Route optimization in home social care: the case study of Cáritas Diocesana de Setúbal

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Abstract

Acceleration of the population ageing index is a current problem, and Portugal has one of the highest levels of population ageing in the European Union. In 2021, there were 182 elderly people for every 100 young people, and 37% of these elderly people are dependent. Home care services are emerging as a social response to the problem of dependency, and as the population ages, its demand is increasing. In Portugal, most of these services are provided by non-profit organizations whose budgets are generally very reduced.

This work aims to assess the impact of using optimization tools in the planning of home social care services, with the general objective of reducing the unproductive time related with the travelling of caregivers to and from patients' homes. Through the application of an optimization model for home social care problem new routes are proposed for the home social care service provided by the Cáritas Diocesana de Setúbal. The results show that the routes achieved by minimizing the travel time will allow the introduction of new patients into the system and contributed to improving the efficiency of such services. Moreover, it demonstrates the potential of mathematical models in logistics planning for home social care.

Keywords

Logistics, Home Social Care, Route Optimization, Continuity of Care, Case Study

1. Introduction

According to Pordata (2021), there are currently around 182 elderly people (aged 65 and over) for every 100 young people (aged up to 14) in Portugal, and the rate of ageing is increasing dramatically. Portugal is considered to be one of the oldest countries in the European Union, also in terms of dependency rates, with approximately 37% of the elderly being dependent (PORDATA, 2021). As a result, the need for home care services is growing, following the trend already observed in other countries where "... many older people prefer to age in the privacy of their own homes rather than in nursing homes. On the other hand, the availability of informal care by relatives is decreasing ..." (Braekers et al., 2016). Vieira et al (2022) identify home health and social care as complementary responses to population ageing.

According to the Instituto da Segurança Social (2017), the Home Social Care Service (HSCS) is a social service for the elderly, people with disabilities and people with physical or psychological dependency. This service is aimed at people who are temporarily or permanently unable to meet their basic needs or carry out daily tasks independently, and who do not have family support for these purposes. The HSCS has the following objectives: to improve the quality of life of individuals and families; to contribute to the reconciliation of the professional and family life of the household; to provide care and services that meet the needs of the patients; to strengthen the skills and capacities of families and other caregivers; to facilitate access to community services; to prevent or postpone the use of institutional care as much as possible; to contribute to maintaining patients in their natural living environment; and to contribute to the prevention of dependency by promoting autonomy. By ensuring that patients receive the care they need, HSCS avoids their institutionalization in nursing homes and helps to facilitate their discharge from hospital (Gil, 2009). This social care should include services that provide hygiene and comfort care, housekeeping and light cleaning at home, meal preparation, transport and distribution, laundry care, as well as services that accompany patients outside and during their leisure time, as well as food shopping and minor home repairs (Bonfim and Veiga, 1996). Home social care services are services often provided to older people with reduced autonomy, but who are not necessarily ill, and the caregivers are not necessarily highly qualified and, therefore, are often interchangeable (Vieira et al., 2022). The authors refer to home health care services (HHCS) as medical and paramedical services provided to patients in their homes. It is therefore provided to patients who are ill and receiving treatment at home. In contrast to HSCS, HHCS caregivers are usually highly qualified (mainly doctors and nurses) and permanently attached to the patient, i.e. HHCS caregivers are not interchangeable.

The strong growth of the home care sector opens new research opportunities in the area of operations management and optimization (Mascolo et al. 2021). The planning of a home care service involves determining which caregiver will visit each patient and at what time will the visit occur. Although, over the years, organizations have realized the benefits of adopting more efficient management strategies, recognizing that planning caregivers' routes to and from patients' homes (usually referred to as rounds) allows them to reduce costs and often to expand their service capabilities (Cheng & Rich, 1998), this type of planning is still mostly usually done by technicians who are not specialized (most of them have a social work background). Moreover, home care providers need to optimize their activities to meet the growing demand for these services (Braekers et al., 2016). Badell et al (2022) suggest that demand for HSCS is not evenly distributed across neighborhoods and that economic and disability factors are related to demand for HSCS through users' average net rent and level of disability characteristics. All of these factors play a role in the planning of HSCS and this is what makes the service so complex.

In Portugal, home social care services are mostly provided by non-profit institutions (Soares, 2019), having the strong growth of the sector been mostly due to the creation of Private Charity Institutions (PCI). Although having some financial support from the Portuguese government, this type of organizations usually faces economic difficulties and limited service capacity (evidenced by long waiting times to become a service patient). The adoption of strategies aimed at reducing costs and time involved in providing home social care services are of utmost importance.

1.1 Objectives

This work aims to optimize the routes taken by caregivers assigned to the home social care service of Cáritas Diocesana de Setúbal (CDS). The focus will be on the characterization of such service so as to allow for the minimization of the time spent travelling during service provision. We aim at understanding to which extend there is room to increase the number of patients to whom such services are provided. We do not aim at reducing costs but at understanding how this service can be planed more efficiently so as to increase the number of patients which will reduce the current waiting list. Following the single case study methodology, interviews, document analysis and participant observation were the main tools used to gather the necessary information to best prepare the study. Then, data was gathered and structured to allow the model proposed by Gomes and Ramos (2019) to be applied to support the assessment of the impact of adopting such approach to plan the service when comparing to the current practice. This study adds up to the still insufficient research on this topic concerning the Portuguese reality. In doing so, we are of value to all those involved in the field of home social care, making it possible to compare practices and, in the future, to establish procedures to minimize the costs and time involved in providing this type of service.

2. Literature Review

The Vehicle Routing Problem (VRP) has been extensively used in the planning and control of logistics operations, when a plan with a set of transport requests and a fleet of vehicles is to be made, in which the set of vehicle routes is determined in order to carry out all the transport requests at minimum cost (Toth & Vigo, 2014). The VRP is a generic name assigned to a class of problems that aim to delineate the set of optimal routes for a given fleet of vehicles to serve a given set of customers (Mor and Speranza, 2022).

There are not many works addressing to home social care services in the scientific literature, as the vast majority of authors address the issue of home care as home health care. The process of organizing Home Health Care Services (HHCS) involves making decisions about assigning caregivers to patients, determining appropriate visit times, and ensuring compliance with a number of constraints. The goal is to optimize some criterion, such as cost or service quality, over a given period of time. As a result, a set of planned routes is generated, indicating the scheduled visits (Mascolo et al. 2021). Several problems addressed by the authors in the scientific literature can be seen as instances or extensions of the VRP, such as VRP with Time Windows (VRPTW), where each customer must be visited within a given time window. Fikar and Hirsch (2017) state that the time window is a very important characteristic of these problems as most often there are patients who need to be serviced at very specific times (e.g. medication that has to be administered within a time frame), so the definition and compliance with the time window requires special attention.

Liu et al. (2014) state that the homecare routing problem can be classified as a Periodic Vehicle Routing Problem with Time Windows (PVRPTW). This problem combines the Vehicle Routing Problem with Time Windows (VRPTW) and the Periodic Vehicle Routing Problem, which addresses how to efficiently serve patients within a given time horizon while respecting predetermined time windows for each patient. Given the specificity case in study, the authors model their home care routing problem as the Periodic Home Health Care Pickup and Delivery Problem (PHHPDP), which is similar to the PVRPTW in that it considers the pickup and delivery of materials and goods (drugs, medical equipment, and biological samples) between the central warehouse of the HHCS, the patient's home, the medical laboratory, and the hospital.

The route optimization problem in home health and social care has characteristics that distinguish it from many other optimization problems and give it great complexity. Mascolo et al. (2021) show that the main characteristics encountered in HHCS are related to visits, caregivers and patients. A certain number of visits have to be made by caregivers to patients' homes and could vary in number, frequency and duration of visits. In some cases, there may be compatibility issues between caregivers and patients based on factors such as gender or language. Typically, different types of caregivers are considered, such as nurses or nursing assistants, each with their own areas of expertise. These professionals are often categorized by skill level and limited to tasks within their respective skill sets. They may use different modes of transportation, including cars, public transportation (Rest and Hirsch, 2016), bicycles, or walking (Fikar and Hirsch, 2015). In addition to the traditional time windows that indicate caregiver availability, there may be additional rules to follow, such as mandatory lunch breaks or restrictions on working hours. Patients may express preferences regarding the gender of the caregiver they prefer for a visit, or they may have other specific preferences or incompatibilities with certain caregivers. They may also have preferred availability windows or specific preferred days and times for visits. In these services, it is also important to maintain continuity of care. This means ensuring that the patient consistently receives visits at the same time, with a specific rotation among caregivers. These unique characteristics lead to constraints that are different from those found in traditional VRP. In addition, there are differences in the objective functions considered. While VRP focuses primarily on minimizing travel costs, in the context of home health and social care, several other cost objective functions are considered, such as costs associated with caregivers, such as reducing their waiting time or working hours (Zhang et al., 2023). Preference objective functions are also modeled that aim to maximize caregiver preferences, such as balancing workload (Decerle et al., 2019), or patient preferences, such as ensuring continuity of care (Lahrichi et al., 2022).

Vieira et al. (2022) distinguish the two concepts inherent in home care (health and social care at home) and address the issue in a synchronous way, proposing two heuristic methods to optimize decisions when users receive health and social care services at home simultaneously. This type of planning is even more complex as it is necessary to coordinate the planning between the two services and it is highly desirable that users are visited by the fewest number of different caregivers at the same type of appointments (continuity of service). The authors address the problem of Home Health and Social Care Routing and Scheduling (HHSCRSP) by developing a web-based decision support system where planners are able to obtain an efficient solution in an intuitive way by providing information about the (minimized) imbalances in workload assigned to caregivers and continuity for the same user. Gomes and Ramos (2019) addressed the topic of optimization in home social care in a case study, proposing a methodological approach based on optimization tools to support the planning of caregivers' work schedules over several weeks, according to the pre-established loyalty scheme between caregivers and patients, and to allow the rescheduling of work schedules in case a user leaves the system. The authors considered PVRPTW as one of the subproblems in the study. A route optimization model with three objective functions is proposed in order to meet the specifications of HSCS service providers. The method used by the authors to implement the developed optimization model was to decompose the model by patient typologies (bedridden and semi-dependent) and time periods (days of the week). The models were implemented separately for bedridden and semi-dependent patients and for each day of the week. To ensure the loyalty of caregivers and patients over the weeks, the model was applied to one of the days and, based on the solution obtained, patients were assigned to the teams for the remaining days. Using this solution method, the authors were able to improve the total travel time spent in the service.

In recent decades, many industries have discovered the benefits of improving the efficiency of their operations by applying optimization models. Organizations providing home social care services are mostly not-for-profit, so minimizing costs is even more important. In a study conducted by Fikar and Hirsch (2017), travel time accounted for between 18% and 26% of the total time of HSCS provision, which, according to the authors, shows a high potential for cost reduction by optimizing and improving route planning.

Akjiratikarl et. al (2007) argue that route optimization in home health and social care enables: (i) reduce distance travelled and therefore transport costs; (ii) improve staff utilization by reducing the time 'wasted' on travel and consequently increasing the number of patients served; (iii) improve the quality of service provided to patients by meeting all service requirements within the specified time windows; and (iv) reduce the workload of the technicians responsible for service planning, thus speeding up the planning processes. From the perspective of HCS providers, the main objective is to find a work scheme that is feasible for the caregivers and their vehicles, meets the needs of the patients, reduces operational costs and improves the quality of service provided (Liu et al., 2014).

3. Home social care service at Caritas Diocesana de Setúbal

Cáritas Diocesana de Setúbal (CDS) provides with a variety of home social care services: meal preparation and delivery, laundry care, housekeeping and personal care (e.g. personal hygiene, bathing and diapering). These services are managed by two social workers who are responsible for the overall planning and control of the HSCS activities. Services are provided seven days a week, with some patients being visited more than once a day.

In order to best characterize the home social care services provided by the CDS, several sources of information were used: interviews, document analysis and participant observation. The interviews were conducted at two different points in time. First, an interview was conducted with the technician in charge of the HSCS of CDS in order to explain the scope and objectives of the study and to understand the organization's interest in participating. After management approval, a second interview was conducted to obtain the information needed to characterize the organization, collect the essential information and plan the activities necessary to prepare the study. In addition to these two meetings, there were other contacts to clarify minor aspects. The CDS provided all the necessary documentation to obtain information to characterize the organization, the services provided and the patients. The participant observation consisted mainly of observing the different rounds of the HSCS of the CDS on three different days and lasted an average of three hours per day, for a total of nine hours of participant observation. Observing the rounds made it possible to collect several pieces of information, namely the times of service provision (timed in order to calculate the average time of provision of each service) and the routes taken by the caregivers. In addition, it was possible to interview the caregivers, which was essential to better understand the functioning and characterization of the HSCS of the CDS.

Currently, CDS provides personal care, housekeeping and clothes delivery/collection services to 35 patients in their homes. Most of these services take place from Monday through Thursday between 8:30 am and 5:30 pm with a one hour of lunch break. On Fridays, Saturdays and Sundays, the service starts also at 8:30 am and finished half an hour earlier, at 4:30 pm, also with a one-hour lunch break. Concerning caregivers, the home services are done by 10 women that work in teams of two. These 5 teams are divided into two groups: two teams for meal preparation and delivery and three teams that only provide personal care and housekeeping. For the laundry services, the Day Center has a laundry where all the patients' clothes are washed and ironed. All the clothes are collected by the teams when they visit the patients and then delivered on another day when they visit the patients again.

Meal delivery is a service with its own routes, provided by two teams of two workers, from Monday through Friday, and a single team on Saturdays and Sundays. Meal preparation begins at 11.30 am at the Day Center (where the meals are prepared and where all the caregivers have their lunch break) and the meals are delivered between 12 pm and 1:30 pm. Currently, Caritas Diocesana de Setúbal distributes the meals to 34 patients. In addition to delivering meals, these teams are may also provide personal care and housekeeping services.

CDS has 10 caregivers who travel in three vehicles to provide personal care and housekeeping services, distributed from Monday to Friday on three different routes: white, brown and green. The white route is performed by team of two caregivers and one vehicle, and this route is dedicated exclusively to providing personal care. The brown and green routes have four caregivers, also working in teams of two, and one vehicle assigned. With only one vehicle, one team drops off the other at a patient's home and continues to another patient's home. At the end of the service, they go back to pick up the other team and drive to the next patients' home, following the same pattern. These teams are also responsible for the meal delivery service. On Saturdays and Sundays, all the visits, including meal delivery, are made by only one team of two caregivers and one vehicle. The patients and services provided are the same on both days, so CDS considers these days to be a single route – the weekend route. All teams start and end their routs at the Day Centre. All caregivers can work together and there are no incompatibilities between them. There are also no incompatibilities between caregivers and patients, who can be visited by any of the caregivers working on the home care service.

With the information on patients' addresses obtained from the analyzed documents, it was possible to draw (using GoogleMaps) the network of the HSCS of the CDS for the teams that only perform personal care, housekeeping and clothes delivery/collection tasks. Figure 1 depicts the geographical distribution of the 35 patients visited by these three routes (the CDS calls them the white, the brown and the green routes). These routes were designed manually by the technicians in charge of the service. We can observe in Figure 1 that there are patients in close proximity to each other that are visited by different teams, which may indicate that there is room for improvement in the established routes. It also shows that in the teams that share a car (brown and green routes), the patients' homes are geographically dispersed, which causes unnecessary displacement and consequently additional costs. Note that two of the patients' locations are so close that they overlap on the map, and that there are two other patients who share the same location.

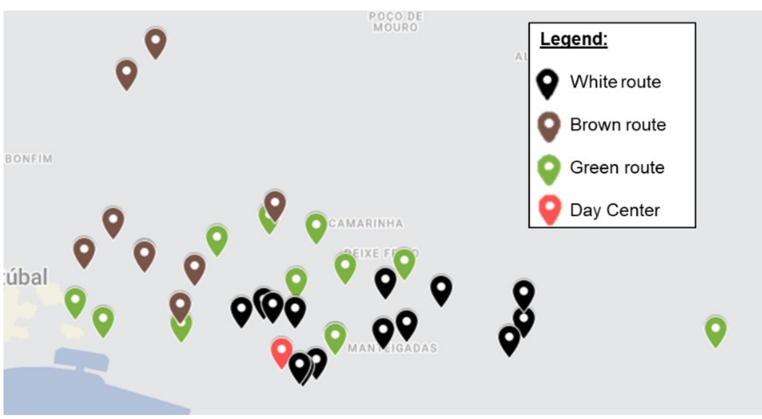

Figure 1: Routes currently operating on the HSCS

The distances between all patients and between patients and the day center were estimated using the GoogleMaps application, allowing the travel time for each route and the total for the week to be calculated (Figure 2). Currently, approximately 18 hours per week are spend travelling to and from patients' homes. This averages out to 3,5 hours on weekdays and 42 minutes on each weekend day. Although the former figure may seem high, it does not take into account the additional travel time caused by the brown and green teams' car-sharing when picking and dropping off the colleagues at patients' homes. It has not been possible to take these movements into account because they do not take place every day and they vary in time. Therefore, this will serve as a lower bound for the travel time currently spent by HSCS teams. As we can see in Figure 2, the green route is where there is more travel time, representing 38% of the total travel time of the HSCS of CDS. The white and brown routes are more balanced, accounting for 31% and 30% of the total travel time respectively.

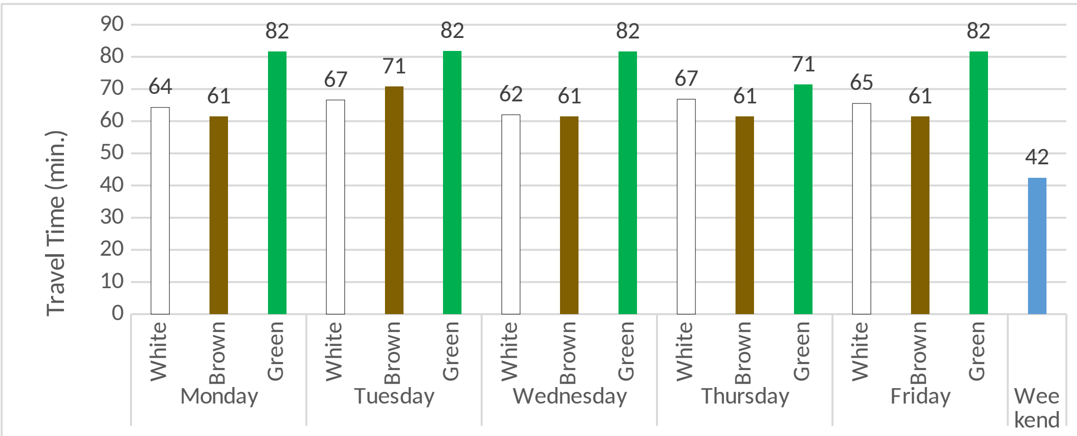

Figure 2: Travel time per route per day of week

In the observation phase and during the rounds, the services provided were timed in order to calculate the average duration of each service. The services analyzed were personal care, bathing and clothes delivery/collection and, on average, these services take 25, 40 and 10 minutes, respectively. After following the rounds and consulting some of the available documentation, a more detailed characterization of the HSCS of Caritas was possible. All information was gathered in Table 1. As can be seen, Monday is the day with the largest number of visits, with a total of 49 visits (38 personal care, 9 bathing and 2 clothing services) requiring approximately 22.2 working hours. Thursday is the day with the lowest workload, only 20.9 hours are needed to carry out 46 visits. Wednesday is the day with the most baths and Friday is the day with the highest workload, requiring 22.3 hours. Saturday and Sunday are exactly the same in terms of service.

Table 1: Visits and services per weekday of the HSCS of Cáritas

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Patients Visited	30	29	28	28	29	4	4
Patients Visited twice a day	19	18	19	18	19	3	3
Total of visits	**49**	**47**	**47**	**46**	**48**	**7**	**7**
Personal Care	38	37	37	37	39	6	6
Baths	9	8	10	8	9	1	1
Clothing Services	2	2	0	1	0	0	0
≈Total Service Time (h)	**22,2**	**21,1**	**22,1**	**20,9**	**22,3**	**3,2**	**3,2**

The time windows in which patients are visited depends on their needs/preferences and has been agreed in advance with the responsible technicians. When a new patient enters the system, he/she is visited according to existing availability, so as not to disturb the already established services.

Caritas wants to ensure intra-weekly rather than inter-weekly loyalty between patients and caregivers. In other words, the same team of caregivers should visit each patient throughout the week, but they should change weekly as caregivers are assigned to the different routes each week. In addition to understanding how the routes could be improved, the CDS is also interested in understanding the impact that purchasing an additional vehicle could have on its HSCS, as vehicle sharing makes route planning difficult and leads to unnecessary trips, creating inefficiencies in the system.

4. Solution approach

The case study described above fits the context addressed in Gomes and Ramos (2019). More specifically both case studies share: (i) caregivers start from a day center (DC); (ii) there are patients in the system who need more than one daily visit; (iii) meals are delivered by caregivers, so some have to return to the DC earlier to prepare and deliver meals; (iv) lunch breaks are taken at the DC; (v) there are no incompatibilities among caregivers, between caregivers and patients, or between caregivers and the services to be provided; and (vi) loyalty between caregivers and patients should be ensured during the week. Nevertheless, some issues are different, namely, we will not address the transportation of patients to and from the day care center, nor will we address the entry and exit of patients into the system (the waiting list). The proposed model was then slightly modified and applied to the entire week, but did not produce a feasible solution in an acceptable computational time. Although the case study described can be considered small, the computational time was too large to consider the entire week. Note that with an average of 47 visits per day, a total of 237 visits over the five days of the week must to be assigned to the five teams and scheduled. Therefore, the model proposed by Gomes and Ramos (2019) was adapted to our case study by considering each day independently. To ensure continuity of care throughout the week, the day with the most visits was chosen as the day to determine the assignment of patients to the different teams. This assignment was then enforced for the remaining days to ensure continuity of care.

For patients requiring more than one visit per day, the strategy was to replicate their nodes as many times as the visits required and define the corresponding time windows. The Day Care Centre node was also replicated so that one node represented the meal preparation, another the lunch break and another the end of the shift. Given that patients are visited more than once a day and that the visits may not be compatible with the caregivers' maximum daily working time, the daily loyalty constraint was modelled as a "soft" constraint, where a second team can visit a user on the same day at the cost of a penalty in the objective function.

Although the model has been previously published, for the sake of completeness of this work we have chosen to present the complete formulation of the model applied with the changes we needed to do to make it fit our case study.

Let $P=\{1,\ldots,n\}$ be the set of all patients and the corresponding replicas, $C=\{0,n+1\}$ be the set of day care center nodes, and $C^L=\{n+2\}\wedge ¿\, C^D=\{n+3\}$ be the replicas of the day care center for the lunch break and the meal preparations, respectively. Let $I = P \cup C \cup C^L \cup C^D$ be the set of all nodes. and A the set of the teams of caregivers. Note that in this modelling approach the caregivers are model through the teams they will be assigned to. Concerning the model parameters the shorter distance between any two nodes $i, j \in I$ be denoted by d_{ij}. Let w_i be the service time and $[e_i, l_i]$ the time window at patient $i \in I$. With respect to the teams, h^a the maximum working hours for the team a and q the number of teams needed at the Day Center to deliver the meals. Three sets of decision variables are needed. Namely, $X_{ij}^a = 1$ if team a goes directly from node i to node j (= 0, otherwise), $Y_i^a = 1$ if the replica of patient i is not visited by the same team (= 0, otherwise), and S_i^a the arrival time of the team a to the node i.

$$\text{Min} \quad \sum_a \sum_{i,j} d_{ij} X_{ij}^a \quad [1]$$

$$\text{s. t.} \quad \sum_a \sum_{i,j} X_{ij}^a = 1, i \in \text{P} \quad [2]$$

$$\sum_{j \in P \cup C^L} X_{0j}^a = 1, a \in A \quad [3]$$

$$\sum_{j \in P \cup C^L} X_{j(n+1)}^a = 1, a \in A \quad [4]$$

$$\sum_j X_{ij}^a = \sum_j X_{ji}^a, i \in P, a \in A \quad [5]$$

$$S_i^a + d_{ij} + w_i - S_j^a \leq M\left(1 - X_{ij}^a\right), a \in A, i, j \in I \quad [6]$$

$$e_i \leq S_i^a \leq l_i, a \in A, i \in P \quad [7]$$

$$S_{n+1}^a - S_0^a \leq h^a, a \in A \quad [8]$$

$$\sum_i X_{ij}^a = 1, a \in A, j \in C^L \quad [9]$$

$$\sum_a \sum_i X_{i(n+3)}^a = q \quad [10]$$

$$\sum_k X_{jk}^a + Y_j^a = \sum_k X_{j'k}^a + Y_{j'}^a, j, j' \in R_i, a \in A \quad [11]$$

$$X_{ij}^a, Y_j^a \in \{0,1\}, S_i^a \geq 0, a \in A, i, j \in I \quad [12]$$

As objective function [1], this model minimizes the total travel time. Equation [2] guarantees that all patients (including all patients' replicas) are visited exactly once. Equations [3] and [4] ensure that all teams start their shift at the day care center and end their shift at the day care center (node $n+1$). These constraints also apply to set C^L since the lunch break is modelled as a fictitious patient visited by all teams. Note that they can start their shift directly at lunchtime, as some teams may only work in the afternoon. Similarly, teams that only work in the morning can finish their shift at the day center after lunch. Equation [5] ensures work continuity, as all teams have to arrive and leave the patients' homes. Constraint [6] defines the start time of the visits to patients i and j when they are visited by the same team. If those patients are assigned to different teams (i.e. if $X_{ij}^{a}=0$), this constraint becomes redundant (M is a value as large as needed). The time windows are ensured by the constraint [7], where e_i and l_i are, respectively, the earliest and latest time the service to patient i have to start. For the day care center nodes ¿), the time windows define the service period. Constraint [8] ensures the maximum working time for team a. The lunch break is modelled by equation [9] as a fictitious patient visited by all teams. The meal preparation is guaranteed by constraint [10], which requires that at least q teams visit the meal preparation node ($n+3$) in the time window defined by the responsible technique and guaranteed by constraint [7]. Continuity of care is guaranteed by constraint [11] in which either the same team can visit patient i and all its replcias or a penalization is incurred. Constraint [12] defines the domain of the variables.

Note that this model will be solved only for one of the week days. This day will provide the allocation of patients to teams and therefore, the remaining days, will only define the routes each team will do for the patients and time windows specifics of the day. In other words, variables Y_i^a values will be fixed. This will ensure weekly continuity of care, i.e., all patients will be visited by the same team.

Since the CDS wishes to know the impact of having one more vehicle available to the HSCS service, the carsharing between the green and brown teams was not modelled. There results presented below will be compared to the current scenario assuming the travel times without taking into account the additional time spend by the brown and the green teams.

5. Results and Discussion

Applying the described methodology, the first day of the week solved was Monday. This is the day with the highest number of visits (a total of 49 visits by 30 patients). The assignment of each patient to a team is shown in Figure 33. It can be seen that the five teams are needed to ensure that all time windows are met and all patients are visited. 39 of the 43 patients are assigned to three teams (teams 1 to 3). The other two teams (teams 4 and 5) visit only two patients each whose homes are very close to the Day Center. These two teams are the ones that are assigned to prepare the meals. With this patient/caregiver assignment, there is no penalty in the objective function, meaning that all patients who need more than one visit are visited by the same team. Comparing CDS home social care service routes (Figure 1) with the ones proposed by the model (Figure 3), the differences are striking. In the current solution, there is an overlap of the routes associated with the different rounds. The solution proposed by the model allows a reorganization of the routes, which significantly reduces the overlap. As a consequence, it leads to a reduction in costs, modeled here as a reduction in the total time spent in the trips to and from the patients' homes.

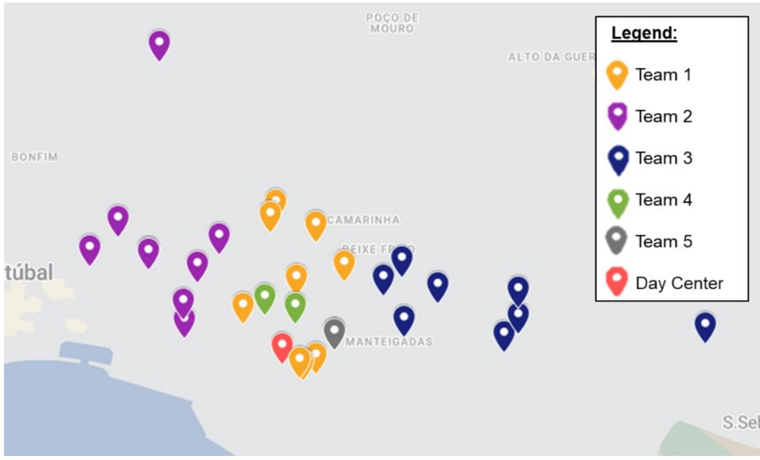

Figure 3: Monday Teams Assignment

The new routes proposed for Monday have a total travel time of 175 minutes (Table 2), with service times ranging from 405 minutes for Team 1 to 155 minutes for Team 4. As for the Tuesday visits, they have similar travel times because the patients are assigned to the same teams as on Monday. The differences come from the fact that some visits change between days (e.g. there is a patient who needs only one visit on Tuesday, while he needs two visits on Monday). If CDS had five vehicles to allocate to each HSCS team, it could reduce the total travel time on Mondays by 32 minutes, an improvement of 16% (Table 3). On Tuesdays, the journey time could be reduced by approximately 39 minutes, an improvement of 18%. For the remaining days, the assignment of patients to teams yields unfeasible solutions. In other words, these assignments together with the remaining data for each of the days did not allow the design of any of the five possible routes. It should also be noted that the services in this HSCS are not regular, so they vary from day to day (e.g., on Monday there are nine patients who need bathing, while on Wednesday there are ten, which increases the service time on these later visits). The main reason for this is that the time windows previously defined are not compatible with the assignments made for Monday. In further studies, the solution approach needs to be improved in order to be able to solve more than one day simultaneously (e.g. we could put together two days that would allow all patients to be visited at least once). However, these results suggest lack of uniformity among days (concerning mostly the time windows agreed with the patients. On the weekend days, we addressed them as a single day because their data is exactly the same. As expected, one team is sufficient to visit these patients and perform all the necessary tasks. The optimal route is very similar to the one currently used in practice. However, we were able to improve it about 3 minutes (about 7% reduction), which can be considered negligible.

Table 2: Solution obtained for the CDS HSCS by applying the route optimization model

Day of the Week	Team	Travel Time (min.)	Service Time (min.)	Total Travel Time/day (min)
Monday	Team 1	45	405	175
	Team 2	59	360	

	Team 3	60	325	
	Team 4	5	155	
	Team 5	7	220	
Tuesday	Team 1	48	375	180
	Team 2	63	370	
	Team 3	60	340	
	Team 4	4	155	
	Team 5	5	185	
Saturday and Sunday	Weekend	39	290	39

Table 3: Comparison of travel times between the current routes and the proposed by the optimization model.

Day of the Week	Total Travel Time (min.) - current situation	Total Travel Time (min.) - models best solution	Δ (min)	Δ (%)
Monday	207	175	-32	-16%
Tuesday	219	180	-39	-18%
Saturday and Sunday	42	39	-3	-7%

These routes were designed with the sole focus of minimizing travel time, therefore, they are quite unbalanced in terms of workload (Figure 4). On Monday, team 1 has the highest service time (a total of 405 and 375 minutes for Monday and Tuesday, respectively), team 2 has the second highest service time and teams 4 and 5 the lowest. Bear in mind that these later teams have other functions, namely, meal preparation, which as not be accounted for since it does not imply travelling. Concerning, the travel times (Figure 5), Teams 2 and 3 are the one spending more time travelling to and from the patients' homes (a total of 122 and 120 minutes, respectively). At the time of this study, this was not an issue for the CDS, as most of the caregivers have other responsibilities at the day care center. Nevertheless, it will be interesting to investigate the impact on the assignment of patients to teams when a workload balance objective function is considered.

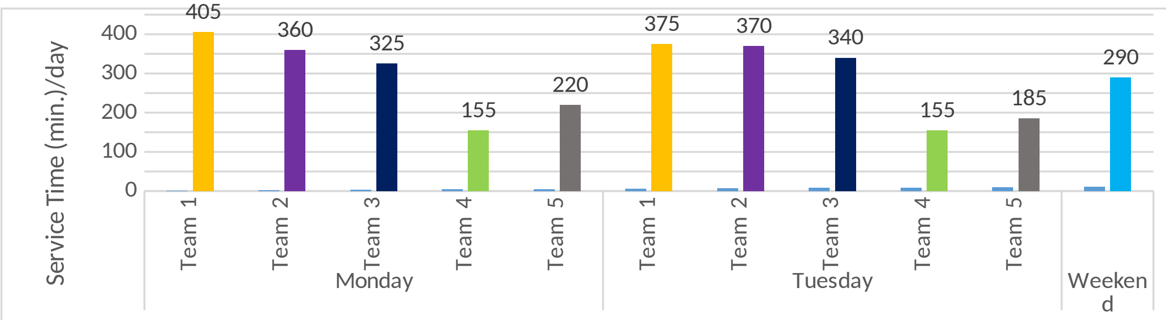

Figure 4: service times associated with each team

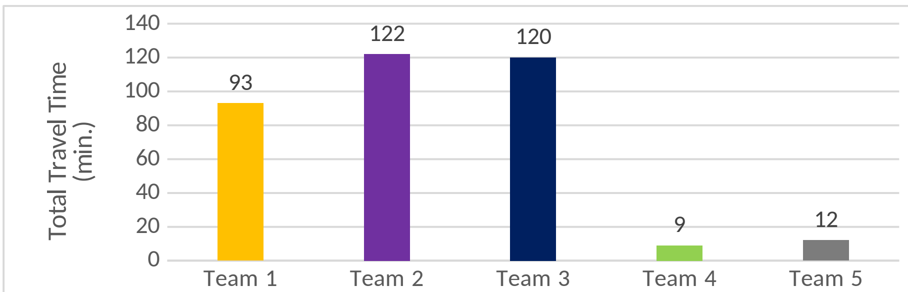

Figure 5: Comparison of total travel times per team

It is clear that with one vehicle per team there would be a large margin to introduce new patients into the system, since team 1 has 780 minutes of service in patient care, while teams 4 and 5 have only 310 minutes and 405 minutes, respectively. With the same number of patients, it would be possible to restructure the teams, since the cumulative workload of teams 4 and 5 is not higher than that of team 1. Since all of this analysis was done considering the current travel times as if there were no carsharing between teams, it reinforces that carsharing is a major source of inefficiency at CDS HSCS and does not allow for the associated cost savings. More patients could be served with the same team of 10 caregivers.

The model was implemented in GAMS/CPLEX system (built 24.2.3) on AMD A4-6210 APU with AMD Radeon R3 graphics 1.8 GHz.

6. Final Remarks and Future Work

In this work, the case study of the Home Social Care Services of Caritas Diocesana de Setúbal was addressed. This HSCS provides a range of home-based social services, including meal preparation and delivery, laundry, housekeeping, and personal care. These services are managed by two social workers and are available seven days a week, with some patients receiving multiple visits per day. Currently, CDS provides personal care, laundry and housekeeping services to 35 patients. Services are provided primarily Monday through Thursday from 8:30 a.m. to 5 p.m., with adjusted hours on weekends. Ten caregivers, divided into five teams, provide these services and also deliver meals. The caregivers' routes are manually planned. In addition, some teams share vehicles, resulting in unnecessary travel and additional costs. CDS aims to improve the intra-week loyalty between patients and caregivers, while exploring the potential benefits of acquiring an additional vehicle to improve route planning and reduce inefficiencies.

The proposed solution for CDS home support services resulted in reduced travel time for Monday and Tuesday, with approximately 32 and 39 minutes saved, respectively. However, for Wednesday, Thursday, and Friday, the model did not provide an acceptable solution. In terms of the weekend, there was a minimal reduction of approximately 3 minutes in total travel time. The imbalance in both total travel time per team and total service time per team on weekends suggest potential issues with the number of teams allocated for the services. Although the solution approach had some limitations, its implementation contributed to improving the efficiency of the home social care service by minimizing travel time and associated costs. Moreover, it demonstrates the potential of mathematical models in logistics planning for home social care.

In addition to the suggested improvement of enhancing the solution approach to allow simultaneous solving for multiple days, it would be beneficial to consider the inclusion of cost data for a more in-depth analysis of the impact of acquiring a new vehicle. By including cost factors, a comprehensive study can be conducted to assess the feasibility and potential benefits of adding an additional vehicle to the system. This would provide valuable insight into the financial implications and efficiencies associated with expanding the home social care service.

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Biography

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