparative analysis of the different scenarios through Table 6.3 is of great importance since it allows the study of conflicting objectives, giving more information to decision-makers regarding the best approach to the daily planning of HBLTC. From the results obtained one can see that:

i) Scenario 1 (where one aims at minimizing travel time) results in a more organized and standard daily route planning;
ii) Under Scenario 2 (in which the aim is to minimize the number of vehicles needed), it is clear that longer and more expensive routes may be required when the aim is to have the lowest investment in vehicles;
iii) In Scenario 3 one can see the impact that a lack of resources (in this case, vehicles) can have on the percentage of satisfied demand.

Under Scenarios 1A and 1B, it is possible to see that with an already optimized route plan (result of minimizing the travel time), the satisfaction of extra demand can be obtained without a costly investment (see how only 2 more vehicles allow for the satisfaction of 10 % of the total inpatient demand).

Regarding Scenario 2A, it shows an alternative evaluation of the problem by finding the minimum number of vehicles to fully satisfy the HBLTC demand, and it is possible to see that with half the resources it is possible to fully satisfy the existing demand at the cost of some longer routes. It sheds light on a quick investment-oriented solution to solve the current situation of long waiting times for patients to start being treated. However, Scenario 2B shows that, to achieve the same goal of adding 10% of the inpatient demand, the added investment is way higher compared to Scenario 1.

On the other hand, the awareness that there are budgetary cuts in health that make it impossible to fully satisfy health care demand is key to understand the importance of studying scenarios of resource scarcity and comprehend the impact that unitary investments can have in the overall performance of the network. Scenario 3A thus represents a key scenario to be explored under these circumstances.

On a final note, it adds value to the whole model the fact that it considers, even at a simple level, the traffic conditions in different periods of the day and the patients' preferences for their visit time.

6.3. Computational results

In Table Table 6.4 it is possible to analyse some of the characteristics of model's runs for each scenario, one of the most relevant being the execution time, which is the time interval necessary for the model to generate an output. The number of iterations and variables needed for each model's run are also displayed, showing the complexity of a problem such as the one under study.

Table 6.4 – Key computations results per scenario

Scenarios	Execution Time [minutes]	Gap	Iterations	Equations	Integer variables	Variables
Scenario 1A	4,17	0	926 952	27 352	6 750	23 106
Scenario 1B	16,67	0	1 881 892	27 352	6 750	23 106
Scenario 2A	16,67	0	1 524 901	27 352	6 750	23 106
Scenario 2B	2,44	0	126 083	27 352	6 750	23 106
Scenario 3A	0,3	0	91 957	4 627	1 125	3 856

Note that the values found in the column Gap for every run is 0. This means that every solution presented was an optimal one. In addition to being optimal, the solutions are obtained in a reasonable amount of time, as observed in column Execution Time.

7. Conclusions and Future Research

7.1. Conclusions

Long-term care demand is growing at a fast pace and many NHS-based countries like Portugal are not prepared to answer back. On the other hand, home-based health care in general, and home-based long-term care (HBLTC) in particular, has been appointed by some studies as an important component of health care systems, having the potential to reduce costs of health care provision and free capacity in overcrowded acute care settings. In fact, HBLTC not only represents an alternative to institutional care whenever one faces these overcrowded acute care settings, but it also represents the preferred setting for LTC patients, since patients tend to prefer to be treated in their own homes when it comes to chronic diseases.

Within this setting, there is clearly the need to plan the adequate provision of HBLTC, with this planning being especially relevant in National Health Service (NHS)-based countries facing high pressures to reduce and control health care spending (such as happens in Portugal). This adequate planning implies, among other issues, the planning of routes for HBLTC provision, with mathematical programming models representing the most widely used approach for that purpose.

This study thus proposes the development of the LTC^{routes} model. This is an optimization model based on mathematical programming developed to support the planning of routes to patients' home within the HBLTC sector in any NHS-based country. This model aims at informing health practitioners on how they can plan their routes and on the required investments in order to meet HBLTC demand. Multiple conflicting objectives that are relevant in this sector are considered, such as the minimization of costs (in terms of travelling time and number of vehicles required to perform the routes) and the maximization of service level (in terms of the percentage of patients visited). Patients' preferences, traffic conditions and budget constraints are also imposed to explore the impact on planning decisions

The key contributes of this paper are as follows:

i) It proposes a generic tool that can be used to support route planning decisions of HBLTC delivery on a daily basis;
ii) It explores the impact of accounting for different objectives relevant in this sector, such as the minimization of costs and the maximization of service level;

iii) It proposes a planning model that allows accounting for patients' preferences and traffic conditions as constraints;
iv) It showcases the possible benefits of using the proposed model in a real-life scenario, using the RNCCI as a case study;
v) It proposes a generic approach that can be used to plan HHC delivery in general, and that can be applied to other regions of Portugal or other countries with a NHS.

To demonstrate the usefulness of the proposed model, it was applied to a Portuguese case study – the provision of home health care within the scope of the National Network of LTC (RNCCI), and the particular data of the region *Lisboa Ocidental* was considered when running the model.

From the study of 5 different scenarios, the main results confirm the importance of analysing conflicting objectives, since different routes are obtained when different planning objectives are imposed. The minimization of travel times reflects a more organized and standard daily route planning, an attractive solution for a daily plan that can ease the schedule of the health practitioners. From another perspective, minimizing the vehicles/teams needed to fully satisfy the existing demand is key when planning future investment or cuts. Also, the maximization of the service level, measured in terms of satisfied demand, shows the impact of the lack of investment on the number of patients that cannot be served by the RNCCI. A comparative analysis of all scenarios and conflicting objectives will improve the planning decisions of daily routing, for example, by understanding the impact of investing or cutting one vehicle/team in the overall service level, or by understanding how much of the current inpatient care can be absorbed with HBLTC.

Finally, it can be concluded that the LTC^{routes} model fulfills the objective herein proposed of planning the delivery of home-based long-term care through a mathematical programming-based tool to support routes' planning. Besides shedding light on the importance of studying the specific state provision of home-based long-term care in Portugal and NHS-based countries, the development of a general and simpler model as a first step creates a path for future iterations and optimizations of this model in search of an evermore complete tool to aid in the provision of this type of health care.

7.2. Suggestions for Future Research

In terms of further research, different lines of research are worth to be pursued. First, as a simplistic and general model, it is certainly possible to take this base and deepen the constraints considered (such as lunch breaks, nurse preferences, team skills, team composition, overtime, weekly planning).

Another research direction can be the development of a stochastic model so as to explore the impact of uncertainty in route planning decisions. Moreover, given the importance noted in analysing multiple conflicting objectives, a multi-objective model that allow exploring the joint impact of multiple objectives, such as minimizing costs together with maximizing preferences, should also be pursued. Particularly, the augmented ε-constraint method may be used for that purpose.

An additional line of research would involve exploring the use of alternative means of transport and its impact on the routes and on costs.

Also, and in addition to the policy objectives mentioned in this study, other key objectives may worth to be considered for planning purposes. In particular, quality of care may need to be considered through the maximization of health and wellbeing benefits – and within such circumstances, QALYs may be used as a proxy for health benefits, while the ICECAP instrument may be used to estimate wellbeing benefits.

Finally, developing an easy-to-use tool based on the proposed mathematical programming model is a very interesting line of research that should be pursued, since it embodies one of the main reasons of developing this model – aiding and improving the daily work of real professionals that deliver HBLTC, through the practical application of the knowledge acquired in this branch of logistics management.

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