Improvement of the Operational Planning of a Social Organisation

ComDignitatis Case Study

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Abstract

Portugal has seen a growing increase in children and young people at risk. To fight against this situation, organisations like ComDignitatis - whose mission focuses on helping to build a better future for these children - gain a fundamental role in our society. To this end, they have to deal with some logistical challenges that hinder the support service from being provided, specifically in planning home visits, which is currently done manually.

An assignment and scheduling model was developed in order to maximise the number of visits carried out in a month, determining which families would be visited, by whom, and when. In the proposed model, a team of two technicians travels by car to a set of locations representing the families' homes, respecting some constraints. Namely, at most two families can be visited during the morning or afternoon, and the distance between them should be less or equal to 20 km. The model was implemented with real data, provided by ComDignitatis, referring to January, February, and March 2022.

In contrast with the current reality, where 32% of the total visits were made in January, 25% in February and 40% in March, the results of this model suggest that it is feasible to increase the number of visits, satisfying 96% of the total visits in January, 94% in February and 100% in March, using only one car, i.e., with this solution it will be possible to triple the number of visits compared to the current situation.

Keywords: Home visits; Home social care; Technicians assigned to families; Problems of assignment and scheduling; Optimisation.

Resumo

Portugal tem assistido a um crescente aumento de crianças e jovens em risco. Para lutar contra esta situação, associações como a ComDignitatis - cuja missão se centra na ajuda à construção de um futuro melhor para estas crianças - ganham um papel fundamental na nossa sociedade. Com este objetivo, têm de lidar com desafios logísticos que dificultam o serviço de apoio a prestar, mais concretamente, no planeamento das visitas ao domicílio que, atualmente, é feito de forma manual.

Um modelo de afetação e agendamento foi desenvolvido de forma a maximizar o número de visitas realizadas, num mês, determinando quais as famílias que seriam visitadas, por quem e quando. No modelo proposto, uma equipa de duas técnicas viaja de carro até a um conjunto de locais, que representam as casas das famílias, respeitando algumas restrições. Nomeadamente, no máximo duas famílias podem ser visitadas durante a manhã ou a tarde, e a distância entre elas deve ser menor ou igual a 20 km. O modelo foi implementado com dados reais, fornecidos pela ComDignitatis, referentes a Janeiro, Fevereiro, e Março de 2022.

Em contraste com a realidade atual, onde 32% do total de visitas foram feitas em Janeiro, 25% em Fevereiro e 40% em Março, os resultados deste modelo sugerem que é viável aumentar o número de visitas, satisfazendo 96% do total das visitas em Janeiro, 94% em Fevereiro e 100% em Março, utilizando apenas um carro, ou seja, com esta solução será possível triplicar o número de visitas em comparação com a situação atual.

Palavras-chave: Visitas ao domicílio; Cuidados sociais em casa; Técnicas afetas a famílias; Problemas de afetação e agendamento; Otimização.

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Acronyms

CAFAP Centro de Apoio Familiar e Aconselhamento Parental

CPCJ Comissão de Proteção de Crianças e Jovens

FP Family Preservation

FR Family Reunification

FRP Family Reunification Point

FRSA First Route Second Assign

GAMS General Algebraic Modelling System

GA Genetic Algorithm

HHC Home Health Care

HHCRSP Home Health Care Scheduling and Routing Problem

LNS Local Neighbourhood Search

LS Local Search

MACO Memetic and Ant Colony Optimisation

PISS Private Institution of Social Solidarity

SPH Set Partitioning Heuristic

VRP Vehicle Routing Problem

VRPTW Vehicle Routing Problem with Time Window

WSRP Workforce Scheduling and Routing Problem

1 Introduction

The purpose of this chapter is to understand the background and motivation behind this dissertation, as well as its objectives, research methodology and structure.

1.1 Background and Motivation

In Portugal, there is an increasing number of children and young people at risk. In order to protect them and place them in a safe family environment, so as to guarantee their safety, health, training, education and well-being and to foster their full development, 4 types of social responses were created: Centro de Apoio Familiar e Aconselhamento Parental (CAFAP), which focuses mainly on families with children and young people at psychosocial risk; Equipa de Rua de Apoio a Crianças e Jovens, which helps children and young people, who do not have any support from any institution, and who are detached from their family; Acolhimento Familiar, in which children and young people, up to the age of 18, are under the responsibility of a single person or a family; and Acolhimento Residencial in which they go to foster homes. These last two responses are measures promoted by the Comissão de Proteção de Crianças e Jovens (CPCJ), which are “non-judicial institutions with functional autonomy”, whose intervention involves the participation of those who exercise the parental responsibility, or by the Court (Ministry of Solidarity and Social Security, n.d.). However, CAFAP, since it is a service linked to childhood and youth, it also becomes a good complement to the CPCJ, Courts and other more traditional social services.

In 2021, the number of children and young people in danger increased in relation to the previous year. Through the Annual Report of CPCJ's Activities, 69 727 children and young people were accompanied, which includes the processes of previous years, plus those reported in that year. Figure 1 shows the evolution of the number of children and young people accompanied between 2017 and 2021.

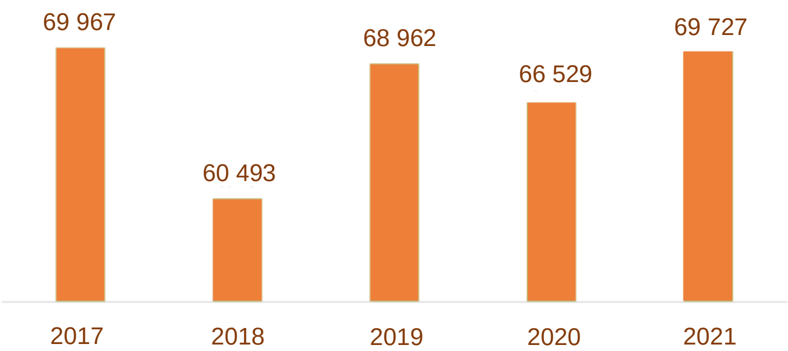


Figure 1. Comparison of the number of children and youth monitored by CPCJ from 2017 to 2021. Adapted from Comissão Nacional de Promoção dos Direitos e Proteção das Crianças e Jovens (2021)

It is noticed a decrease in the number of children and young people being accompanied from 2017 to 2018, from 2019 to 2020, and an increase in 2021 (*CPCJ Relatório Anual*, 2021). Compared to the previous year, this number increased by about 4.6% and was only slightly lower than the highest number recorded, in 2017.

Therefore, all help is needed in order to provide support to these children and young people who are in constant danger. As a matter of fact, ComDignitatis, the case study of this dissertation, a non-profit organisation that aims to support families with children and young people at risk by strengthening family relationships and enhancing the skills necessary for them to have a happy growth and future, provides CAFAP services. However, there are numerous challenges that make the whole logistics of the service more complex. Hence this work arises, with the aim of helping to improve the operational planning of this organisation and, indirectly, helping these children to receive all the support and follow-up they need.

1.2 Objectives

The present work aims to develop and implement a MILP model that takes into account all the constraints that hinder ComDignitatis' operational planning, whose main output is to determine which families will be visited, by whom and when.

Thus, the main objectives of this dissertation are the following.

1. Understand the concept and functioning of one of the social responses provided to families with children and young people at risk, CAFAP, in Portugal;
2. Describe the organisation under study, ComDignitatis, how it operates, its objectives and activities;
3. Characterise the CAFAP services provided by ComDignitatis;
4. Clarify all the logistical challenges of these services that the organisation faces;
5. Study what has been done in the area of home visits and the different characteristics, objectives and solution methodologies considered by different authors;
6. Relate the challenges presented in the problem characterisation with the contributions of the authors in the literature review to develop a mathematical model to determine which visits will be carried out, by whom and when;
7. Analyse the impact of this new visit planning on the organisation and compare it with the current situation.

1.3 Research Methodology

To accomplish the objectives listed above, the proposed methodology is divided into several steps, as found in the diagram in Figure 2.

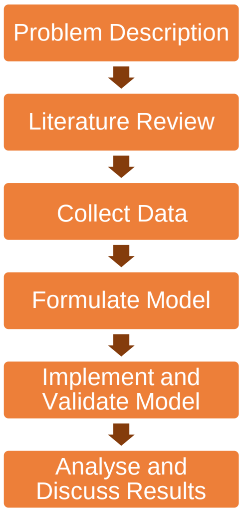


Figure 2. Main steps of the proposed methodology

- **Problem Definition**: In the first phase, the concept and context of CAFAP will be described, as well as its objectives and principles, who it is aimed at and its intervention process. This information was taken from Portaria nº 139/2013 of 2 April by the Ministry of Solidarity and Social Security in 2013. To understand how CAFAP works in ComDignitatis and what problems they are facing, several meetings were conducted, the first of which was face-to-face, at the office in Ericeira, to get to know the facilities as well and the following ones were held online.

- **Literature Review**: This second step will be necessary to gain knowledge about which models already exist in this area. However, there are still no publications about the specific problem addressed in this dissertation but it is known that there is another problem - Home Health Care Scheduling and Routing Problem (HHCRSP) - where its features are very similar to the case study. Therefore, the literature review will be based on this type of problem, whose articles were found in various search engines, such as ScienceDirect, Scopus and Web of Science, using the keywords: home health care, scheduling and routing problems, staff scheduling, among others. The majority of the models present in the articles found are an extension of the Vehicle Routing Problem (VRP) model.

- **Collect Data**: The next step will be to collect and process the actual data, provided by ComDignitatis, on the number of visits, the interval between them and the technicians assigned to all families that are accompanied, in the months of January, February and March 2022.

- **Formulate Model**: To address the problem, a model will be developed for assigning and scheduling technicians to families, whose objective is to maximise the total number of visits made and to know who makes them and when.

- **Implement and Validate Model**: The proposed mathematical model will be implemented in General Algebraic Modelling System (GAMS) software, and the input data are those provided by ComDignitatis.

- **Analyse and Discuss Results**: The model results will be analysed and discussed, comparing with the current ones.

1.3 Outline

This dissertation is divided into 7 chapters:

- **Chapter 1** – **Introduction**: It corresponds to the present chapter and aims to explain the background and motivation behind this dissertation, as well as its objectives, the research methodology and its structure, which is this section.

- **Chapter 2** – **Problem Description**: This chapter explains how CAFAP works and how it is important for families with children at psychosocial risk. It also describes the problem under study, the case of ComDignitatis, how CAFAP works in this organisation and what current challenges they encounter.

- **Chapter 3** – **Literature Review**: As the literature review addressing the problem under study is non-existent, the focus was on literature from the HHCRSP.

- **Chapter 4** – **Methodology:** Describes the proposed model, considering the main characteristics of the problem under study.

- **Chapter 5** – **Data Collection and Treatment**: The data required to implement the model is presented, while clarifying all the assumptions.

- **Chapter 6** – **Results**: This chapter presents the results, coming from the developed model, and which are compared with the original ones. In addition, to test the robustness of the results, a sensitivity analysis was performed for a parameter.

- **Chapter 7** – **Conclusions and Future Work**: The last chapter outlines the main findings and conclusions, as well as limitations of the study and possible future research steps.

2 Problem Description

This chapter aims to characterise the problem at hand. Initially, the general functioning of CAFAP, one of the social responses provided to families with children and young people who are at psychosocial risk, is described in Portugal. Following this, the organisation in analysis - ComDignitatis - is presented, being the focus of this thesis the functioning of CAFAP within it and what problems it is currently facing.

2.1 General Functioning of CAFAP in Portugal

This section discusses the intervention, organisation and functioning of CAFAP, published in Portaria nº 139/2013 of 2 April by the Ministry of Solidarity and Social Security in 2013. In detail it addresses the context it emerged, how it is currently defined, its objectives and principles, as well as for whom it is intended.

2.1.1 Context and Concept

Considering that the family, as a structure of full citizenship, is currently characterised by a diversity of composition, structure, and dynamics, in which the affective, relational, educational, and parental responsibility aspects assume special importance, the State is particularly attentive to the resulting vulnerabilities, to which it is necessary to respond with specialised family support mechanisms. Thus, the need for a specialised intervention aimed at families where a situation of psychosocial risk is recognised, is of particular importance in the light of the child and youth protection system and the promotion of their rights.

In fact, Law 147/99, of 1 September, which approved the Law for the Protection of Children and Young People in Danger, consecrates, among its guiding principles, the principle of parental responsibility, which implies an intervention carried out so that parents assume their parental role through the acquisition of personal, family, and social skills.

In this context, the family support and parental counselling centres (the CAFAPs) take on a special relevance in the diagnosis, prevention, and repair of families' psychosocial risk situations, it is also very important in the promotion of a positive parenting, taking into account the social reality in which their intervention is envisaged.

As such, the family support and parental counselling centres develop a specialised intervention aimed at families with children and young people, to enhance parental, personal and social skills of families, taking into account the full development of children and young people within the family. This intervention favours the promotion of positive parenting and aims at family qualification, through close and systematic work with families for their empowerment and autonomy, the improvement of the parental function and, in certain situations, the reintegration of the child or young person into their family environment (Portaria n.º 139/2013 de 2 de Abril, 2013).

2.1.2 Objectives and Principles

According to Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo I, Artº 3, CAFAP's main objectives are:

a) To prevent situations of risk and danger by promoting the exercise of positive parenting;
b) To evaluate the dynamics of risk and protection of families and the possibilities of change;
c) To develop parental, personal, and social competences that allow for an improvement in the performance of the parental function;
d) Empower families by promoting and reinforcing quality relational dynamics and daily routines;
e) To enhance the improvement of family interactions;
f) To mitigate the influence of risk factors in families, preventing situations of separation of children and young people from their natural living environment;
g) To increase family and individual resilience;
h) To favour the reintegration of the child or the young person in their family environment;
i) Strengthening the quality of the family's relations with the community, as well as identify resources and the respective ways to access them.

According to Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo I, Artº 5, CAFAP's governing principles include:

a) Promotion of the rights and protection of children and young people;
b) Systemic intervention;
c) Valorisation of parental skills;
d) Autonomy of families;
e) Participation and co-responsibility of families;
f) Collaboration between professionals;
g) Minimum intervention;
h) Privacy;
i) Mandatory information.

2.1.3 Families at Psychosocial Risk

A family is considered to be at psychosocial risk if, for various factors of a personal, relational and/or environmental nature, those responsible for the child or young person act inappropriately with regard to the exercise of parental functions, thus harming or endangering the full development of the child or young person (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo I, Artº 4). Families at psychosocial risk shall benefit from the support provided by CAFAP, namely when:

a) The risk situation requires intervention, in a timely manner, that avoids the declaration of danger and the withdrawal of the child or young person;
b) The risk assessment points out the inadequacy of the family's relational dynamics and educational and formative practices, with negative consequences for the well-being and development of the child or young person;
c) The application of a promotion and protection measure in a natural life environment, namely a support measure with the parents, a support measure with another family member and the trusting of a suitable person, requires a specialised intervention with the family;
d) The family situation has led to the application of a promotion and protection measure of placing the child or young person in a foster family or in an institution;
e) The specialised support to the family has been recommended as a complement to an intervention of psychosocial or therapeutic nature;
f) The contract celebrated within the scope of the Social Integration Income foresees a specialised intervention for the family.

CAFAP may also provide support in situations of conflict or family breakdown that jeopardise the well-being and family life of children or young people.

2.1.4 Modalities of Intervention

According to the type of intervention, CAFAP develops differentiated actions depending on the situation and characteristics of the families, reinforcing, and strengthening their involvement in social support networks. These actions include parental training, and psycho-pedagogical and social support (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo II, Artº 11). The main objective of parental training is to reinforce and acquire skills for exercising the parental responsibilities necessary to guide and train children and young people, ensuring their harmonious development and providing families with the necessary skills and resources for a better family dynamic, namely at physical, affective, relational, community and family organisation level (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo II, Artº 12). As for psycho-pedagogical and social support, this consists of an integrated intervention, of psychological, pedagogical, and social nature, which aims to develop the families' autonomy and resilience, fostering awareness that they are able to overcome difficulties and modify the dynamics of personal and family functioning, as well as improve their living conditions (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo II, Artº 13).

According to Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo II, Artº 8, there are three types of intervention:

- **Family Preservation (FP)**: aims to prevent the removal of the child or young person from their natural living environment;
- **Family Reunification (FR)**: aims at the return of the child or young person to their family environment, namely in cases of foster care in institutions or foster families, through a

focused and intensive intervention which may take place at home and/or in the community;

- **Family Reunification Point (FRP)**: is a neutral and appropriate space aimed at maintaining or re-establishing family ties in cases of interruption or serious disturbance of family cohabitation, namely in situations of parental conflict and marital separation.

2.1.5 Intervention Process

The CAFAP intervention with families comprises four phases: Assessment of the Family Situation, which is the first moment of intervention where information is collected or updated and protective factors, risk factors and family dynamics are analysed; Preparation of the Integrated Family Support Plan (PIFSP) (discussed further below); Development and Follow-up of the PIFSP, which includes monitoring and evaluation of the intervention and finally, the End of Intervention that ceases with the fulfilment of the PIFSP, with the CAFAP being able to keep itself informed about the evolution and life path of the family, whenever the family does not object.

It is important to emphasise that the phases of intervention should be adapted to the respective intervention modality, according to the particular situation of each family and the goals to be achieved (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo II, Artº 9).

The PIFSP, as previously mentioned, is defined according to the respective modality of intervention, and should respect the capacities, potentialities and expectations of the families and involve, in a continuous and articulated way, the community resources necessary for its implementation (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo II, Artº 10). To this end, this intervention is ensured by a multidisciplinary technical team, composed by social workers, psychologists, and social educators (Portaria n.º 139/2013 de 2 de Abril, 2013, Capítulo IV, Artº 23).

2.2 Organisation ComDignitatis

ComDignitatis - Portuguese Association for the Promotion of Human Dignity - is a Private Institution of Social Solidarity (PISS) with head office in Lisbon and a delegation in Ericeira, in the Municipality of Mafra. It focuses its intervention on the families and/or individuals according to their specific needs, collaborating with the Courts, Multidisciplinary Advisory Teams to Courts (EMAT - Social Security Institute), CPCJ, Social Network, Schools, Health Centre, Institute for Employment and Vocational Training. Also establishes partnerships with the National Commission for the Promotion of the Rights and Protection of Children and Young People, Local Authorities, among other entities present in the territory, having put into practice several projects, in the following scopes (CSPPSA, 2020):

- Support for the family;
- Support for children, young people, and the elderly;

- Social and community integration;
- Health promotion and protection;
- Education and professional training of citizens;
- Literacy;
- Combating social exclusion;
- Humanitarian support for people in need of assistance.

Promoting the emotional, social, and economic well-being of the family and each of its members is their main goal so that in the future the community would be made up of happy families capable of harmonious interpersonal relationships and aspiring to a better future. The whole team works hard every day to accomplish their mission, going through several areas, namely social, health, education, psychology and training, culture, leisure, and quality of life. It is with this dedication to families and commitment to helping others that ComDignitatis has got as far as it has today, helping 800 families since its beginning in 35 municipalities. With 10 years of experience, ComDignitatis now has a multidisciplinary team available to meet each family, whether at home, at school or at work (ComDignitatis, n.d.).

ComDignitatis acts mainly in three branches: Programa + Família, Social Responses and Services. The Programa + Família was the first programme created by the organisation that targets the family and each of its members with the aim of increasing the family's capabilities, helping them to acquire emotional and/or material resources that enable each member to improve their quality of life. It currently covers a panoply of programmes, seeking to support the community, help families living in a weaker socio-economic situation and provide school support to children in primary and secondary education. The Social Responses include CAFAP, Early Intervention Service and Home Support. As for the Services, they provide parental counselling, psychology, individual or family therapy, among others (ComDignitatis, n.d.). Figure 3 shows in detail these three major initiatives and what each of them consists of .

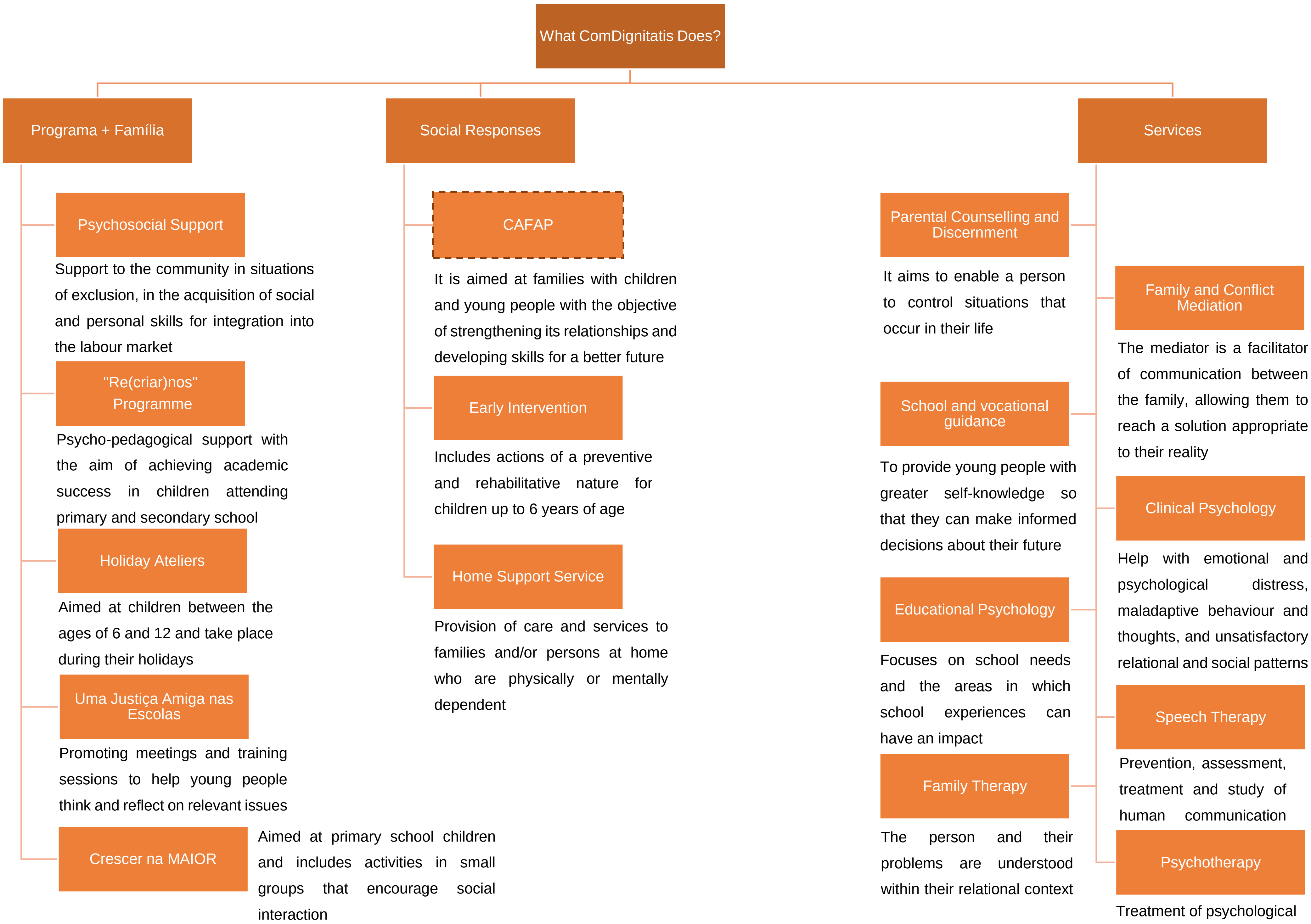


Figure 3. What ComDignitatis does

2.3 Functioning of CAFAP in ComDignitatis

Since the focus of this dissertation is on CAFAP, and having already analysed how it works in general, the next step is to look at how it works in the organisation under analysis.

The CAFAP team is composed of 7 professionals: two social educators, one psychologist, one social worker, one family mediator and two psychology trainees. Although an internship is for a limited period of time and generally of short duration, varying from 6 months, in the case of an academic internship, to 1 year, in the case of a professional internship, the institution can always count on this type of help every year.

Each technician has maximum flexibility in her timetable, working around 35 hours per week. Everyone does their own time management, having to balance their time between studying the families' files, writing reports on them, and visiting the families (at their homes), providing the necessary assistance. Each technician fills the "Time Sheet", which indicates the time each one arrives at the Ericeira office and the time they leave it, as well as any kind of justified delay. In addition, the lunch break is 1 hour and is usually between 1pm and 2pm. However, in case of any unforeseen event, they adjust this schedule.

These 7 technicians are currently responsible for 74 families, acting in 5 municipalities (Mafra, Sobral de Monte Agraço, Lourinhã, Torres Vedras and Cadaval), in the district of Lisbon. ComDignitatis has offices in 3 of these 5 municipalities to receive certain families who are not willing to be visited at home (Ericeira, Torres Vedras and Mafra).

The 74 families are divided through the three types of intervention:

- **Family Preservation (FP)**: this is the modality that gathers more families - 51 of the total. Here the visits usually take place at the family residence and each technician adapts to the schedule of each one. The visiting hours are not fixed, as they depend on the family members' free days or due to a change of shifts at work. In addition, there are often unforeseen events, such as families not answering the technicians' calls to confirm the scheduled visit and consequently it has to be cancelled at the last minute. As a more extreme situation, it has already happened the family not opening the door at the time of the visit.
- **Family Reunification (FR)**: comprises only 3 families. Such visits take place mainly at weekends, on Saturdays, or during school holidays, in the households of the families.
- **Family Reunification Point (FRP)**: encompasses 18 families. Here, the timetable for the visits is more rigid and can be more demanding and they usually take place on Fridays at the ComDignitatis offices.

The visits, in any modality, can start weekly and then evolve to every 2 or 3 weeks, depending on the evolution of the family situation. Normally, all visits last one hour and there may be a meeting with the parents before or after the visit, which takes about 30 minutes, to give feedback on the situation. Each family is accompanied by a team of at least two technicians at the same time. However, two trainees can never go alone. In the FRP, a third technician can be integrated, in some cases, in order to have a rotation. The division of technicians, for each family, is made only taking into account the workload each one has, how many cases they have in their hands at the moment and where they are located. The profession itself is not a relevant factor for this division. However, it is necessary to ensure that at least one same technician, named as reference, is present in all visits for a given family, and the second element may rotate. It is worth mentioning that the visits can also be made in public spaces or in premises prepared for intervention after technical assessment and according to the availability of resources.

Each technician fills in the weekly agendas, which consist of recording everything that has been done in terms of visits: which families have been visited, by whom and when. Ideally, this agenda is done on Thursdays and is validated on the Friday of the following week to see what has actually been done. Every Tuesday morning there is a meeting with the whole team to discuss these plans together.

The technicians go to the families' homes using cars belonging to the institution, always departing from the Ericeira office, and returning there after the visits. There are two cars - one that is always available to ComDignitatis and another available only in the morning, as it is shared with the Home Support Service. There is also a van that is used for the collection and distribution of food, but it has been used to visit families as well. The logistics of the cars are done in an Excel, filled in by all the technicians, to see at what time they are available to be used for the visits and by which team.

2.4 Problem Identification

Family support service has been an increasingly important and discussed topic in Portugal. Although progress has already been made, there are still areas that can be improved. In meetings held with ComDignitatis, it was possible to understand and identify the main challenges faced by the organisation - the planning of family visits. This is done manually and is subject to numerous schedule restrictions. At the same time, there are more cases of conflictive divorce, more domestic violence, more psychological problems, which leads more families to seek help from this type of organisation. Therefore, the number of families has increased and, in the meantime, there has been a decrease in the number of technicians and consequently an increase in the workload for those who remain. In July 2021, 15 families were added to the FRP and 2 technicians left.

Having 7 technicians for 74 families, spread over 5 different municipalities, with practically a single car available, and the families themselves defining the schedules of their visits, which are usually not fixed, due to family members' days off, shift changes or unforeseen events at work, becomes a complex and difficult logistics to manage. In addition, at least two technicians should be available at the same time to provide service, and for each family, at least one of them should be the same for the whole process. The technicians leave the Ericeira office to make the visit and, when the visit is over, they have to return to the centre and only then they go back home, even if still far away. Sometimes they have more than one visit per day, requiring multiple trips.

Balance of the technicians' workload, maximum limits of working hours per week, lunch breaks, are all characteristics that have to be taken into account when planning the visits. Besides, studying each family's files and writing reports on them is a time-consuming task that needs to be planned in conjunction with the visits.

It is extremely important that this service is done in the best possible way so that both parties, the families and the CAFAP team, benefit from it. Having said this, this dissertation aims to study the problem of assignment and scheduling, in order to determine which technicians are allocated to a family and when do they visit them. Planning and scheduling the visits in advance allows each technician to manage her daily routine better, finding time to conciliate all the tasks, dedicating themselves to each family to the maximum.

2.5 Chapter Conclusions

The aim of this chapter was to provide a context for the problem under study with regard to the general functioning of CAFAP, a brief description of the organisation under study and how CAFAP specifically functions within it. In addition, the specific problems faced by the organisation were discussed. The number of families with children and youth at psychosocial risk has been increasing over the years and, as a result, support services have become more in demand. Asking for external help is the solution for these families. This is why the management and logistics of all the planning is so important, so that nothing fails and 100% dedication is given to those who need it most. However, in ComDignitatis there are some issues in this management. Few technicians for many families, in different municipalities, without fixed schedules for the visits, and their planning being done manually, it becomes difficult to reconcile and manage everything. In this way, the goal of this thesis would be to study the assignment and scheduling problem - which technicians are responsible for the families and when do they visit them. It will be necessary to collect real data in the institution, model the problem using optimisation tools, propose solutions and recommendations for the organisation.

3 Literature Review

This chapter seeks to discuss the existing literature on Home Health Care, an example of Workforce Scheduling and Routing Problem, which is very similar to the case study presented in this dissertation, briefly explained in the previous section. Then, the main characteristics of relevant works, such as the objectives optimised and the constraints of the problems, as well as the solution methodologies of several scientific contributions will be presented. In the last section, a comparison will be made between the literature review and the case study.

3.1 Workforce Scheduling and Routing Problems

There are many scenarios where it is necessary to schedule staff to perform tasks at distinct locations following a certain route by means of transport. Examples of these scenarios are: nurses visiting patients at home (Demirbilek et al., 2021), technicians carrying out repairs at customer sites (Pourjavad & Almehdawe, 2022) and manpower allocation (Zhang et al., 2017). This type of scenarios is modelled as Workforce Scheduling and Routing Problems (WSRP). The scheduling part concerns the possible combination of schedules for each worker and the availability of vehicles, since, normally, the number of workers available is not proportional to the number of activities to be performed. Furthermore, the problem also implies routing because these activities are usually spread over several locations, making it necessary to define a visiting sequence (route). The routing part is frequently modelled as a Vehicle Routing Problem with Time Windows (VRPTW), an extension of an already well-known model - VRP, being the main objective to reduce the total distance travelled by a set of vehicles serving customers spread across different locations, where each customer can only be visited once per vehicle and it is the customer itself that defines a time window within which services can be provided. There are other objectives associated with WSRP, such as ensuring that tasks are performed by qualified people (Çakırgil et al., 2020), reducing the cost of hiring staff (Nasir & Dang, 2018), ensuring that workers are used in an efficient manner (Yurtkuran et al., 2018), among others (Castillo-Salazar et al., 2016).

No paper has yet been published in the literature on the specific problem that this dissertation addresses. However, the type of problem closely resembles WSRP. Thus, this literature review will focus on the case of Home Health Care (HHC), due to its shared similarities with the case study to be researched.

3.2 Home Health Care Routing and Scheduling Problem

HHC offer a range of care, such as medical, paramedical, and social services, to be provided in patients' homes rather than in hospitals. It has seen a strong growth over the years, largely due to the ageing population, bringing numerous advantages to patients as it helps them maintaining and improving their living conditions. At the same time HHC organisations contribute to control the costs of the healthcare systems by reducing the number of beds occupied in traditional hospitals (Di Mascolo et al., 2021a).

HHCRSP is an extension of the HHC concept, involving a series of logistical decisions regarding network design, transportation, inventory, and personnel management at the strategic, tactical, operational, and real-time levels. Regarding the network design, this decision involves two major issues, namely the facility location problem, which determines the number, location, and capacity of HHC centres, and also the districting problem, which allows the service to be delivered to the patient, at the stipulated place and time and ensures a balance in the workload of medical staff by defining districts that are composed of several basic units of territories. Transportation management involves three decisions: fleet selection and sizing, which concerns the mode of transportation used by the medical staff; fleet assignment, in which a limited fleet is assigned to the various districts in order to balance the workload of the medical staff and maximise the visits performed; and finally, staff routing, which consists of designing routes from the centre to patients who are geographically dispersed. Concerning personnel management, this involves 4 decisions: staffing, which aims to determine the number of qualified staff needed to provide the service; shift scheduling, which assigns staff to their shifts; staff assignment, when there is a need to employ temporary staff in order to cope with over demand or understaffing; and lastly, staff assignment, which provides the assignment of visits to the respective medical staff. Inventory management involves decisions such as the selection of suppliers of medicines and devices; inventory policies, which indicate when to replenish the inventory of the supplies and inventory control that controls the entire flow of supplies in order to reach the patient according to their medical treatments. All these decisions are made depending on the level of horizon planning they are at. Facility location, districting, fleet selection and sizing, staffing and supplier selection are at the strategic level, i.e. decisions that are made in the long term, more than one year. Fleet assignment, shift scheduling, staff allocation and inventory policies are at the tactical level, medium-term decisions, usually a year. Staff assignment, staff routing and inventory control are at the operational level, short-term decisions that are made on a daily basis. There is also a fourth level - real time level - where decisions can be changed in the short-term depending on the actual execution of the system's service processes. (Gutiérrez et al., 2013).

Nevertheless, issues arise that make these logistical decisions more complex and challenging, such as uncertainty in the length of travel between the HHC centre and patients' homes, the duration of care, the evolution of patient needs, different skills and competencies among medical staff, the wishes of families and patients, staff assignment to patients, route design, patient preferences, and quality of service. That said, these issues have been investigated within the scope of industrial engineering and optimisation (Di Mascolo et al., 2021). In addition to this, the planning of social services may also present another particularity that makes this logistics more challenging, which is to manually schedule the caregivers' routes (Gomes & Ramos, 2019).

There are several models in the literature to address this problem, each having its own characteristics, particularities, and a different approach to model it. However, most models are formulated from the VRP or extensions of it, being the most used: VRPTW; Multiple Depot Traveling Salesman Problem with Time Windows; Periodic Vehicle Routing Problem and Periodic Vehicle Routing Problem with Time Windows (Cissé et al., 2017).

In the following subsections, the features that make HHCRSP models special and more complex will be discussed.

3.2.1 Features considered in the HHCRSP Models

Through the literature, distinctive characteristics are identified in the models depending on if it concerns the HHC organisation, the patient, or the care worker (Cissé et al., 2017). Within each of these groups, they can also be divided into: temporal features, how many times a patient is visited in a given time horizon and whether or not there is a regular visiting frequency, depending on the time window defined by the patient, while respecting the maximum limit of hours per day or per week of care workers' work, assignment features, where the allocation of care worker to patients is made, which may depend on the different qualifications of each care worker to provide a service, the preferences of both and/or the continuity of care, geographical features, depending on the location of patients, care workers and the centre of the organisation and finally, uncertainty features, since in reality emergencies happen, visits are cancelled, there are patients entering and leaving the system, the hiring of new care workers and the unavailability of existing ones. Table 1 shows this classification.

Table 1. Classification scheme based on features. Adapted from Cissé et al. (2017)

Actors	Temporal Features	Assignment Features	Geographical Features	Uncertainty Features
HHC	Planning Horizon	Continuity of Care	Districting Types of HHC services	Travel Time Service Time
Patient	Frequency of Visits Time Window Temporal Dependencies	Preferences	Type of Network	New Demands
Care Worker	Time Window Type of Contract/ Working hours Lunch Break	Qualifications/ Skills Workload Balancing	Depot Transportation Mode	Unavailability Hiring

3.2.1.1 Characteristics related to the HHC Organisation

Temporal Features

It is necessary to define a period for which scheduling and routing decisions are made, i.e. within a given horizon planning, which visits have to be conducted, by whom and when. This planning can be single-period, when it is only one day (Liu et al., 2019) or multi-period (Grenouilleau et al., 2019), which can be two days, a week or even months. Although the multi-period is starting to be studied more (Cissé et al., 2017), especially the one-week horizon planning, single-period is the most common, as the first one involves greater complexity, in terms of the qualifications of the care workers and their workload.

Assignment Features

Continuity of care is one of the most important features when it comes to the organisation of HHC and is being incorporated more and more into the models by several authors. Carello & Lanzarone (2021) studied the three types of continuity of care that exist: total, partial or none. As for the first case, patients are assigned to one and only one reference care worker throughout the time horizon. Partial continuity consists of assigning reference care workers in different time periods; however reallocations must be avoided, otherwise it is penalised in the objective function. Finally, non-continuity of care allows several care workers to provide services in the same period of time.

Patients prefer to be accompanied by the same care worker, as they already feel in a more familiar environment, building a relationship of greater trust with them. For the organisation, it also brings advantages since it avoids the loss of information among care workers. However, the full continuity of care is preferred, and frequently modelled as a hard constraint. There are not always care workers available to serve the patients through all the planning horizon. Therefore, some authors make this restriction soft (W. Liu et al., 2021b).

Geographical Features

The HHC organisation may decide to group patients and caregivers, the so-called basic units, which refers to the geographic clustering of patients who are then assigned to a caregiver so that they can provide better services to their group, increasing both worker and patient satisfaction. This is called districting. Nikzad et al. (2021) divided these basic units into several districts on the basis of routing costs and staff size, which is an important tactical decision in order to know how many care workers need to be recruited in a given district. Each care worker can only provide service to the district that corresponds to him or her. This division is normally made taking into account the residential area of both. However, some authors do not agree with districting, such as Demirbilek et al. (2021), who said that in practice it is difficult to do so, as there are care workers who have several skills and can only provide services to certain patients (this feature will be explained later).

There are several types of HHC services, in addition to the usual health care. Fathollahi-Fard et al. (2020) studied route scheduling that involves going to pharmacies, laboratories, and patients' homes. Initially, patients are assigned to a pharmacy and laboratories are assigned to a pharmacy. Following this, the route and schedule of the caregivers in each time period is planned. They begin their daily activities at the pharmacy to collect drugs and medical instruments, who then take them to the patients' homes. Here biological samples are collected that are later analysed in the laboratory. Once in the laboratory, electronic health records are updated each time period and depending on their results, home visits can be changed.

Uncertainty Features

Travel and service time are two critical parameters, which considerably influence the scheduling of HHC services. Most authors consider them deterministic (Tanoumand & Ünlüyurt, 2021) but, in reality, involve a lot of uncertainty, and therefore an increasing number of authors are adopting a stochastic model (Bazirha et al., 2021). As for the travel time, road conditions, traffic, weather, and individual driving skills are the most common sources of uncertainty. As far as service time is concerned, its duration is not always fixed as expected, due to diagnosis time and parking situations (Shi et al., 2019). Grenouilleau et al. (2019) studied the impact that traffic has on travel time, through a time-dependent distance matrix.

R. Liu et al. (2019), to maintain decent quality service, introduced a chance constraint to ensure the probability of timely service to customers, i.e. the probability with which the patient is visited in a time window cannot be less than a given predefined value. However, calculating this probability in a stochastic situation is complicated.

Due to the uncertainty in travel and service time, the actual service start time can also be considered uncertain. Yang et al. (2021) calculates this time using inverse uncertainty distributions of uncertain variables, and this time effectively depends on the actual time the caregiver arrives at the patient's home and when the patient is actually ready to be received.

3.2.1.2 Characteristics related to Patients

Temporal Features

Patients can be visited several times in a day (Yadav & Tanksale, 2022) or only once on a day but several times during the defined horizon planning (W. Liu et al., 2021b). Within this time period, there may be a minimum number of visits requested or a temporal dependence between visits, such as a time interval between two visits. For example, if a patient requires two visits in a week with at least one day in between, a possible solution would be Monday to Wednesday or Tuesday to Friday, but Tuesday to Wednesday or Thursday to Friday would be prohibited (Grenouilleau et al., 2020). Some authors also define a pattern for each patient, depending on the corresponding profile. Lahrichi et al. (2022) considered possible patterns for patient visits, in terms of combinations of days when visits can take place, such as every Monday and Thursday.

When these visits occur with a regular frequency, on the same days and at the same times, this is consistency. A few authors deal with this criterion. Nevertheless, Cappanera & Scutellà (2022) went a bit further and considered three types of consistency: arrival time consistency, which consists of visiting each patient at approximately the same time, which allows patients to have greater trust with care workers, to better organise their day and to take advantage of flexibility in service design; person-oriented consistency (also known as continuity of care), which uses the same subset of care workers for all of a patient's visits; and lastly, delivery consistency, in which the same amount or frequency of care is delivered at all times.

Regarding the time window, some authors model it as hard constraints, such as the authors Liu et al. (2021a), in which care workers may arrive earlier at the patients' home but have to wait until the set time, but late arrival is forbidden. Other authors define a soft time window, in which professionals may start the visit slightly earlier or later than the defined hours, and the level of tolerance to respect the time window varies because it depends on the care to be provided. When this time window is not respected, there is a penalty in the objective function (Decerle et al., 2019). Yadav & Tanksale (2022) defined the inconvenient time window, which gives the time interval in which patients cannot receive visits.

When patients require multiple services per day, time dependencies sometimes exist between them. The services may be disjunctive, meaning that they should not overlap, synchronised, have to occur simultaneously, or there may be a precedence between them, with one succeeding the other (Di Mascolo, Espinouse, and Ozkan (2014) as cited in Di Mascolo et al. (2021b)). Decerle et al. (2019) studied the case of visit synchronisation, where a service needs to be provided by two care workers at the same time (e.g., picking up a patient) and if they do not arrive at the same time, there is a penalty in the objective function. Although not so often considered, Shahnejat-Bushehri et al. (2021) evaluated the dependency between synchronised precedence services and the appropriate level of continuity of care. This means that precedence services related to the first service should be operated by the same care worker within the defined time horizon. The services may also be independent of each other, and a patient may be served several times a day by different professionals (Yadav & Tanksale, 2022).

Assignment Features

Patients may have preferences regarding the care workers to whom they have been assigned, especially in terms of gender or the language they speak. Yadav & Tanksale (2022) modelled them as hard constraints but Grenouilleau et al. (2019) only considered them optional.

Geographical Features

HHC services can be provided in urban or rural areas, with dense or sparse population. Due to these contexts, the type of network influences travel times between visits, which can be long in areas with higher traffic and, consequently, service times. In addition, it also affects the workload of care workers (Lahrichi et al., 2022). So the relationship between care and journey time is different in rural and urban areas (Cissé et al., 2017).

Uncertainty Features

Unexpected events, cancelled visits, new patients entering the system as well as patients leaving the system due to their health condition, changes the whole planning, so it is important to address these types of uncertainties. Cappanera & Scutellà (2022) addressed uncertainty in demand, where some patient requests are certain, i.e. those that will actually happen, plus uncertain requests. Thus, each patient has an associated treatment plan, where the exact number of requests needed is specified, plus an uncertain treatment plan.

It may happen that the number of patients to be visited is too high for the number of care workers available. Consequently, a certain priority has to be defined, according to, for instance, the time of the last visit and the severity of the patient's health condition. This priority is considered dynamic and should be updated over time. As time goes by, a patient who has not been visited gains priority over the others, in an exponential way, to take into account the increasing urgency. However, patients who cannot be visited within the planning horizon are controlled by phone calls (Cinar et al., 2021).

3.2.1.3 Characteristics related to Care Workers

Temporal Features

Although it is more common for patients to define a time window according to their availability, care workers can also define a time window, that is, they define a time interval during which they are available to provide services (Bazirha et al., 2021). Or work limits can be set for care workers, depending on the type of contract each one has (Grenouilleau et al., 2019). Grenouilleau et al. (2020) defined a maximum weekly working limit, while Yang et al. (2021) has defined a daily maximum limit. If these limits are exceeded, professionals work overtime. According to the literature, there are essentially two ways to approach this situation: either overtime is forbidden and the professional has to comply with the maximum limits (Tanoumand & Ünlüyurt, 2021) or overtime is possible but with an associated cost (Carello & Lanzarone, 2021). In this last scenario, these authors modelled the cost in two ways: a constant cost for each overtime hour and an increasing cost whose value increases gradually as care workers do more overtime, so as to balance the workload of overtime between care workers, trying to reduce as much as possible their overtime.

In some cases, lunch breaks for care workers are mandatory. A lunch period is defined and care workers have to take this break if their working hours exceed the first hour defined in the lunch break. Usually, this break is taken at the patients' premises, before or after the visit. These pauses can be considered as fictitious visits on the routes, having to be scheduled as well (W. Liu et al., 2021a).

Assignment Features

According to the patients' needs and the different qualifications/skills of the care workers, a possible matching is made between them, in order to allocate the different care workers to the different patients. Qualifications refer to the type of care worker, for example, a nurse and an auxiliary (Tanoumand & Ünlüyurt, 2021) or to their specialty, where each has a specific skill level and can only serve patients whose minimum required level for that patient is equal to or lower than the skill level of the care worker. Yadav & Tanksale (2022) considered not only the compatibility of the care worker' skills with the patients' requirements, but also the fact that the care worker must speak the same language and be of the same gender as the patient. On the other hand, there are authors who do not consider this difference of skills, all care workers can serve the patients regardless of their requirements (Lahrichi et al., 2022).

Workload balance is also considered as an assignment feature and is normally considered in the objective function, through the minimisation of the maximum difference in working time between care workers, and varies according to their type (Decerle et al., 2019).

Geographical Features

Most papers consider that care workers start and end their working day at the HHC centre (Cappanera & Scutellà, 2022), equivalent to considering a single depot in VRP. However, the use of multi-depot has been addressed, such as the case where there are multiple HHC centres (Decerle et al., 2018a) or care workers leave and return to their own homes at the end of the day (Demirbilek et al., 2021). Nasir & Dang (2018) on the other hand, gives the option of departing from home or departing from the HHC centre, depending on the type of transport they use - private car or car rented by the organisation. If the care worker has a private car or if they have rented the car the day before a visit, they can leave from home. Otherwise, they start at the centre to pick up the rented car. There are other modes of transport care workers use to get to the patients, such as using public transport (Yadav & Tanksale, 2022) or just use the organisation's own car (Decerle et al., 2018b).

Uncertainty Features

Care workers getting sick, taking a holiday or cancelling a visit due to an unexpected event are unpredictable situations that change the entire planning and scheduling of visits (Xie & Wang, 2017 as cited in Di Mascolo et al., 2021b)). Another type of uncertainty associated with care workers is the hiring of new ones thus adding another decision to the initial scheduling and referral problem. Nasir & Dang (2018) has studied the recruitment of care workers, the selection of patients and the integration of new patients and new care workers into the system simultaneously. Each new care worker is hired or reconsidered as a new care worker in the following planning days, but once hired, it is mandatory to assign him/her a route every day until his/her contract ends. However, these decisions have to take into account the associated costs, which will be modelled in the objective function. This approach is in line with what it is like in reality for home healthcare companies and thus has great practical applicability.

The main characteristics found in the literature are summarised in Table 2, and the most common characteristics, the ones that appear in almost all the articles reviewed, is the regulation of working hours, the time windows, and the care workers' qualifications/skills. It should be noted that continuity of care, especially in multi-period models, and stochastic parameters, such as uncertain length of service and travel time, have been increasingly addressed by the authors.

Table 2. Characteristics considered in the literature review of HHCRSP

Article	Planning Horizon			Time Window								Temporal Dependencies							
	SP	MP	CC	HTW	STW	ITW	D	WL	B	Q	P/C	DS	SS	PS	PP	SD	MD	SP	DA
Lahrichi et al., 2022		x	x				x	x			x					x			
Liu et al., 2021		x	x	x				x	x				x				x		
Nikzad et al., 2021	x		x	x			x	x		x							x	x	
Decerle et al., 2018	x				x			x					x			x			
Yadav & Tanksale, 2022	x					x		x	x	x				x	x		x		
Liu et al., 2021	x			x				x	x				x				x		
Yang et al., 2021		x		x				x								x		x	
Cappanera & Scutellà, 2022		x	x					x		x	x					x			x
Demirbilek et al., 2021		x	x	x				x		x	x						x		x
Carello & Lanzarone, 2021		x	x					x										x	
Tanoumand & Ünlüyurt, 2021	x			x				x		x						x			
Cinar et al., 2021		x		x				x									x		x
Grenouilleau et al., 2019		x	x	x				x		x					x		x		
Fathollahi-Fard et al., 2020		x		x				x									x	x	
Decerle et al., 2019	x				x			x					x			x			
R. Liu et al., 2019	x			x				x									x	x	
Grenouilleau et al., 2020		x	x					x		x	x								
Bazirha et al., 2021	x		x	x				x		x			x			x		x	
Shahnejat-Bushehri et al., 2021	x		x		x			x				x	x	x			x	x	
Nasir & Dang, 2018	x			x				x	x	x						x			
Shi et al., 2019	x		x					x		x							x	x	
This paper		x	x	x	x								x	x		x	x		

Legend

SP (Single-Period); MP (Multi-Period); CC (Continuity of Care); HTW (Hard Time Window); STW (Soft Time Window); ITW (Inconvenient Time Window); D (Districting); WL (Working Limits); B (Breaks); Q (Qualifications); P/C (Patterns/ Consistency); DS (Disjunctive Services); SS (Synchronised Services); PS (Precedence Services); PP (Patient Preferences); SD (Single Depot); MD (Multi Depot); SP (Stochastic Parameters); DA (Dynamic Aspects)

3.2.2 Objective Function

From the literature, there are essentially two broad categories involving various criteria for evaluating a solution: cost optimisation and service quality optimisation. The first category involves route costs and staff costs, while the second points to patient and care worker preferences.

Most papers consider minimising route costs, which include travel time (Decerle et al., 2018a), travel cost (Shahnejat-Bushehri et al., 2021) and/or travel distance (Tanoumand & Ünlüyurt, 2021), the latter being particularly important when vehicles are rented and paid for by the total distance travelled. W. Liu et al. (2021b) minimised operating costs, which include the salaries of the carers and the total transport costs for the vehicles used. Nasir & Dang (2018) minimised the cost of hiring care workers along with transport costs.

Concerning staff costs, Carello & Lanzarone (2021) considered the minimisation of assignment costs, which are a function of both overtime and reassignment penalties. Working time is another factor that is widely used, as it has a great impact on cost optimisation. Decerle et al. (2019) minimised the maximum difference in working time between carers. Grenouilleau et al. (2019) incorporated in the objective function a weighted sum of the associated costs, namely the costs of routes, care workers' overtime per week, care workers' waiting times and the cost of unscheduled visits.

Some authors are already starting to incorporate service quality in the objective function. Decerle et al. (2018b) added penalties to their objective function when time windows defined by patients are not met and when visit synchronisation is not respected. Other authors maximise patient satisfaction which is measured by the cost penalty to reassign care workers (W. Liu et al., 2021b). Maximising the number of patients that have to be served is another criterion for evaluating a solution (Yadav & Tanksale, 2022). Demirbilek et al. (2021) maximises the number of patient visits in a given time horizon, and this criterion is different from the previous one since patients need several visits. When patients are not visited, there is a penalty in the objective function (R. Liu et al., 2019). Shahnejat-Bushehri et al. (2021) minimises the cost-of-service provision according to the qualifications and experience of the care workers and also minimises their number, and these costs are considered fixed. There is also another extremely important criterion related to care workers - workload balance. Cappanera & Scutellà (2022) minimised the maximum utilisation factor of the care worker, this factor being expressed as the total workload of the care worker in the worst-case scenario over his maximum possible workload.

There are also multi-objective functions, which very often conflict with each other, although less studied than single-objective functions. Fathollahi-Fard et al. (2020) proposed a bi-objective optimisation methodology, in which the first objective is the minimisation of total costs, including transport, allocation costs and a global distance penalty for care workers, in order to manage their routes and to balance their trips in a given period, and the second objective is to maximise patient satisfaction. Yang et al. (2021) modelled three objectives, one of which is the minimisation of operational costs, measured by the sum of the cost of travel, the cost of service and penalties due to late arrival at the patient's home, another is the minimisation of care worker inconsistency and the last one aims to balance the workload among them. However, involving multiple optimisation decisions leads to greater problem complexity.

The main objective functions found in the literature are summarised in Table 3. To simplify, the Routing Costs encompass the time, distance, and cost of the travel and these are the most common objectives, when analysing the different articles. The columns referring to overtime, time windows, synchronisation of visits and continuity of care are soft constraints that, if violated, are penalised in the objective function.

Table 3. Objective functions considered in the literature review of HHCRSP

Article	SO	MO	WS	RC	OC	WB	S	NV	NP	NCW	OT	TW	SV	CC	UV
Lahrichi et al., 2022	x			x		x									
Liu et al., 2021	x				x		x								
Nikzad et al., 2021	x			x	x										
Decerle et al., 2018	x			x											
Yadav & Tanksale, 2022	x								x						
Liu et al., 2021	x				x										
Yang et al., 2021		x		x		x						x			
Cappanera & Scutellà, 2022	x					x									
Demirbilek et al., 2021	x							x							
Carello & Lanzarone, 2021	x										x			x	
Tanoumand & Ünlüyurt, 2021	x			x											
Cinar et al., 2021	x			x											
Grenouilleau et al., 2019			x	x							x				x
Fathollahi-Fard et al., 2020		x		x	x		x								
Decerle et al., 2019	x			x		x							x		
R. Liu et al., 2019	x				x										x
Grenouilleau et al., 2020	x								x						
Bazirha et al., 2021	x			x											
Shahnejat-Bushehri et al., 2021	x			x						x					
Nasir & Dang, 2018	x			x											
Shi et al., 2019	x			x											
This paper	x							x							

Legend

SO (Single-Objective); MO (Multi-Objective); WS (Weighted Sum); RC (Routing Costs);

OC (Operational Costs); WB (Workload Balance); S (Satisfaction Patients/ Care Workers);

NV (Number of Visits); NP (Number of Patients Visited); NCW (Number of Care Workers); OT (Overtime);

TW (Time Window); SV (Synchronised Visits); CC (Continuity of Care); UV (Unscheduled Visits)

3.2.3 Solution Methods

Through the literature, three solution methods are highlighted to address this type of problems: exact methods, metaheuristics, and hybrids.

To solve single-period problems, Tanoumand & Ünlüyurt (2021) proposed the Branch and Price algorithm, using literature acceleration techniques to increase the effectiveness of the method, however, it is not the most effective when dealing with large problems. Because exact methods cannot solve large-scale NP-hard problems within a reasonable time frame, approximate methods arise.

R. Liu et al. (2019) proposed the same algorithm, considering the uncertainty of travel and service time, but added a discrete approximation method to solve the problem and, in order to improve its efficiency, used cutting-edge acceleration strategies and hierarchical branching scheme. Nikzad et al. (2021) addressed the uncertainty of the same parameters in a different way through the development of a Multi-Phase Matheuristic algorithm, demonstrating its effectiveness in finding optimal or near-optimal solutions in a reasonable computational time, even for large instances that cannot be solved by the commercial solver, like Gurobi. Bazirha et al. (2021) used two heuristics - a Genetic Algorithm (GA) and the General Variable Neighbourhood Search - to solve the deterministic problem, knowing in advance the number of patients, number of caregivers, the time windows of both, and the cost of transport between patient locations and on the other hand used Monte Carlo simulation to estimate the expected resource value in order to solve the stochastic problem, namely in terms of service duration and travel time. Yadav & Tanksale (2022) used a variant of GA - Parallelly-Processed Genetic Algorithm - where it produces a feasible solution for all instances. The robust optimisation model is also considered in the literature and to solve it, it was employed Simulated Annealing, Tabu Search, and Variable Neighbourhood Search (Shi et al., 2019) and it proved to be stronger, even considering uncertainties, than the stochastic model with recourse.

As for hybrid methods, W. Liu et al. (2021a), considered 4 hybrid metaheuristics, and the one with the best results was Hybrid Genetic General Variable Neighbourhood Search, with 64% of the tested instances and maintains a difference of less than 2% in relation to the optimal solutions found by Gurobi. Memetic algorithm was implemented by Decerle et al. (2018b), which is the hybridisation of a GA with a Local Search (LS) procedure. This algorithm was tested in instances of the literature and real instances, concluding that in any of the instances, it presents excellent results regardless of strong or soft constraints concerning the time window, synchronisation of visits, location of HHC centres or qualifications of the care workers. Although not so common, Decerle et al. (2019) combined the Memetic and Ant Colony Optimisation (MACO) algorithm and comparing this new algorithm with the two algorithms separately, it was shown to be more efficient as it obtained the lowest average objective function for most instances, in addition to the fact that when the problem size increases, the commercial solver becomes unable to find even a feasible solution for most instances, whereas MACO finds a feasible solution for every instance.

Within the methodologies addressing multi-period problems, Grenouilleau et al. (2019) used a combination of an exact method modelling a Set Partitioning Problem with a Large Neighbourhood Search (LNS) heuristic, that originated the algorithm Set Partitioning Heuristic (SPH). It was tested in real instances and the results indicated a 37% reduction in travel time and a 16% increase in continuity of care. Lahrichi et al. (2022) adopted a two-phase approach with a First Route Second Assign (FRSA) paradigm, where first the routing problem is solved and then the assignment. In the literature, it is more common to use the decomposition method in reverse, that is, First Assign Second Route, which is more intuitive and simpler. Comparing these two methods, the best results point to FRSA, especially when travel times are very relevant and when the aim is to improve the service, it was observed an improvement of 10%-12% in the routing cost in most of the tested cases. Cappanera & Scutellà (2022) used a pattern-based decomposition approach, considering consistency and uncertainty in the demand. Demirbilek et al. (2021) also took a different approach - Scenario Based Approach for Multiple Nurses - which generates different scenarios, including the current hours of nurses and randomly generated requests, and the model decides whether or not to accept new patients, which nurses are in charge of them, as well as the days of visits. W. Liu et al. (2021b) used a metaheuristic incorporating the heuristic Adaptive Large Neighbourhood Search (ALNS) with Gurobi, to solve cases on a large scale and efficiently. Cinar et al. (2021) also used ALNS, providing near-optimal solutions in short runtimes, but together with the metaheuristic SPPH. A highly efficient method for dealing with consistency was the one used by Grenouilleau et al. (2020), which consisted of extending the Logic-based Benders decomposition also introducing Dantzig-Wolfe formulation and LNS, coming to the conclusion that it can resolve all reference instances in less than 20 seconds. Implementor-adversary approach, a robust approach, was performed by Carello & Lanzarone (2021), tested in real instances, in one of the largest Italian providers, covering a region with about 800 km^2 with about 1000 patients to be visited at the same time, by 50 nurses. Regarding multi-objectives models, Yang et al. (2021) developed the Improved Multi-Objective Artificial Bee Colony metaheuristic, using the LNS to conduct a LS. The results conclude that better consistency of care workers can be achieved through high total costs and workload balancing and at the same time workload balancing can be improved with little deterioration in care worker consistency, while Fathollahi-Fard et al. (2020) adopted a diffuse approach named as the Jimenez method, which takes into account the uncertainty of service times, patient preferences for care workers and other critical parameters of the model, and this estimate is made using fuzzy triangular numbers to consider the three possible scenarios for these parameters and in order to efficiently solve the problem, a multi-objective version of Social Engineering Optimiser was added using an adaptive memory strategy – AMSEO.

3.3 Comparison between the Case Study and the Literature Review

Given that none of the works analysed focused on the same application as this Master's dissertation, this subsection analysed the similarities and differences between the case study and the literature.

In the case of the dissertation, the main objective is to determine which technicians are responsible for providing services to families, in their homes, and when. This objective is quite similar to most of the articles reviewed in the literature, but with regard to doctors, nurses, and patients. Each family/patient is usually accompanied by the same technicians/doctors throughout their entire process. However, in the case of ComDignitatis, two technicians are always needed for each family, and there is no distinction between the different skills of each one. In the review, few works consider the synchronisation of services and when they do, usually a service can only be performed according to the specialty of each doctor or nurse.

The day and time of the visit depend on the availability of the families/patients and the technicians/physicians themselves, safeguarding a balance in the workload of the latter. However, the frequency of visits differs in both cases. While in the literature review, as the services are mainly medical in nature, the patients need them more often. Thus, in the same day, several services may be needed or even in a week. In the case study, this is not the case, the frequency is usually much less. In a month, 2 or 3 services may be needed, and there is no pattern, consistency, or dependency between them, only that a minimum and maximum interval between visits is ensured.

In the dissertation at hand, a single depot is considered, from which the technicians go out to visit the families and at the end they come back, using a car provided by the organisation. Many authors in the literature review consider the same situation.

Regarding the objectives, as ComDignitatis is a non-profit organisation, the primary objective is not to reduce costs but to maximise the number of visits made, unlike in the review, where most consider minimising route costs and travel times. However, when it comes to maximising the number of visits made, this is sometimes subject to uncertainties as unforeseen events and last-minute cancellations arise on the part of families or technicians. The most common uncertainties that appear in the review have to do with uncertainties in travel and service times.

3.4 Chapter Conclusions

This literature review aimed to understand what has already been done on a very similar type of problem as the dissertation under study and what might be done in the future.

With regard to characteristics, it was concluded that the most commonly used were the time window defined by patients, working time regulations and the qualifications/skills of care workers.

Continuity of care and synchronisation of visits have been increasingly recognised. However, there is still room for improvement regarding dynamic aspects, to cope with unpredictable situations, and parameters subject to greater uncertainty, especially travel and service time, which affect all logistical planning. Many authors suggest in the future to consider green emissions, so that all this planning becomes more environmentally sustainable.

In relation to objective functions, most works deal only with a single objective. However, considering multiple objectives should be further explored, as it is more similar to reality due to the trade-off between costs and service quality. Workload balance is not present in many of the reviewed articles and is a highly important criterion as it ensures that care workers are not overloaded with work.

It was concluded that most of the articles reviewed address the same characteristics as the dissertation. It is therefore vital to carefully plan the assignment, scheduling, and routing of this type of problem as each model has its own characteristics that make it special and more complex.

4 Methodology

The purpose of this chapter is to present the mathematical model that outlines the case of ComDignitatis. In section 4.1 the problem is defined, as well as the assumptions made to the model. In section 4.2, the mathematical formulation is described.

4.1 Problem Definition

The HHCSRP consists of outlining routes so that, within a given horizon planning, it is possible to define which visits will be performed, when and by whom to a set of geographically dispersed patients, while respecting certain constraints, as discussed in the previous chapter. To achieve this purpose, this problem can be subdivided into three: assignment, scheduling, and routing (Yadav & Tanksale, 2022), where the first one consists in assigning caregivers or teams to patients, the second one defines the schedule of visits and the last one draws the route of each caregiver. These three decisions can be made simultaneously (Nikzad et al., 2021).

As previously mentioned, this type of problem resembles the one addressed in this dissertation, due to the several constraints that compose it. However, some modelling aspects differ, since there are few visits per day (as the visits take a long time and the families are scattered throughout the intervention area), which does not justify delineating a route for each technician. Thus, this problem can be reduced to an assignment and scheduling problem.

The planning period is one month and the objective is to maximise the number of visits within this time frame. The result of this planning indicates which visits will occur, by which technicians and when. However, as discussed in Chapter 2, there are several characteristics that make the case study particular. Each family needs a specific number of visits per month and those who need more than one must respect the minimum and maximum intervals between them. Also, the day of the visit depends on the availability of the families, which can vary from day to day, and the availability of the technicians. In each visit, 2 technicians are needed and preferably they should be the same ones during the whole process. They travel by car provided by the organisation.

To simplify the model, assumptions had to be made. Firstly, the days are divided into slots - one in the morning (9am to 1pm) and one in the afternoon (2pm to 7.30pm). It is known that there is a lunch hour for technicians, usually between 1pm and 2pm, and since the change of slots is in this period, it is understood that the lunch hour is in this interval. However, this period may be adjustable. Next, this work focused only on the FP and FR modalities (although the model does not differentiate between them). The FRP modality was excluded since its visits are fixed and more constant, so it is not justified to know when they will be scheduled but nevertheless this time affects the availability of the technicians to carry out the other visits. Because of this, if a technician, on a given day and slot, has at least one visit of this modality, then it is assumed that she no longer has availability to carry out another visit. Finally, only one car was considered, since only one is always available.

Although the routing part is not being modelled, but as it is intended that the solution obtained in the assignment and scheduling model is feasible from the routing point of view, a maximum distance between families that are visited in the same slot - parameter $maxdist$ - was considered. This way, it is avoided that families that are very far away from each other are visited in the same slot, by the same team of technicians.

The following diagram, presented in Figure 4, outlines the problem.

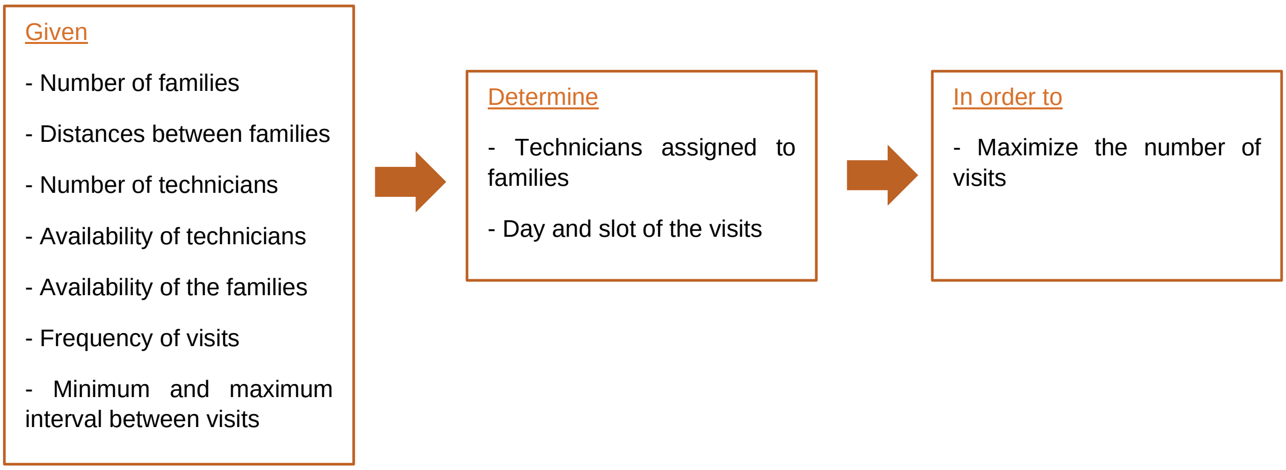


Figure 4. Schematic representation of the case study

4.2 Mathematical Formulation

This subchapter aims to present the mathematical formulation of the single-objective MILP model and all the notation required for its implementation.

4.2.1 Notation

Table 4 describes the sets, parameters, and decision variables.

Table 4. Sets, parameters, and decision variables

Sets and Indexes	Description
I	Set of families ($i \in I$)
A	Set of technicians ($a \in A$)
S	Set of slots ($s \in S$)
T	Set of days ($t \in T$)

Parameters	Description
$ATS_{i,s,t}$	1, if family i is available in slot s on day t; 0 otherwise
$ATA_{a,s,t}$	1, if technician a is available in slot s on day t; 0 otherwise
$NV_{i,a}$	1, if technician a is assigned to family i; 0 otherwise
g_i	Frequency of visits
$Tmin_i$	Minimum interval between visits
$Tmax_i$	Maximum interval between visits
$d_{i,j}$	Distance between family i and j
$maxdist$	Maximum distance between families
$BigM$	Large number

Decision Variables	Description
$b_{i,s,t}$	1, if family i is visited on day t in slot s; 0 otherwise
$x_{i,a,s,t}$	1, if family i is visited on day t in slot s by technician a; 0 otherwise
$y_{a,s,t}$	1, if technician is active in slot s on day t; 0 otherwise
$p_{i,t}$	1, if the visit is not performed; 0 otherwise

The sets are the building blocks of the model and, in this case, represent the families, technicians, slots and the defined horizon planning. As for the parameters, these contain the data required to implement the model. The first three, listed in Table 4, are binary parameters, where the first two have to do with the availability of the families and technicians to perform the visits, on each day and in each slot, and the third, makes an assignment between possible technicians and families. The remaining parameters are not binary, and indicate the frequency of visits, that is, for each family, how many times it is necessary to visit it in the given time horizon, respecting the maximum and minimum intervals between visits, given by the parameters $Tmin_i$ and $Tmax_i$. The parameter $d_{i,j}$ allows to calculate the distance between families and the last one ensures that the distance between families that are visited in the same slot does not exceed $maxdist$.

Finally, the decision variables are four and all binary, the first three being what is intended to be achieved with this model: which technicians are assigned to which families and on which days. The last variable has the purpose of penalising the visits that are not carried out.

4.2.2 Mathematical Model

Given the characteristics of the problem and the sets, parameters and decision variables defined, the mathematical model is presented below, with the objective function and all restrictions described.

$$Max \sum_{i \in I} \sum_{s \in S} \sum_{t \in T} b_{i,s,t} - 0{,}01 \sum_{i \in I} \sum_{t \in T} p_{i,t} \quad (4.1)$$

$$\text{s. t. } \; x_{i,a,s,t} \leq NV_{i,a} \quad (4.2)$$

$$\left(\sum_{a} x_{i,a,s,t}\right) * 0.5 = b_{i,s,t} \quad \forall i \in I, s \in S, t \in T \quad (4.3)$$

$$\sum_{t \in T} \sum_{s \in S} b_{i,s,t} \leq g_i \quad \forall i \in I \quad (4.4)$$

$$b_{i,s,t} \leq ATS_{i,s,t} \quad \forall i \in I, s \in S, t \in T \quad (4.5)$$

$$y_{a,s,t} \leq ATA_{a,s,t} \quad \forall a \in A, s \in S, t \in T \quad (4.6)$$

$$\sum_{i \in I} b_{i,s,t} \leq 2 \quad \forall s \in S, t \in T \quad (4.7)$$

$$\sum_{i \in I} x_{i,a,s,t} \leq 2 * y_{a,s,t} \quad \forall a \in A, s \in S, t \in T \quad (4.8)$$

$$\sum_{a \in A} y_{a,s,t} \leq 2 \quad \forall s \in S, t \in T \quad (4.9)$$

$$\sum_{tt=t}^{tt=t+Tmin_i} \sum_{s} b_{i,s,tt} \leq 1 \quad \forall i \in I, t \in T - Tmin_i \quad (4.10)$$

$$\sum_{tt=t}^{tt=t+Tmax_i} \sum_{s} b_{i,s,tt} + p_{i,t} \geq 1 \quad \forall i \in I, t \in T - Tmax_i \quad (4.11)$$

$$-BigM * \left(2 - b_{i,s,t} - b_{j,s,t}\right) + d_{i,j} \leq maxdist \quad (4.12)$$

$$\sum_{s \in S} \sum_{t \in T} b_{i,s,t} = 1 \quad \forall f(i) \in I \quad (4.13)$$

$$b_{i,s,t} \in \{0,1\} \quad \forall i \in I, s \in S, t \in T \qquad (4.14)$$

$$x_{i,a,s,t} \in \{0,1\} \quad \forall i \in I, a \in A, s \in S, t \in T \qquad (4.15)$$

$$y_{a,s,t} \in \{0,1\} \quad \forall a \in A, s \in S, t \in T \qquad (4.16)$$

$$p_{i,t} \in \{0,1\} \quad \forall i \in I, t \in T \qquad (4.17)$$

The objective function is the maximisation of the number of visits undertaken, given by equation (4.1), and if there are visits that are not fulfilled, they are penalised. Equations (4.2) to (4.13) are constraints. Equation (4.2) ensures that families are accompanied by technicians assigned to them at the beginning of the process. Equation (4.3) defines the variable $b_{i,s,t}$. The variable $x_{i,a,s,t}$ is multiplied by 0.5 since for each family two technicians are associated. Equation (4.4) indicates the number of times families have to be visited in that horizon planning. Equations (4.5) and (4.6) ensure that visits are carried out when families and technicians have availability, respectively. Equation (4.7) indicates that there are a maximum of two visits in each slot of each day. Equation (4.8) defines the variable $y_{a,s,t}$, guaranteeing that two technicians are required for each family and that, in each slot, of each day, only two technicians perform the visits, given by equation (4.9). Equation (4.10) indicates the minimum interval between visits, while equation (4.11) is the maximum interval. Nonetheless, the latter is modelled as a soft constraint, allowing for deviations in this interval. Equation (4.12) states that families that are visited in the same slot, cannot be further away than the $maxdist$. Finally, equation (4.13) serves to oblige a subset of families to be visited in a given month if they were not visited in the previous one. Equations (4.14) to (4.17) indicate the domain of binary variables.

4.3 Chapter Conclusions

This chapter presented and described the mathematical formulation of the single-objective MILP model that addresses the problem under study. The model was implemented in GAMS software. In order to simplify it, assumptions were made regarding the number of families, the availability of technicians, the time considered and the means of transport.

5 Data Collection and Treatment

In order to implement the model, ComDignitatis provided data about the families being monitored, the number of visits that each one had in the months of January, February and March 2022, the minimum and maximum interval between these visits and the technicians assigned to them, through Excel files. They also supplied weekly agendas, which, as discussed in Chapter 2, allows verifying which visits were actually carried out and by whom. Still, this data was not structured or computerised, so an Excel was created from scratch in order to organise and complete this information with the number of visits that would be expected to happen. All assumptions were validated with ComDignitatis. Due to data confidentiality, families and technicians are represented by codes.

5.1 Number and Location of Families

In January and February, ComDignitatis was responsible for 81 families and in March, for 74. This difference is due to the archiving of the process of families in FP. In addition to this, within the 74 families in March, there are 3 that still do not have an address associated, since they have not had any type of intervention so far. It is also known that from those 74 families, 18 families belong to the FRP modality, whose visits are more rigorous and stricter. Therefore, a total of 53 families is considered.

The families are distributed among the municipalities of Torres Vedras, Mafra, Sobral de Monte Agraço, Lourinhã and Cadaval, in the district of Lisbon. The map in Figure 5 shows the location of the 53 families and the ComDignitatis office in Ericeira.

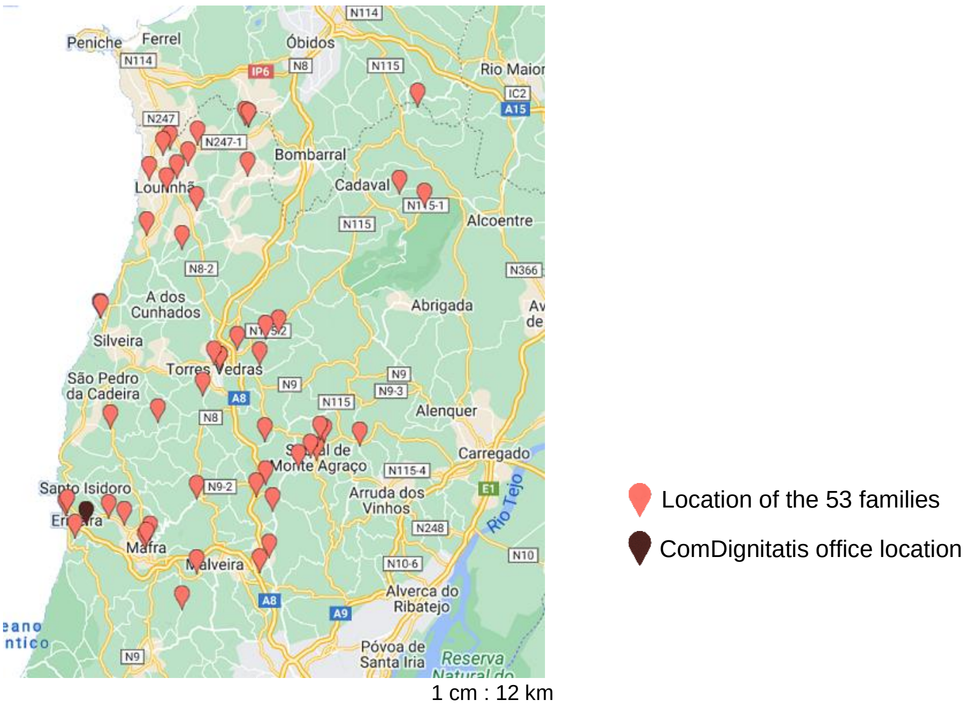


Figure 5. Location of the families

There is a higher concentration of families in the municipality of Mafra (16), followed by Lourinhã (14), Torres Vedras (12), Sobral de Monte Agraço (8) and Cadaval, with the lowest concentration (3).

5.2 Distances

As the families are spread over different municipalities, it is useful to know the distances between them, so that when there are two visits in the morning, for example, they would not be far from each other.

In the Excel provided by the organisation, all the families had an address associated. With that information, it was possible to obtain the real distances between a set of locations, through the openrouteservice API. It is a service that provides a matrix time-distance, which is returned through a JSON structured response.

5.3 Interval between Visits

In the data files provided by the organisation, there was information missing regarding the expected interval between visits for 42 families. So, a pre-processing step was carried out to infer the frequency pattern of visits that had occurred in the months of January, February, and March. The assumptions made based on the available data are presented as follows.

The visits that did occur are recorded in the weekly agendas of these three months. For families with only 1 visit in at least one of the three months analysed it was assumed that the minimum interval would be 30 days and the maximum 60. For families with no visits at all in the three months that interval would be between 30 and 90 days and it could not go beyond this maximum, as it is too long for a family not to be visited. For families that had 2 visits in a month, the interval would be from 15 to 30 days. These intervals have been validated with the organisation.

That said, Table 5 aggregates the number of visits in the weekly agendas by month, for each family, along with the expected interval between visits estimated from the previous assumptions. Each line characterises a family and is interpreted, for example, as follows: for family i_1, there were no visits in January, only one in February and none in March, and the expected interval between visits is between 30 and 60 days. Families with a longer interval between visits are already being followed for some time and do not need to be visited more frequently. On the other hand, families whose interval is between 15 and 30 days are usually families that have recently entered, and their situation is more delicate, having to be visited more frequently.

Table 5. Visits that took place in January, February, and March

Family	January	February	March	Interval (in days)
i_1	0	1	0	30 - 60
i_2	0	0	0	15 - 25
i_3	1	0	1	15 - 25
i_4	0	1	0	30 - 60
i_5	1	0	0	30 - 60
i_6	1	0	1	30 - 60
i_7	1	0	1	30 - 60
i_8	0	0	0	30 - 90
i_9	0	0	0	30 - 90
i_{10}	0	1	0	30 - 60
i_{11}	0	0	0	30 - 90
i_{12}	1	0	1	30 - 60
i_{13}	1	0	2	15 - 25
i_{14}	0	0	0	30 - 90
i_{15}	1	0	1	30 - 60
i_{16}	0	0	0	30 - 90
i_{17}	0	0	1	30 - 60
i_{18}	0	0	0	30 - 90
i_{19}	0	0	0	30 - 90
i_{20}	1	0	0	30 - 60
i_{21}	2	0	0	15 - 30
i_{22}	0	0	0	30 - 90
i_{23}	1	0	0	30 - 60
i_{24}	0	0	0	30 - 90
i_{25}	0	0	0	30 - 90
i_{26}	0	1	0	30 - 60
i_{27}	0	1	0	30 - 60
i_{28}	0	0	0	30 - 90
i_{29}	1	0	1	30 - 60
i_{30}	1	0	1	15 - 40
i_{31}	1	2	1	15 - 30
i_{32}	0	1	1	15 - 30
i_{33}	0	1	0	15 - 60
i_{34}	0	0	0	30 - 90
i_{35}	0	0	0	30 - 90
i_{36}	0	0	1	30 - 60
i_{37}	0	1	0	15 - 60
i_{38}	0	0	0	30 - 90
i_{39}	0	1	0	30 - 60
i_{40}	1	0	1	30 - 60
i_{41}	0	0	0	30 - 90
i_{42}	1	1	1	15 - 30
i_{43}	0	1	0	30 - 60
i_{44}	2	0	1	15 - 30
i_{45}	1	1	1	30 - 60
i_{46}	1	1	2	15 - 30
i_{47}	0	1	0	30 - 60
i_{48}	0	0	1	30 - 60
i_{49}	2	0	1	15 - 30
i_{50}	0	0	2	15 - 30
i_{51}	0	0	1	30 - 60
i_{52}	0	1	1	30 - 60
i_{53}	0	0	2	15 - 30

However, there are 30 families whose visits did not comply the expected interval (those shaded in brown in Table 5) - about 56.6% of the total. The main reason behind this is the cancellation of visits by families.

Table 6 indicates the number of families and their interval between visits.

Table 6. Number of families and their interval between visits

Number of Families	Interval between Visits (in days)
3	15 - 25
9	15 - 30
1	15 - 40
2	15 - 60
23	30 - 60
15	30 - 90

As evidenced, most families have a longer expected intervals, from 30 to 60 days or 30 to 90 days. For families that need to be visited twice, it can be assumed that the ideal interval between visits would be between 15 and 25 days, to ensure that the two visits take place in the same month. If the maximum interval was 30 days or more, then the second visit could take place in the following month.

Knowing the expected intervals between visits for each family, it is possible to verify if a family visiting schedule complied them. Ideally, all visits should be within this interval and should preferably be consistent. Based on this principle, it is possible to reach the number of visits that would be expected to take place. It is this data that will serve as input for the model.

For families for which the visits did not respect the interval, it was considered that they should comply with the minimum interval, i.e., for example, family i_2 whose interval between visits is between 15 and 25 days and has not been visited in the three months, it would be expected to have at least two visits in each of the months because the minimum interval is every fifteen days. For families whose visits were within the considered interval but were not consistent, it would also be expected to always have the same number of visits in each month, as for example, in family i_1, which had only one visit in February, but as the minimum interval between its visits is 30 days, it would be necessary to have at least one visit in each month. In fact, the minimum interval is actually the "ideal number of days between visits".

Table 7 reveals the number of visits that would be expected to occur during the three months.

Table 7. Visits that took place in January, February, and March

Family	January	February	March	Interval (in days)
i_1	1	1	1	30 - 60
i_2	2	2	2	15 - 25
i_3	2	2	2	15 - 25
i_4	1	1	1	30 - 60
i_5	1	1	1	30 - 60
i_6	1	1	1	30 - 60
i_7	1	1	1	30 - 60
i_8	1	1	1	30 - 90
i_9	1	1	1	30 - 90
i_{10}	1	1	1	30 - 60
i_{11}	1	1	1	30 - 90
i_{12}	1	1	1	30 - 60
i_{13}	2	2	2	15 - 25
i_{14}	1	1	1	30 - 90
i_{15}	1	1	1	30 - 90
i_{16}	1	1	1	30 - 90
i_{17}	1	1	1	30 - 90
i_{18}	1	1	1	30 - 90
i_{19}	1	1	1	30 - 90
i_{20}	1	1	1	30 - 60
i_{21}	2	2	2	30 - 60
i_{22}	1	1	1	30 - 90
i_{23}	1	1	1	30 - 60
i_{24}	1	1	1	30 - 90
i_{25}	1	1	1	30 - 90
i_{26}	1	1	1	30 - 60
i_{27}	1	1	1	30 - 60
i_{28}	1	1	1	30 - 90
i_{29}	1	1	1	30 - 60
i_{30}	2	2	2	15 - 40
i_{31}	2	2	2	15 - 30
i_{32}	2	2	2	15 - 30
i_{33}	2	2	2	15 - 60
i_{34}	1	1	1	30 - 90
i_{35}	1	1	1	30 - 90
i_{36}	1	1	1	30 - 90
i_{37}	2	2	2	15 - 60
i_{38}	1	1	1	30 - 90
i_{39}	1	1	1	30 - 60
i_{40}	1	1	1	30 - 60
i_{41}	1	1	1	30 - 90
i_{42}	2	2	2	15 - 30
i_{43}	1	1	1	30 - 60
i_{44}	2	2	2	30 - 60
i_{45}	1	1	1	30 - 60
i_{46}	2	2	2	30 - 60
i_{47}	1	1	1	30 - 90
i_{48}	1	1	1	30 - 90
i_{49}	2	2	2	30 - 60
i_{50}	2	2	2	30 - 90
i_{51}	1	1	1	30 - 90
i_{52}	1	1	1	30 - 60
i_{53}	2	2	2	30 - 60

All cells highlighted in brown in Table 7 correspond to visits that were expected to happen and did not happen in reality. The remaining are visits that would remain the same as in the current situation.

Table 8 summarises how many families would have more visits in an ideal situation in one, two or in all three months and the families that even in an ideal situation would have the same number of visits as happened in reality.

Table 8. Number of families whose number of visits would be different in an ideal situation

Number of Families	None of the Months	All Months	1 or 2 Months
1	x		
22		x	
30			x

Only one family was found to be unchanged, that is, in an ideal situation, this family would have exactly the same number of visits as they did in reality. The remaining families (52), as shown in Table 8, would have more visits than they actually had, with 22 of them having more in all the three months and 30 having only in one or two months.

It should be noted that all assumptions related to the interval between visits and the number of visits that should take place, were validated with the organisation.

5.4 Families' Time Windows

The schedules of the visits depend essentially on the availability of the families for them. Figure 6 depicts an agenda with the possible schedules for 6 families, as an example.

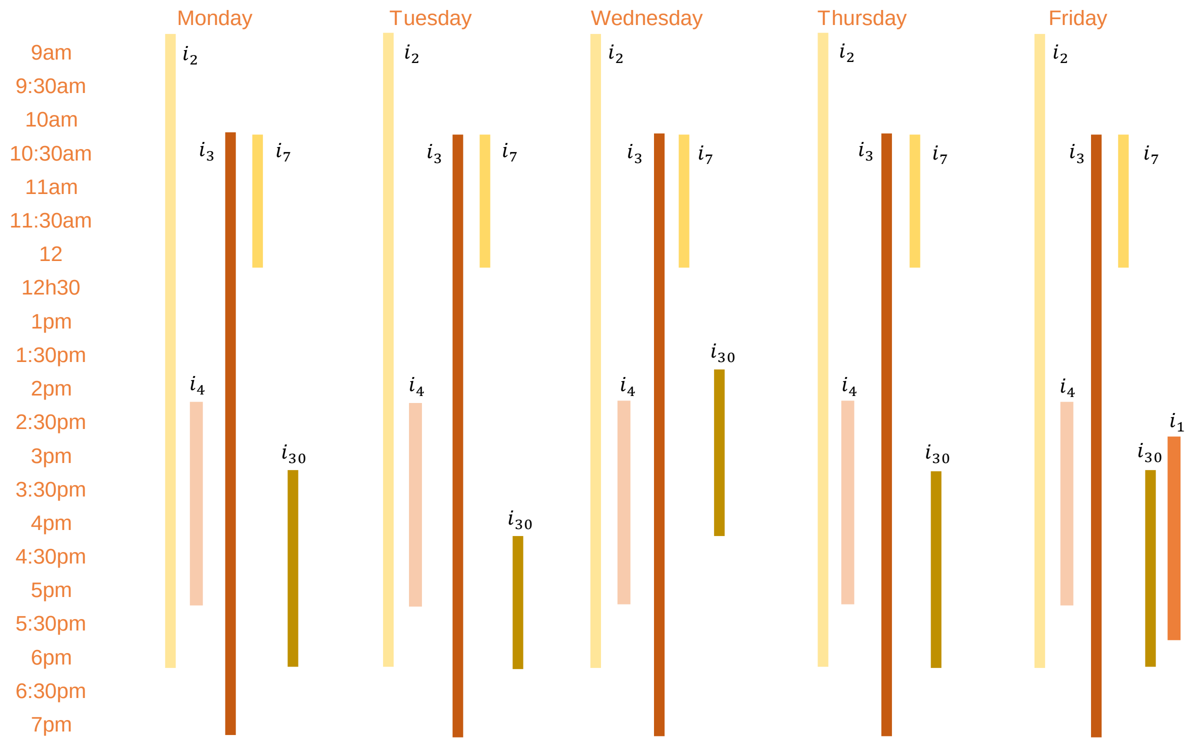


Figure 6. Families' available visiting times

The bars represent each family's availability for visits, indicating the earliest and latest start times. Bars of the same colour indicate the same family. So, for example, family i_2 is available Monday to Friday between 9am and 6pm, the latter being the latest possible start time for visits. Family i_1 is only available on Fridays from 3pm to 5pm. Family i_{30} is available between 3:30pm and 6pm on Mondays, Thursdays, and Fridays, between 4:30pm and 6pm on Tuesdays and from 2pm to 4pm on Wednesdays.

However, assumptions had to be made in the time windows of some visits as this data was missing. Where such information was not available in any of the months, a wider time window was assumed - Monday to Friday, 9am to 6pm. On the other hand, if there was no indication of the possible timetable in the month of March but there was in January and/or February, it was then assumed that the third month would have the same time window as the other months. The same is true if there was no timetable in January or February.

That being said, Table 9 outlines the master schedule of the 53 families to carry out the visits.

Table 9. Schedules of all families

Number of Families	Wider Time Window	Morning Time Window	Afternoon Time Window	One-day Time Window	Multiple Time Windows
22	x				
7		x			
21			x		
2				x	
1					x

As shown, 22 families have a longer time window, such as from 9am to 6pm, every day. Only 7 families have availability in the morning, such as from 10am to 11.30am, every day, while in the afternoon, more families prefer this schedule, such as from 3pm to 7pm, also every day. Only two families have their availability limited on Fridays. And as for multiple time windows, only one has and it was given as an example in Figure 7 (i_{30}).

5.5 Technicians

Technicians are assigned to families at the beginning of each process. Normally three are assigned but only two are necessary to accompany a family in a visit. The aim is that at least one of the reference persons is always present (in cases where the second person in the process cannot be present because of illness or holidays, for example).

The seven technicians also have their availability to carry out the visits, as shown in Table 10.

Table 10. Technicians ' available visiting times

Technicians	Monday	Tuesday	Wednesday	Thursday	Friday
a_1	2pm - 6pm	-	10am - 6pm	9:30am - 7:30pm	3pm - 8pm
a_2	9:30am - 5:30pm	2pm - 8pm	10:30am - 8:30pm	9:30am - 5:30pm	9:30am - 5:30pm
a_3	9:30am - 5:30pm	2pm - 7pm	9:30am - 7pm	9:30am - 7pm	9:30am - 7pm
a_4	9:30am - 7:30pm	2pm - 5pm	9:30am - 2pm	9:30am - 7:30pm	9:30am - 5pm
a_5	9:30am - 7:30pm	2pm - 5:30pm	9:30am - 6pm	9:30am - 7:30pm	9:30am - 5:30pm
a_6	9:30am - 7:30pm	2pm - 5:30pm	9:30am - 8pm	9:30am - 5:30pm	9:30am - 8:30pm
a_7	9:30am - 7:30pm	2pm - 5:30pm	9:30am - 8pm	9:30am - 5:30pm	9:30am - 8:30pm

These availabilities, like those of the families, also indicate the earliest and latest possible start time to provide the service. Nevertheless, although not very often, sometimes the technicians adjust their schedule to those of the families. For example, if a family only has availability between 6pm and 7:30pm, on a Tuesday, and one of the technicians responsible is a_5, whose later visiting time is at 5:30pm (as seen in Table 10), then she would have to extend her schedule a little more to provide the service.

As previously mentioned, no staff can perform visits in the morning on Tuesdays, as they all have a meeting together to discuss the planning of the following week's visits. In addition, their lunch period is usually between 1pm and 2pm, but if they need to leave earlier, this schedule is adaptable.

It should be noted that this availability is used to carry out visits of the three modalities. However, as explained in Chapter 4, if a technician has scheduled a FRP visit on a particular day then she is unavailable to conduct another visit in the slot that took place.

5.6 Transport

The technicians travel to meet the families using a car provided by the organisation itself. In reality, there are two cars, one only for the CAFAP team and the other shared with the Home Support Service, and a van, responsible for the collection and delivery of food. The car which is only for the CAFAP team is the most used, as it is the only one which is always available. The shared car is more available in the morning, but as most of the visits take place in the afternoon, it is not very useful. And as for the van, although very rarely, it has already been used to go and visit families. However, in none of the cars is it known in advance when they will be available.

The technicians leave the main centre of Ericeira to go to each family and normally, after the visit is over, they return to the same place. However, there are exceptions and sometimes they can make two visits in a row and only then return to the centre. Normally a car takes only one team but it has happened to take two teams and make two stops.

5.7 Chapter Conclusions

This chapter aimed to collect and process the data necessary for the implementation of the model, regarding the number and location of families, the interval between their visits, their time windows, as well as of the technicians, and the means of transport used by them to travel to the families' homes. Assumptions had to be made due to the lack of data in certain families but validated with the organisation.

6 Results and Discussion

The proposed model has been implemented and in this chapter the solution for the ComDignitatis organisation's problem will be presented. In the first section, an individual analysis is made of what happened in reality and the results obtained by the model, which were validated by the organisation. Then, a comparison is made between them. In the third part of this chapter, a sensitivity analysis is made for a parameter.

The model was implemented in GAMS 39.2.0 and the case study was solved using CPLEX 22.1.0.0.

6.1 Analysis of Current Situation and Proposed Solution

This section is dedicated to the analysis of the current situation and the results provided by the model, i.e. which families should be visited, by whom and when. In order to be comparable, the original solution had to be translated into the way the model was programmed, that is, instead of referring the exact time of the visit, only the slot in which it took place was considered - in the morning (from 9am to 1pm) or in the afternoon (from 2pm to 7pm). The time was also something that changed, as in the model, only the working weeks were considered, from Monday to Friday, and not counting Saturdays, as they count in reality, since on this day only the families of the FRP are visited.

Both the current situation and the proposed solution are analysed in terms of the number of visits, the technicians assigned to them and their workload, their availability and those of the families, and the distances between them. What happened in reality and the results provided by the model are presented in calendar form so as to be more visual and more easily perceptible. The slots are distinguished by colours, as well as the meetings, which take place on Tuesday mornings and the existing holidays, so that it can be seen that at those times, no visits take place.

6.1.1 Current Situation

The number of visits, which actually took place, in each month is shown in Figure 7. Table 5 (in Chapter 5) gives a detailed view about which family was visited in each month.

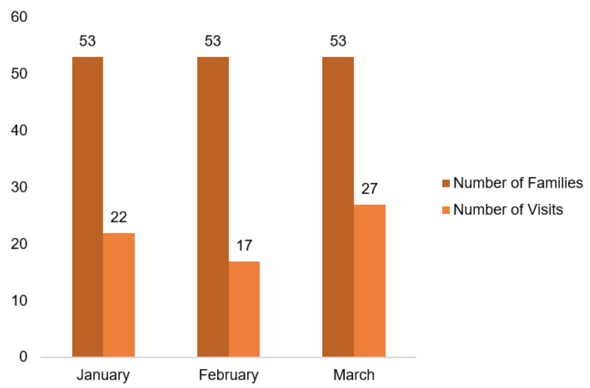


Figure 7. Comparison between the number of visits and the total number of families

As mentioned before, the target of this study is 53 families. As is easily observed in Figure 7, there is a major discrepancy between this total with the number of visits that actually occurred. In January, there were a total of 22 visits, which corresponds to 19 families, as three families had two visits each, therefore 35.8% of the total of families were visited this month. February, on the other hand, had 17 total visits, the month with the lowest number, corresponding to 16 families, since one had 2 visits, which is equivalent to 30.2% of the total. March was the month that had more visits, 27, in which 4 families needed two visits that month, thus corresponding to 43.4% of the number of families being followed.

However, there were families who were planned to be visited and, for certain reasons, did not happen. This information was taken from the weekly agendas, which is highlighted by the fact that these families' appointments were erased. It was also possible to view those who were visited earlier or later than expected.

Table 11 then presents the number of families whose visits were erased in the January, February, and March agendas and into which category they fall.

Table 11. Number of families whose visits were cancelled or postponed/anticipated

	January	February	March
Number of families whose visits were cancelled	1	2	1
Number of families whose visits were postponed or anticipated	2	1	2

Observing Table 11, it is concluded that if the families that were planned to be visited, actually happened, then in January, the number of visits rose to 23, in February to 19 and March to 28. As for the other families whose visits were postponed or brought forward, it simply means that there was an unforeseen reason for the visit not taking place on a certain day and it had to be rescheduled. This could be due to either unforeseen problems with the families or the technicians, who sometimes get held up in court and take this time away from them.

Detailing the visits that have taken place, Figure 8 shows a calendar of these, for the month of March, as an illustrative example. The calendars for January and February can be found in Appendix 1 and 2, respectively.

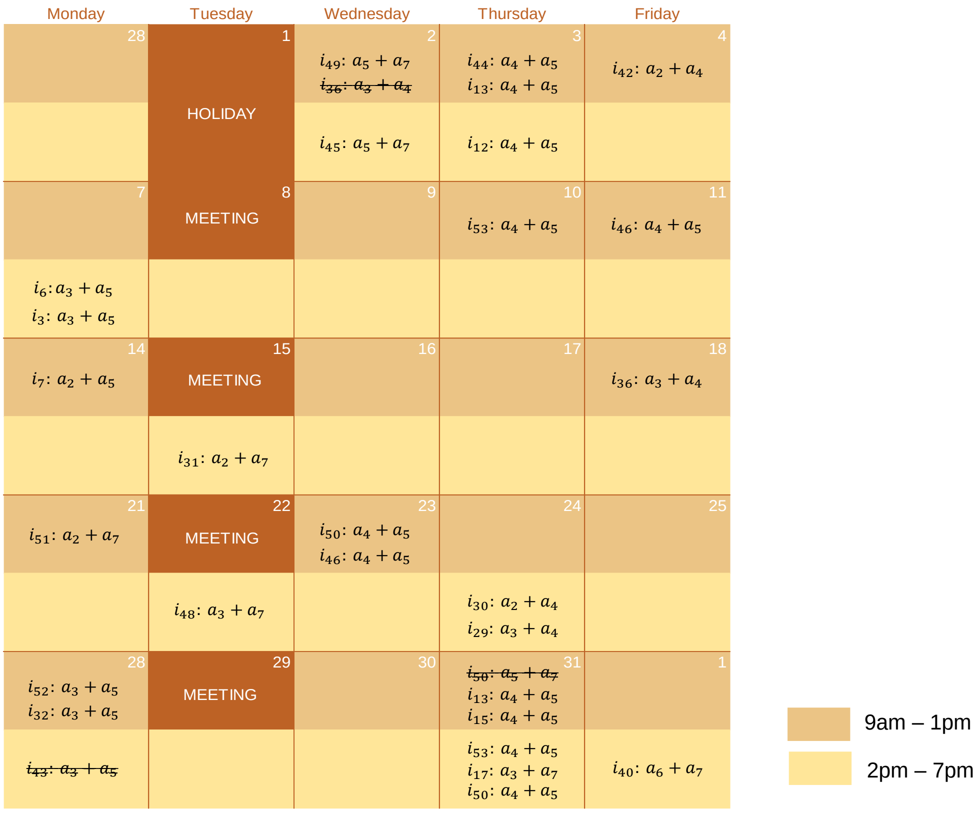


Figure 8. Calendar with current visits in March

As confirmed, there were 27 visits in total and, as it can be seen, there are 3 families visits that are crossed out, which means, as explained above, and in this specific case, two of the families were planned to be visited on a certain day but ended up being earlier and a family was supposed to be visited this month but was not.

Table 12 displays, for each month, how many empty slots there are and how many have visits.

Table 12. Organisation of visits over the three months in the current situation

	January	February	March
Empty slots	21	21	25
Slots with 1 visit	9	13	12
Slots with 2 visits	5	2	6
Slots with 3 visits	1	0	1
Total number of slots	36	36	44

As may be observed, there are many empty slots, i.e. no FP or FR visits.

To better visualise the dispersion of the families, Figure 9 depicts a map with the 53 families that are being followed by the organisation (as shown in Chapter 5), where the 27 families that were visited in March are highlighted. Moreover, it is also showed the families that were visited in the same slot that are 20 km further away from each other (on the 3rd and 23rd of March).

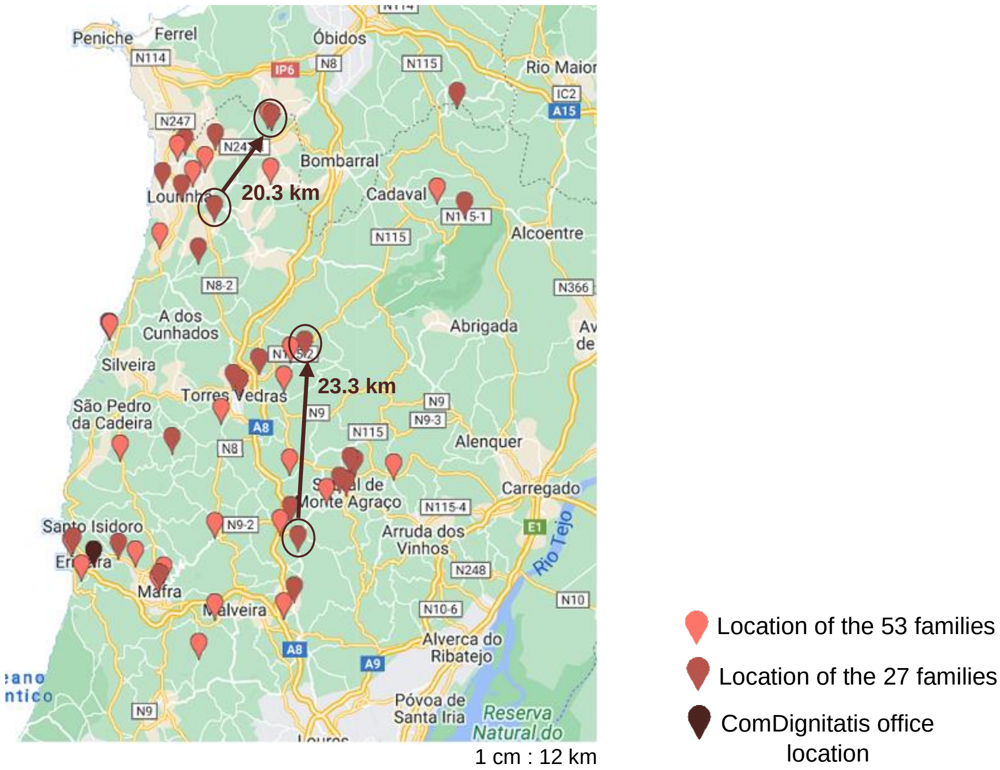


Figure 9. Location of the families visited in March

The purpose of highlighting these 4 families, which are more than 20 km away from each other (in March), is due to the fact that in the model, as mentioned in Chapter 4, families that are in the same slot cannot be more than 20 km away from each other. This means that, in the results provided by the model, these families would not be visited together.

Nevertheless, many of the visits made, in any given month, are not within the availability given by the family and there are technicians accompanying a particular family that had not been assigned to them at the beginning of the process. Table 13 indicates how many times these two types of situations occurred.

Table 13. Visiting schedules that are not within the availability given by the family and technicians that are not assigned to the process

	January	February	March
Visiting schedules not within the availability of families	5	3	0
Technicians not assigned to the process	4	6	5

There was a total of 9 inconsistencies in January, either from families or technicians, 9 in February and 5 in March.

Regardless of these inconsistencies, Table 14 presents, for the three months, the workload of each technician, meaning the number of visits that each one participated in and the % of total visits, dividing that number by the total visits made per month.

Table 14. Workload of each technician in the current situation

	January		February		March	
	Number of Visits	% of Total Visits	Number of Visits	% of Total Visits	Number of Visits	% of Total Visits
a_1	0	0%	0	0%	0	0%
a_2	0	0%	4	23.5%	5	18.5%
a_3	5	22.7%	8	47.1%	8	29.6%
a_4	11	50%	6	35.3%	15	55.6%
a_5	18	81.8%	9	52.9%	18	66.7%
a_6	0	0%	1	5.9%	1	3.7%
a_7	10	45.5%	6	35.3%	7	25.9%

In fact, technicians a_4 and a_5 are the ones who are responsible for more families, in any of the three months. But in January, it is noticeable that a large concentration of visits is in these two technicians, with three having none. The proportion of visits seems more similar between February and March.

Finally, as a last analysis in this section, the interval between visits (in days), for those families that needed to be visited twice a month, is shown in Table 15. As mentioned at the beginning of this chapter, 3 families were visited twice in January, one in February and four in March.

Table 15. Interval between visits (in days) in the current situation

Family	January	February	March
i_{13}			20
i_{21}	11		
i_{31}		5	
i_{44}	6		
i_{46}			8
i_{49}	11		
i_{50}			6
i_{53}			15

In reality, the ideal interval between visits for families who need more than one visit per month is between 15 and 25 days (as seen in Chapter 5) but as mentioned at the beginning of the chapter, in this study, only working days are being considered, so it is equivalent to having an expected interval of between 10 and 15 days. As is evident from Table 15, only three families meet this range (i_{21}, i_{49}, i_{53}). The remaining families either have an interval between visits that is longer than expected or shorter. It should also be noted that none of the families present here have visits during these three months, that is, they are only visited in one of the three months, which should not happen, as they are families who need two visits per month, and consequently more support.

6.1.2 Proposed Solution

Adding all visits together, the visits that were expected to take place in January, February, and March, gives a total of 68 per month, assuming the interval between visits is maintained (Table 7 in Chapter 5). Given the results of this model, this maximum, however, is only guaranteed for the month of March. In January, the model is able to schedule 65 visits, which means that three families were not visited. Therefore, these families are "obliged" to be visited in February, as if they gained priority over the others. So, in this second month, a total of 64 visits are scheduled, leaving out two families and two others that were visited only once, when they should have been visited twice. However, only the two families that had not been visited at all gained priority in March. Finally, the month of March, managed to ensure that all families were visited and the required number of times, therefore 68 visits in total, including the two families that were not visited in the previous month.

That said, Figure 10 compares the number of visits that were obtained from the model with the actual number of visits.

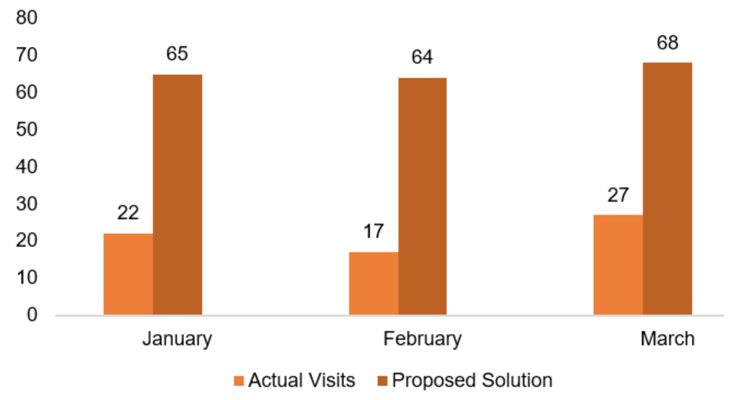


Figure 10. Comparison of the current number of visits with the proposed solution

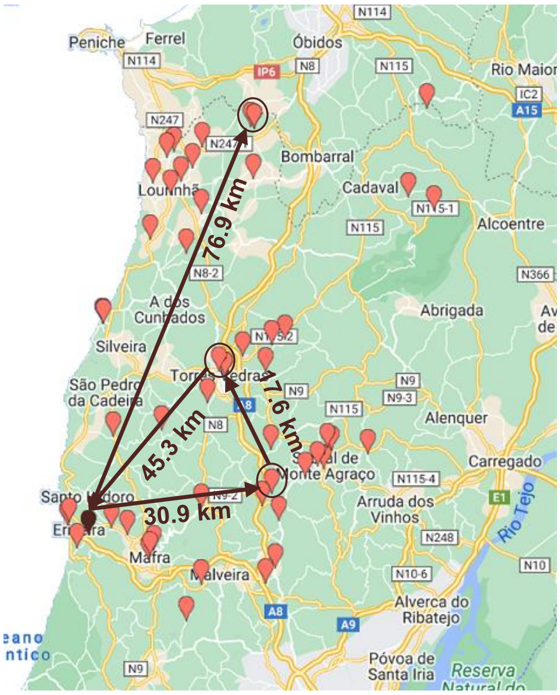
In fact, there is a major difference between reality and the visits that would be expected to happen, according to the solution obtained by the model. In January, there would be 43 more visits, in February 47 and in March 41 than the current situation.

The calendar for March, with the visits obtained by the model, is shown in Figure 11, as an example. The calendars for January and February can be found in Appendix 3 and 4, respectively.

	Monday	Tuesday	Wednesday	Thursday	Friday
9am – 1pm	28 $i_{32}: a_3 + a_5$ $i_{52}: a_3 + a_5$	1 HOLIDAY	2 $i_{46}: a_4 + a_5$ $i_{53}: a_4 + a_5$	3 $i_{43}: a_3 + a_5$ $i_{47}: a_3 + a_5$	4 $i_{44}: a_4 + a_5$
2pm – 7pm	$i_{15}: a_4 + a_5$ $i_{24}: a_4 + a_5$		$i_{9}: a_3 + a_7$ $i_{27}: a_3 + a_7$	$i_{23}: a_3 + a_7$ $i_{48}: a_3 + a_7$	$i_{2}: a_4 + a_5$ $i_{22}: a_4 + a_5$
9am – 1pm	7 $i_{42}: a_2 + a_4$	8 MEETING	9 $i_{49}: a_5 + a_7$	10 $i_{34}: a_3 + a_7$	11 $i_{41}: a_2 + a_7$
2pm – 7pm	$i_{37}: a_2 + a_5$	$i_{26}: a_2 + a_4$ $i_{30}: a_2 + a_4$	$i_{19}: a_2 + a_7$ $i_{31}: a_2 + a_7$	$i_{16}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$
9am – 1pm	14 $i_{3}: a_3 + a_5$	15 MEETING	16 $i_{14}: a_2 + a_6$	17 $i_{46}: a_4 + a_5$ $i_{53}: a_4 + a_5$	18 $i_{36}: a_3 + a_4$
2pm – 7pm	$i_{13}: a_3 + a_4$ $i_{39}: a_3 + a_4$	$i_{25}: a_3 + a_5$	$i_{5}: a_5 + a_7$	$i_{10}: a_5 + a_6$	$i_{32}: a_3 + a_5$
9am – 1pm	21 $i_{44}: a_4 + a_5$	22 MEETING	23 $i_{2}: a_2 + a_5$ $i_{42}: a_2 + a_5$	24 $i_{49}: a_5 + a_7$	25 $i_{20}: a_4 + a_5$
2pm – 7pm	$i_{18}: a_2 + a_3$	$i_{37}: a_2 + a_5$	$i_{12}: a_5 + a_7$ $i_{45}: a_5 + a_7$	$i_{8}: a_2 + a_7$ $i_{31}: a_2 + a_7$	$i_{4}: a_4 + a_7$ $i_{30}: a_4 + a_7$
9am – 1pm	28 $i_{35}: a_2 + a_7$ $i_{51}: a_2 + a_7$	29 MEETING	30 $i_{3}: a_3 + a_5$ $i_{6}: a_3 + a_5$	31 $i_{7}: a_2 + a_7$ $i_{38}: a_2 + a_7$	1 $i_{13}: a_3 + a_4$ $i_{28}: a_3 + a_4$
2pm – 7pm	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{11}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_{17}: a_3 + a_7$ $i_{23}: a_3 + a_7$	$i_{29}: a_4 + a_7$	$i_{1}: a_2 + a_3$

Figure 11. Calendar with the proposed solution for March

To illustrate what a visiting day would look like, Figure 12 depicts what would happen on the 17th of March.



1 cm : 12 km

Figure 12. Illustrative examples of one-day visits

Interpreting this example, and being only one of the possible solutions (this is because there are relatively large families' time windows and so, there may be different times to start a visit), the technicians a_4 and a_5, leave the office, in Ericeira, around 9:30am and the first family they visit is i_{46}, whose visit starts at 10am and the travel time until there is only 22 min. After an hour's visit (assuming the visiting time is this long), they go to family i_{43}, and stay there from 11:30am until 12:30. The two families are at a distance of 17.6 km from each other, corresponding to a travel time of approximately 20 min. After finishing it, they return to the centre after 35 min. In the afternoon, there is only one visit, and it starts only at 5:30pm. Technicians a_5 and a_6 leave the centre at around 4:30pm, as this trip is relatively long, lasting approximately 50 min. This visit is until 6:30pm. Then, the technicians return to the centre and arrive there around 7:30pm and finish their day's work.

Looking at the three calendars, and in order to understand how the visits are organised by slots, Table 16 puts this information together, so as to analyse if there are empty slots or how many are occupied with two visits or with only one, in the three months.

Table 16. Organisation of visits over the three months in the proposed solution

	January	February	March
Empty slots	0	0	0
Slots with 1 visit	7	8	20
Slots with 2 visits	29	28	24
Total number of slots	36	36	44

In fact, in any given month, there are no empty slots, i.e. every day is occupied with FP and FR visits and the vast majority of slots, have two visits. Even more important is the fact that, in each slot, the same technicians perform the two visits. This is because if the technicians are the same for the two visits which take place in the morning or afternoon, and if the distance between them is not greater than 20 km, so as not to lose too much time driving, then these visits can be sequential, avoiding having to pass through the centre between them.

In addition, it was verified if there were incompatibilities between the schedules of the families that were visited in the same slot, that is, if these schedules overlapped. This could happen since the days are only divided into two slots, not taking into account the exact availability of each family. But the results show the opposite. Nonetheless, as mentioned in Chapter 5, sometimes the technicians have to adjust their availability to carry out visits according to those of the families. The fact that the model only considers two slots makes it complicated to define exactly the latest time to conduct the visit. Thus, in this solution, there are schedules that are less preferable for the technicians. Apart from this, all visits are within the availability of families and of technicians and for those families that need two visits per month, the expected interval is respected, to be precise, 10 to 15 days.

Table 17 indicates the number of visits that each technician would participate in, in these three months, as well as the % of total visits.

Table 17. Workload of each technician in the proposed solution

	January		February		March	
	Number of Visits	% of Total Visits	Number of Visits	% of Total Visits	Number of Visits	% of Total Visits
a_1	0	0%	0	0%	0	0%
a_2	14	21.5%	18	28.1%	19	27.9%
a_3	26	40%	25	39.1%	27	39.7%
a_4	26	40%	18	28.1%	26	38.2%
a_5	36	55.4%	38	59.4%	36	52.9%
a_6	0	0	2	3.1%	2	2.9%
a_7	26	40%	25	39.1%	23	33.8%

To better understand the workload of each technician, individual calendars were made, with the FP and FR visits that each technician performs, plus the FRP visits. The objective is to analyse the time allocated to the visits and the time allocated to other tasks. These calendars are shown in Appendix 5 for the month of March as an example of what the individual workload would look like.

Accordingly, Table 18 provides, for each technician, in March, how many slots with visits, of any of the modalities, and how many empty slots each has.

Table 18. Empty slots and slots with visits, for each technician

	a_2	a_3	a_4	a_5	a_6	a_7
Empty slots	26	23	24	15	26	13
% Empty Slots	59%	52%	55%	34%	59%	30%
Slots with 2 visits	6	13	10	13	5	14
Slots with 1 visit	12	8	10	16	13	17
4 Visits per day	0	2	0	2	0	0

As it appears, all the technicians have a large number of empty slots, i.e. there are no FP, FR and FRP visits in these slots. These empty slots are necessary for the technicians to be able to dedicate themselves to other tasks, such as produce reports, court visits, which may last an entire afternoon, for example, meetings about cases to evaluate the family situation or having to be absent for a while for personal reasons. In fact, the second row of Table 16 gives a better idea of the % of free time that technicians have to dedicate to these tasks. Technician a_7 is the one with the least free slots, as she is responsible for many cases of FRP and families from other modalities. In relation to the slots with 2 visits and with 1 visit, most of the technicians have more slots with only 1 visit, which in a way is useful, because they do not occupy a whole morning or afternoon with visits, and at the end of that visit, the two technicians who conducted the visit may still have time to write the report on that visit, together. Regarding the 4 visits in one day, only technician a_3 and a_5 have it, which can become demanding and tiring.

6.2 Comparison of Results

This section is devoted to the comparison of the results for the three months.

Table 19 compares the two situations, in terms of the total number of visits, the number of free slots, with two visits or with only one, the distance between families that are visited in the same slot, how many families were visited twice and the interval between them.

Table 19. Comparison of results

	Current Situation			Proposed Solution			
KPI´s	January	February	March	January	February	March	Average Variation
Total number of visits	22	17	27	65	64	68	+ 198%
Maximum number of visits/slot	3	2	3	2	2	2	
Number of empty slots	21	21	25	0	0	0	- 100%
Number of slots with 2 visits	5	2	6	29	28	24	+ 528%
Number of slots with 1 visit	9	13	12	7	8	20	+ 3%
Distances between families/slot	< 25 km	< 34 km	< 65 km	<= 20 km	<= 20 km	<= 20 km	
Number of families that were visited twice	3	1	4	15	13	15	+ 430%
Interval between visits (in days)	<= 11	5	<= 20	10 to 15	10 to 15	10 to 15	
Visits outside the availability of families	5	3	0	0	0	0	- 100%
Technicians not allocated to families	4	6	5	0	0	0	- 100%

Given this, it can be concluded that it is possible to schedule 43 more visits in January, 47 more in February and 41 more in March, in the solution obtained by the model, using only one car, satisfying 95.6% of the total visits in the 1st month, 94.1% in the 2nd month and 100% in the last month.

At most, there are only two visits per slot, instead of three, as happened in the real situation, so as not to overload the technicians with too many visits in the morning or afternoon. In total, there are no empty slots in the proposed solution. However, as seen earlier in the individual calendars per technician, each one is able to allocate it’s time to other tasks. There are more slots with two visits than with only one, but the fact that the visits in each slot are performed by the same technicians and that they are less than or equal to 20 km apart allows them to be made sequentially, without the technicians having to pass through the centre between them. In this way, time and fuel are saved. On the other hand, in the current situation, in January, the greatest distance between families that were visited in the same slot was 24.3 km, in February 33.3 km and in March 64.7 km.

The solutions proposed by the model ensured that in January and March 15 families would receive two visits each. In the actual situation, only 3 families in January and 4 families in March had two visits each, corresponding to 20% and 26.7% of the total. In February the model allowed for 13 families to be visited twice and in reality only one had. The interval between visits, in the proposed solution, was always between 10 and 15 days, which is the expected interval and, in the current situation, this interval varied, with the longest interval in January being 11 days, February 5 days and March 20 days. The visits being within the expected interval gives a certain regularity to the process.

In the current situation, although this did not happen in March, in January and February there were families that were visited outside their time window, whereas the model ensures that the visits are only carried out in that time slot. In this way, a change of schedule is avoided and families are always accompanied within their availability, so there is a certain routine. The model also ensures that families are accompanied only by the technicians assigned to them initially.

The last column concerns the average variation, of the three months, where it is possible to quantify the increase or decrease, in %, of the proposed solution in relation to the current situation, of 7 KPI's shown in Table 17. In fact, the largest increase is in the number of slots with 2 visits, logically because, as more visits are made, the slots are filled with more visits and the major reduction (of 100%) is in the number of empty slots, visits outside the family's available time and technicians that were not assigned to the family at the beginning of the process.

The KPI's related to the technicians, meaning the number of visits that each one participates in, is represented in the following graphs of Figure 13, comparing it in the two situations, for the three months.

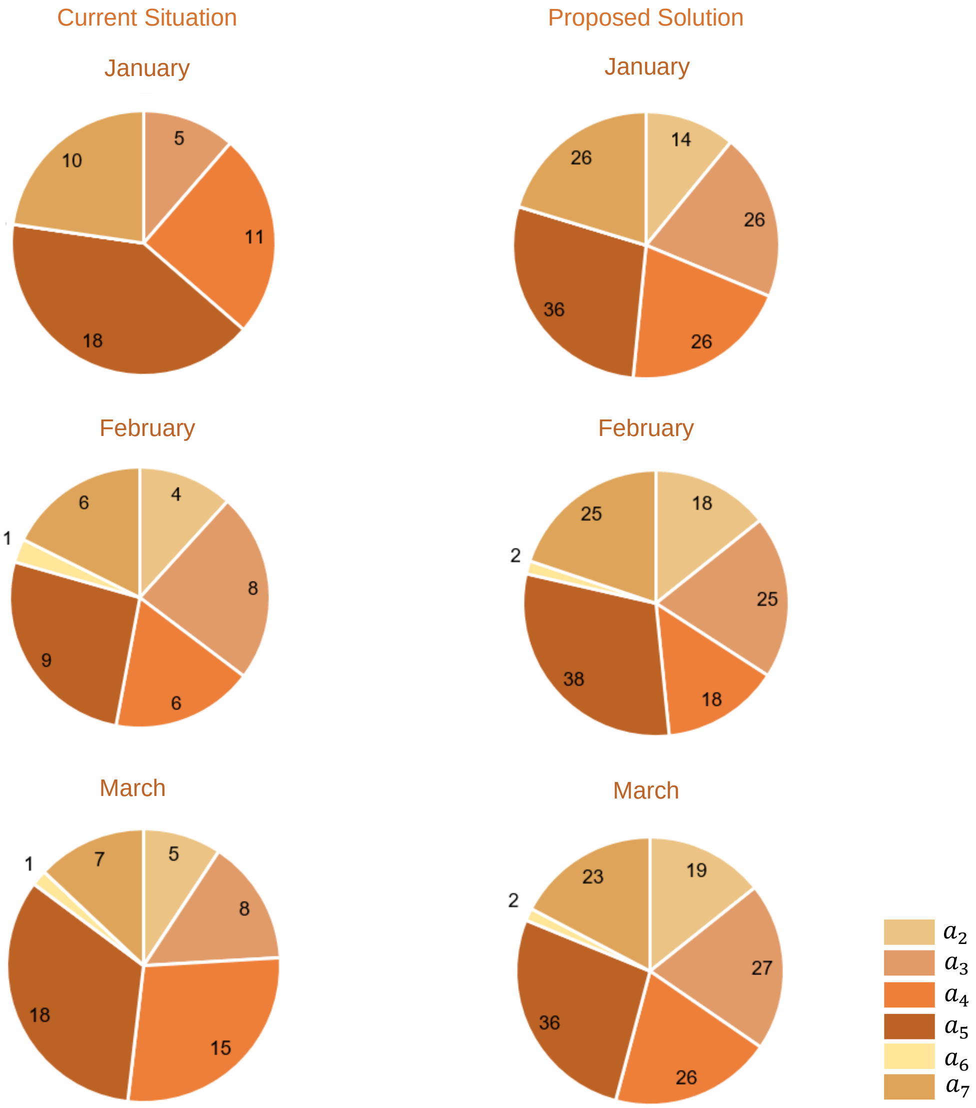


Figure 13. Comparison of the number of visits per technician

Although the number of visits that each technician participates is higher in the proposed solution, as there is a greater number of visits in total, the proportion is quite similar between the two, especially in February and March. It is noted that technicians a_3, a_4 and a_5 are in charge of more families. In January, in the current situation, technician a_5 was in charge of more than half of the 22 visits that took place, and technicians a_1, a_2 and a_6 did not participate in any visit. But according to the results obtained by the model, the workload seems better balanced, since technician a_2 carries out some visits.

Despite the fact that there are no empty slots in the proposed solution (global view), as evidenced by the individual calendars of each technician (Appendix 7), each one has enough available slots to allocate her time to tasks other than visits, such as studying new family cases that have recently entered the system, meetings to discuss and evaluate the cases currently in progress, journeys to the courts, absences due to personal reasons, among others. All this demands time from the technicians, so it is necessary to ensure that it exists.

6.3 Sensitivity Analysis

In this section, a sensitivity analysis was carried out on a parameter in order to quantify the effect that a variation in it causes on the total number of visits made. Notwithstanding, although most of the parameters were estimated based on assumptions but validated by the organisation, this parameter emerged in this dissertation and had never been taken into account by ComDignitatis' technicians, which is the maximum distance between visits in the same slot. Thus, the purpose of this analysis is to test the robustness of the model results when lowering the value of the maximum distance to 12 km.

With this change of parameter, the number of visits in January decreased to 59, two of the families who need to be visited twice, were visited only once and 4 families were not visited at all, so these families were obliged to be visited in February. In this month the total number of visits also decreased to 59 and four families also gained priority in the following month. The month of March, on the other hand, decreases only by one amount, to 67 visits in total, which means that the family that was not visited would gain priority in April over the others.

Figure 14 compares the values of the current situation, the solution provided by the model initially and the solution after decreasing the value of the maximum distance, for the three months.

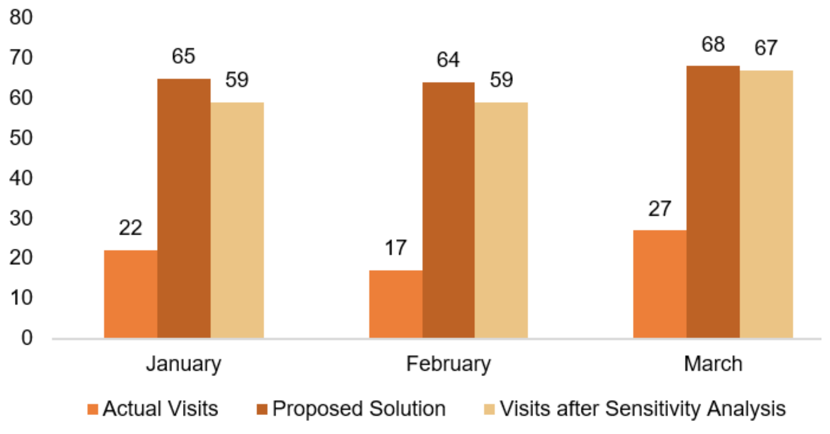


Figure 14. Comparison between the three types of results

As it is observed, January and February were the months that underwent more alterations, in terms of total number of visits, with this change in the parameter. The month of March does not seem to have been affected by this restriction. With only one car, in January and February it was possible to satisfy 86.8% of the total visits and in March, 98.5%.

Table 20 reveals how many empty slots, with only one visit or two visits, these three months would turn out to be with this restriction. The new calendars, for the three months, are in Appendix 6, 7 and 8.

Table 20. Organisation of visits over the three months after the sensitivity analysis

	January	February	March
Empty slots	0	0	0
Slots with 1 visit	13	13	21
Slots with 2 visits	23	23	23
Total number of slots	36	36	44

It can be seen that in January and February there was an increase in slots with only one visit and a decrease in slots with two visits, compared to the initial solution given by the model. As for March, there was only a decrease in the value of slots with two visits.

The workload of the technicians, i.e. the number of visits that each one takes part in, is shown in Table 21.

Table 21. Workload of each technician after the sensitivity analysis

	January	February	March
a_1	1	1	1
a_2	20	13	18
a_3	19	23	25
a_4	19	21	26
a_5	35	33	36
a_6	1	0	2
a_7	22	23	24

The proportion of visits by technicians is similar but some differences are found. It is worth noting that technician a_1 participates in all three months and in the initial solution she had not been allocated to a family. In January, although the total number of visits is smaller and logically, fewer visits per technician, technician a_2 and a_6, with this new restriction, would participate in more visits than before. Regarding February and March, there is no significant change.

Another difference in these new results was the number of families needing to be visited twice. In the initial solution, in January and March, the results ensured that the total number of families that are visited per month (15), are. In February, the results pointed to 13 families. After this sensitivity analysis, the months of January and February only guarantee that 13 families are visited twice.

Although the number of visits per month has decreased and it is not possible to guarantee that all the families that need two visits will have those (since they are families in a more delicate situation, so it is crucial to have them), it is still a better planning than the current one. Also because the restriction of distance, as said before, does not include the distance from the centre to the families, and sometimes, these distances can become long. Thus, if the distance between families is reduced, the total travel time, from leaving the centre to perform all the visits and then back to the centre, is reduced, saving even more time and fuel. In addition, having more slots with one visit, instead of two, allows the technicians to coordinate and manage their day even more, having more free time to dedicate to other tasks.

6.4 Chapter Conclusions

This chapter aimed to analyse and compare the current situation with the proposed solution provided by the model. In the current situation, it was assessed what was actually done in terms of visits, who made them and when. This information was checked in the weekly agendas provided by ComDignitatis. The results proposed by the model, which was developed in the GAMS software, indicated which families would be visited, according to what was expected to happen in terms of visits, by whom and when. Both results were compared in terms of the total number of visits, the way visits were distributed across slots, the technicians assigned to the processes, as well as their workload, the distances between families and the intervals between visits.

There is a considerable difference between the total number of visits that happened and the total number of visits expected, according to the model, in any month analysed. This is because, although the model has guaranteed, especially for March, the maximum number of visits, in reality not everything is that simple. There is a high probability of families cancelling visits at the last minute or even technicians cancelling them because they are detained in Court. There are numerous factors that make it difficult to achieve this number. However, the results of the model have been validated by the organisation and it is ensured that technicians do not have too many visits in a day, that there is a well-balanced distribution of work between them and that they have time to dedicate to other tasks. It also saves them time and fuel if they make two visits in a row which are no more than 20 km apart and are made by the same team.

After performing the sensitivity analysis on the parameter of maximum distance between visits of the same slot, the results varied more in the months of January and February and it was found that even if this distance was decreased to 12 km, the total number of visits is still much higher than the current one, ensuring that 86.8% of the total number of families are visited using only one car in January and February, and 98.5% in March.

7 Conclusions and Future Work

Unfortunately, the reality in Portugal is quite hard when it comes to children and young people in danger, who are increasingly seeking external help. ComDignitatis, a social organisation, through CAFAP (one of the social responses to be used in this type of situation), aims to provide support to families with children and young people at psychosocial risk, helping them to develop and strengthen family relationships and social skills for the future. However, the logistics of this service have certain challenges.

Currently, ComDignitatis accompanies 74 families, in 5 different municipalities, in the district of Lisbon, and there are 7 technicians available to perform the service, which consists in visiting the families at home or providing this service in the organisation's offices. These 74 families are divided into three modalities: Family Preservation (FP), Family Reunification (FR) and Family Reunification Point (FRP). The visits in the first two modalities are more flexible and are carried out at the families' home, while in the last one they are more rigid and are carried out in an office. In any of the modalities, a team of two technicians is always necessary to provide the service. The schedule of visits must be within the availability given by the family, which can vary from day to day, and of the technicians. Besides, they only have one car always available and the team leaves the centre, in Ericeira, to go and meet a family and, when they finish it, they normally return to the centre and only then leave on another visit. However, there have been exceptions and two visits have taken place sequentially. Having said this, the focus of this thesis is the 53 families (the FRP families were excluded, since their visits are usually fixed, therefore it is not so necessary to schedule them) and the main objective consists in developing a MILP model, which takes into account all the constraints that hinder this planning, so that at the end, in a time horizon of one month, it is possible to find out which families will be visited, by whom and when.

In order to understand what had already been done in this area, a literature review was done. Although no work on this specific topic has been published, there is another problem (HHCSRP) which is very similar to the case study due to its numerous constraints. Nevertheless, the major difference between the literature review and the case study is the fact that patients need several services during a week or even a day, so it is useful to develop a scheduling and routing model to determine the route of each professional. In the case study, the families need two visits at most, so it is only justified to model the scheduling and assignment problem, i.e., to determine which technicians are assigned to which families and when do they visit them.

Therefore, an assignment and scheduling model was developed and implemented in the GAMS software, which addresses the constraints of the case study. To simplify this model, each day of the planning horizon was divided into two slots (one in the morning and another in the afternoon). In order to be feasible from the routing point of view, families that are visited in the same slot cannot be more than 20 km away. The data that served as input to the model was provided by ComDignitatis, referring to the months of January, February, and March 2022.

Accordingly, the results provided by the model were analysed and compared with the current situation. It was found that with only one car, it was possible to triple the number of visits made, with 96% of the total visits in January, 94% in February and 100% in March, i.e. 68 visits that were expected to happen. In addition, there are at most only two visits in each slot and they are at a distance of less than 20 km, so the technicians are able to carry out these two visits sequentially without having to pass through the centre, saving time and fuel. It was also possible to analyse in more detail the workload of each technician, including the FRP visits, to understand if they have time to dedicate to other tasks that are very time consuming for them. And the conclusion was that they do. Even with the sensitivity analysis, whose objective was to understand the impact of decreasing the distance between families, although the total number of visits decreased slightly (as expected), they ensured that 87% of all families were visited in January and February and 99% in March.

Due to the simplifications of the model, there are features that were not taken into account in the model, and which makes it limiting, such as the fact of not having considered different skills between senior technicians and trainees, because two trainees cannot perform a visit alone and also the technicians not being the same for families who need two visits per month, because ideally they should be. Another limitation is present in the availability of the technicians. In a slot when they performed at least one FRP visit in it, their total availability was removed, which is not well in accordance with reality, because they can have one FRP visit and one or two more of another modality. Furthermore, the fact that the days are divided into two slots is limiting in the sense that it is not possible to detail the visits, i.e. it is only known whether the visit takes place in the morning or in the afternoon, not the exact time.

As a future work, these characteristics could be incorporated in the model and also include a restriction that guarantees that the technicians are different in both slots, so as not to overload them with 4 visits in a single day. Besides, all these features could be integrated in a model with four slots instead of two (splitting the morning and afternoon in two). With this new model, the visits would be more detailed and it would also be possible to define exactly the availability of the technicians. In addition, it could be interesting to study the allocation of technicians to each process. This allocation has to take into account the location of the families that are dispersed among the different municipalities, the processes that each technician already has (and those who have fewer processes could be in charge of the new families that enter the system), in order to be able to form the team responsible for that family, being that both technicians must also have availability to carry out the visits according to the possible schedule for the visit provided by the family and to make sure that they do not overlap with any FRP visit. It would also be useful for the organisation to have a simple tool, in Excel, in order to manage not only the planning of visits, i.e. which families will be visited in a given month, by whom and when, but also the rescheduling of visits that have been cancelled, either by the technicians or by the families, so that these families are not forgotten. All this would be done automatically to ensure greater efficiency in this planning.

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Appendices

Appendix 1 - Calendar with current visits in January

Monday	Tuesday	Wednesday	Thursday	Friday
3	4	5	6	7
$i_{30}: a_4 + a_7$	MEETING	$i_{21}: a_5 + a_7$	$i_{15}: a_4 + a_5$ $i_{13}: a_4 + a_5$	
~~$i_{36}: a_3 + a_4$~~	$i_{49}: a_5 + a_7$ ~~$i_{28}: a_3 + a_4$~~ ~~$i_{36}: a_3 + a_4$~~	$i_{23}: a_3 + a_7$	$i_{44}: a_4 + a_5$ $i_{12}: a_4 + a_5$	
10	11	12	13	14
	MEETING	$i_{31}: a_5 + a_7$	~~$i_{50}: a_5 + a_7$~~	$i_{44}: a_4 + a_5$
			$i_3: a_3 + a_5$ $i_6: a_3 + a_5$	
17	18	19	20	21
	MEETING	$i_{45}: a_5 + a_7$ $i_{49}: a_5 + a_7$	$i_{46}: a_4 + a_5$	
	$i_{29}: a_3 + a_4$	$i_5: a_5 + a_7$ $i_7: a_5 + a_7$	$i_{42}: a_4 + a_5$ $i_{20}: a_4 + a_5$ $i_{21}: a_4 + a_5$	
24	25	26	27	28
	MEETING			
~~$i_{49}: a_6 + a_7$~~		$i_{40}: a_3 + a_7$		

Appendix 2 - Calendar with current visits in February

Monday	Tuesday	Wednesday	Thursday	Friday
31	1	2	3	4
$i_{27}: a_3 + a_7$	MEETING	$i_{52}: a_3 + a_5$ $i_{32}: a_3 + a_5$	~~$i_{53}: a_5 + a_7$~~	$i_{47}: a_3 + a_5$
$i_{37}: a_5 + a_6$	$i_{26}: a_3 + a_4$		~~$i_1: a_5 + a_7$~~	
7	8	9	10	11
	MEETING	$i_{31}: a_5 + a_7$	$i_{39}: a_3 + a_4$	
$i_1: a_5 + a_7$	$i_{33}: a_2 + a_5$	$i_{45}: a_5 + a_7$	$i_{10}: a_2 + a_4$	
14	15	16	17	18
	MEETING	$i_{43}: a_3 + a_5$ $i_{31}: a_2 + a_7$	$i_{42}: a_2 + a_4$	
			$i_4: a_4 + a_7$ ~~$i_{29}: a_4 + a_7$~~	
21	22	23	24	25
	MEETING			$i_{46}: a_3 + a_4$

Appendix 3 - Calendar with the proposed solution in January

Monday	Tuesday	Wednesday	Thursday	Friday
3 $i_{51}: a_5 + a_7$ $i_{49}: a_5 + a_7$	4 MEETING	5 $i_3: a_3 + a_5$ $i_6: a_3 + a_5$	6 $i_{46}: a_4 + a_5$	7 $i_{32}: a_3 + a_5$
$i_{18}: a_2 + a_7$ $i_{31}: a_2 + a_7$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_4: a_4 + a_7$ $i_{30}: a_4 + a_7$	$i_{16}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_1: a_3 + a_7$ $i_{40}: a_3 + a_7$
10 $i_{44}: a_4 + a_5$	11 MEETING	12 $i_2: a_4 + a_5$ $i_{42}: a_4 + a_5$	13 $i_{27}: a_3 + a_7$ $i_{34}: a_3 + a_7$	14 $i_{41}: a_2 + a_7$
$i_{23}: a_3 + a_7$ $i_{48}: a_3 + a_7$	$i_{13}: a_3 + a_4$ $i_{39}: a_3 + a_4$	$i_9: a_3 + a_7$ $i_{17}: a_3 + a_7$	$i_{37}: a_2 + a_5$	$i_5: a_2 + a_7$ $i_{38}: a_2 + a_7$
17 $i_{43}: a_3 + a_5$ $i_{47}: a_3 + a_5$	18 MEETING	19 $i_{35}: a_2 + a_7$ $i_{51}: a_2 + a_7$	20 $i_{49}: a_5 + a_7$ $i_{51}: a_5 + a_7$	21 $i_{36}: a_3 + a_4$
$i_{29}: a_4 + a_7$	$i_{19}: a_2 + a_7$ $i_{31}: a_2 + a_7$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{26}: a_2 + a_4$ $i_{30}: a_2 + a_4$	$i_2: a_3 + a_5$ $i_{33}: a_3 + a_5$
24 $i_{32}: a_3 + a_5$ $i_{52}: a_3 + a_5$	25 MEETING	26 $i_8: a_5 + a_7$ $i_{45}: a_5 + a_7$	27 $i_{22}: a_4 + a_5$ $i_{42}: a_4 + a_5$	28 $i_{13}: a_3 + a_4$ $i_{28}: a_3 + a_4$
$i_{20}: a_4 + a_5$ $i_{46}: a_4 + a_5$	$i_{12}: a_4 + a_5$ $i_{15}: a_4 + a_5$	$i_{10}: a_2 + a_6$ $i_{14}: a_2 + a_6$	$i_{24}: a_4 + a_5$ $i_{44}: a_4 + a_5$	$i_{11}: a_3 + a_5$ $i_{25}: a_3 + a_5$

Appendix 4 - Calendar with the proposed solution in February

Monday	Tuesday	Wednesday	Thursday	Friday
31 $i_2: a_2 + a_5$ $i_{42}: a_2 + a_5$	1 MEETING	2 $i_{32}: a_3 + a_5$	3 $i_{49}: a_5 + a_7$ $i_{53}: a_5 + a_7$	4 $i_3: a_3 + a_5$ $i_{47}: a_3 + a_5$
$i_{18}: a_2 + a_3$	$i_{26}: a_2 + a_4$ $i_{30}: a_2 + a_4$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{31}: a_2 + a_7$	$i_{11}: a_3 + a_5$ $i_{33}: a_3 + a_5$
7 $i_{13}: a_3 + a_4$ $i_{28}: a_3 + a_4$	8 MEETING	9 $i_{10}: a_2 + a_6$ $i_{14}: a_2 + a_6$	10 $i_{22}: a_4 + a_5$	11 $i_{41}: a_2 + a_7$
$i_{20}: a_4 + a_5$ $i_{46}: a_4 + a_5$	$i_8: a_2 + a_5$ $i_{37}: a_2 + a_5$	$i_5: a_2 + a_7$ $i_{38}: a_2 + a_7$	$i_{23}: a_3 + a_7$ $i_{48}: a_3 + a_7$	$i_{17}: a_3 + a_7$ $i_{40}: a_3 + a_7$
14 $i_{35}: a_2 + a_7$ $i_{51}: a_2 + a_7$	15 MEETING	16 $i_7: a_5 + a_7$ $i_{12}: a_5 + a_7$	17 $i_2: a_4 + a_5$ $i_{42}: a_4 + a_5$	18 $i_{32}: a_3 + a_5$ $i_{52}: a_3 + a_5$
$i_9: a_3 + a_7$ $i_{27}: a_3 + a_7$	$i_{16}: a_3 + a_5$ $i_{25}: a_3 + a_5$	$i_4: a_4 + a_7$ $i_{30}: a_4 + a_7$	$i_{24}: a_4 + a_5$ $i_{44}: a_4 + a_5$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$
21 $i_{49}: a_5 + a_7$ $i_{53}: a_5 + a_7$	22 MEETING	23 $i_{13}: a_3 + a_4$ $i_{39}: a_3 + a_4$	24 $i_3: a_3 + a_5$ $i_6: a_3 + a_5$	25 $i_{15}: a_4 + a_5$
$i_{19}: a_2 + a_7$ $i_{31}: a_2 + a_7$	$i_{45}: a_5 + a_7$	$i_{32}: a_3 + a_5$ $i_{43}: a_3 + a_5$	$i_{37}: a_2 + a_5$	$i_1: a_3 + a_7$ $i_{34}: a_3 + a_7$

Appendix 5 - Individual calendars for each technician in March

a_2

Monday	Tuesday	Wednesday	Thursday	Friday
28	1	2	3	4
	HOLIDAY			
		PEF		
7	8	9	10	11
i_{42}	MEETING			i_{41}
i_{37}	i_{26} i_{30}	i_{19} i_{31}		
14	15	16	17	18
	MEETING	i_{14}		
		PEF		
21	22	23	24	25
	MEETING	i_2 i_{42}		
i_{21}	i_{37}	PEF	i_8 i_{31}	
28	29	30	31	1
i_{35} i_{51}	MEETING		i_7 i_{38}	
	PEF	PEF		i_1

a_3

Monday	Tuesday	Wednesday	Thursday	Friday
28	1	2	3	4
i_{32} i_{52}	HOLIDAY		i_{43} i_{47}	PEF
		i_9 i_{27}	i_{23} i_{48}	PEF PEF
7	8	9	10	11
	MEETING		i_{34}	
			i_{16} i_{33}	PEF PEF
14	15	16	17	18
i_3	MEETING			i_{36}
i_{13} i_{39}	i_{25}			i_{32}
21	22	23	24	25
	MEETING			
i_{18}				PEF PEF
28	29	30	31	1
	MEETING	i_3 i_6		i_{13} i_{28}
	i_{11} i_{33}	i_{17} i_{23}		i_1

a_4

Monday	Tuesday	Wednesday	Thursday	Friday
28	1 HOLIDAY	2 i_{46} i_{53}	3	4 i_{44}
i_{15} i_{24}			PEF	i_2 i_{22}
7 i_{42}	8 MEETING	9	10	11
PEF	i_{26} i_{30}			i_{21} i_{50}
14	15 MEETING	16	17 i_{46} i_{53}	18 i_{36}
i_{13} i_{39}	PEF			
21 i_{44}	22 MEETING	23	24	25 i_{20}
PEF				i_4 i_{30}
28	29 MEETING	30	31	1 i_{13} i_{28}
i_{21} i_{50}			i_{29}	

a_5

Monday	Tuesday	Wednesday	Thursday	Friday
28 i_{32} i_{52}	1 HOLIDAY	2 i_{46} i_{53}	3 i_{43} i_{47}	4 i_{44}
i_{15} i_{24}			PEF	i_2 i_{22}
7 PEF	8 MEETING	9 i_{49}	10	11
i_{37}			i_{16} i_{33}	i_{21} i_{50}
14 i_3	15 MEETING	16	17 i_{46} i_{53}	18
PEF	i_{25}	i_5	i_{10}	i_{32}
21 i_{44}	22 MEETING	23 i_2 i_{42}	24 i_{49}	25 i_{20}
PEF	i_{37}	i_{12} i_{45}		
28	29 MEETING	30 i_3 i_6	31	1
i_{21} i_{50}	i_{11} i_{33}			

a_6

Monday	Tuesday	Wednesday	Thursday	Friday
28 PEF PEF	1 HOLIDAY	2	3	4
PEF		PEF		
7	8 MEETING	9	10	11
14	15 MEETING	16 i_{14}	17	18 PEF PEF
	PEF	PEF	i_{10}	PEF
21	22 MEETING	23 PEF	24	25
PEF		PEF		PEF PEF
28	29 MEETING	30	31	1 PEF
PEF	PEF PEF	PEF		PEF PEF

a_7

Monday	Tuesday	Wednesday	Thursday	Friday
28 PEF PEF	1 HOLIDAY	2	3	4 PEF
PEF		i_9 i_{27}	i_{23} i_{48}	PEF PEF
7 PEF	8 MEETING	9 i_{49}	10 i_{34}	11 i_{41}
PEF		i_{19} i_{31}		PEF PEF
14	15 MEETING	16	17	18 PEF
PEF		i_5		PEF PEF
21	22 MEETING	23 PEF	24 i_{49}	25
PEF		i_{12} i_{42}	i_8 i_{31}	i_4 i_{30}
28 i_{35} i_{51}	29 MEETING	30	31 i_7 i_{38}	1 PEF
PEF	PEF	i_7 i_{23}	i_{29}	PEF PEF

Appendix 6 - Calendars after the sensitivity analysis in January

Monday	Tuesday	Wednesday	Thursday	Friday
3 $i_3: a_3 + a_5$ $i_6: a_3 + a_5$	4 MEETING	5 $i_{32}: a_2 + a_5$ $i_{52}: a_2 + a_5$	6 $i_{36}: a_3 + a_4$	7 $i_2: a_2 + a_4$ $i_{42}: a_2 + a_4$
$i_{30}: a_2 + a_7$ $i_{38}: a_2 + a_7$	$i_{16}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_{17}: a_3 + a_7$ $i_{27}: a_3 + a_7$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{11}: a_3 + a_5$ $i_{43}: a_3 + a_5$
10 $i_{46}: a_5 + a_7$ $i_{53}: a_5 + a_7$	11 MEETING	12 $i_7: a_5 + a_7$ $i_{12}: a_5 + a_7$	13 $i_{22}: a_4 + a_5$	14 $i_{46}: a_4 + a_5$
$i_{31}: a_2 + a_7$	$i_5: a_2 + a_5$ $i_{10}: a_2 + a_5$	$i_{37}: a_2 + a_5$	$i_{14}: a_2 + a_6$	$i_1: a_2 + a_7$ $i_{18}: a_2 + a_7$
17 $i_8: a_5 + a_7$ $i_{45}: a_5 + a_7$	18 MEETING	19 $i_3: a_3 + a_5$ $i_{47}: a_3 + a_5$	20 $i_{33}: a_3 + a_5$	21 $i_{13}: a_3 + a_4$
$i_9: a_3 + a_7$ $i_{34}: a_3 + a_7$	$i_{30}: a_4 + a_7$ $i_4: a_4 + a_7$	$i_{26}: a_2 + a_4$	$i_{44}: a_4 + a_5$	$i_{15}: a_4 + a_5$ $i_{24}: a_4 + a_5$
24 $i_2: a_2 + a_4$ $i_{42}: a_2 + a_4$	25 MEETING	26 $i_{35}: a_2 + a_7$ $i_{51}: a_2 + a_7$	27 $i_{46}: a_5 + a_7$	28 $i_{53}: a_4 + a_5$ $i_{20}: a_4 + a_5$
$i_{25}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{19}: a_1 + a_2$	$i_{23}: a_3 + a_7$ $i_{48}: a_3 + a_7$	$i_{37}: a_2 + a_5$

Appendix 7 - Calendars after the sensitivity analysis in February

Monday	Tuesday	Wednesday	Thursday	Friday
31 $i_{39}: a_3 + a_4$	1 MEETING	2 $i_{13}: a_3 + a_4$	3 $i_2: a_4 + a_5$ $i_{42}: a_4 + a_5$	4 $i_3: a_3 + a_5$ $i_{47}: a_3 + a_5$
$i_{19}: a_1 + a_2$	$i_{50}: a_4 + a_5$	$i_{20}: a_4 + a_5$ $i_{21}: a_4 + a_5$	$i_{30}: a_2 + a_7$ $i_{38}: a_2 + a_7$	$i_5: a_2 + a_5$ $i_{10}: a_2 + a_5$
7 $i_{32}: a_3 + a_5$ $i_{52}: a_3 + a_5$	8 MEETING	9 $i_{49}: a_5 + a_7$ $i_{53}: a_5 + a_7$	10 $i_7: a_5 + a_7$ $i_{12}: a_5 + a_7$	11 $i_{22}: a_4 + a_5$
$i_{25}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_{37}: a_2 + a_5$	$i_9: a_3 + a_7$ $i_{34}: a_3 + a_7$	$i_{23}: a_3 + a_7$ $i_{48}: a_3 + a_7$	$i_{17}: a_3 + a_7$ $i_{27}: a_3 + a_7$
14 $i_{35}: a_2 + a_7$ $i_{51}: a_2 + a_7$	15 MEETING	16 $i_{44}: a_4 + a_5$	17 $i_{13}: a_3 + a_4$	18 $i_2: a_2 + a_4$ $i_{42}: a_2 + a_4$
$i_{31}: a_2 + a_7$	$i_{40}: a_3 + a_7$	$i_{11}: a_3 + a_5$ $i_{43}: a_3 + a_5$	$i_{46}: a_4 + a_5$	$i_1: a_2 + a_3$ $i_{18}: a_2 + a_3$
21 $i_3: a_3 + a_5$ $i_6: a_3 + a_5$	22 MEETING	23 $i_{28}: a_3 + a_4$	24 $i_{49}: a_5 + a_7$ $i_{53}: a_5 + a_7$	25 $i_8: a_5 + a_7$ $i_{45}: a_5 + a_7$
$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{15}: a_4 + a_5$ $i_{24}: a_4 + a_5$	$i_4: a_4 + a_7$ $i_{30}: a_4 + a_7$	$i_{29}: a_4 + a_7$	$i_{16}: a_3 + a_5$ $i_{33}: a_3 + a_5$

Appendix 8 - Calendars after the sensitivity analysis in March

Monday	Tuesday	Wednesday	Thursday	Friday
28 $i_{36}: a_3 + a_4$	1 HOLIDAY	2 $i_7: a_5 + a_7$ $i_{12}: a_5 + a_7$	3 $i_{32}: a_3 + a_5$	4 $i_{44}: a_4 + a_5$
$i_3: a_3 + a_5$ $i_6: a_3 + a_5$		$i_{40}: a_3 + a_7$	$i_{31}: a_2 + a_7$	$i_{15}: a_4 + a_5$ $i_{24}: a_4 + a_5$
7 $i_{39}: a_3 + a_4$	8 MEETING	9 $i_{49}: a_5 + a_7$ $i_{53}: a_5 + a_7$	10 $i_2: a_2 + a_4$ $i_{42}: a_2 + a_4$	11 $i_{41}: a_2 + a_7$
$i_5: a_2 + a_5$ $i_{10}: a_2 + a_5$	$i_{29}: a_4 + a_7$	$i_{30}: a_2 + a_7$ $i_{38}: a_2 + a_7$	$i_{11}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$
14 $i_{46}: a_4 + a_5$	15 MEETING	16 $i_{13}: a_3 + a_4$	17 $i_3: a_3 + a_5$ $i_{47}: a_3 + a_5$	18 $i_{32}: a_3 + a_5$ $i_{52}: a_3 + a_5$
$i_{28}: a_3 + a_4$	$i_{25}: a_3 + a_5$ $i_{43}: a_3 + a_5$	$i_{23}: a_3 + a_7$ $i_{48}: a_3 + a_7$	$i_{37}: a_2 + a_5$	$i_1: a_2 + a_3$ $i_{18}: a_2 + a_3$
21 $i_{35}: a_2 + a_7$ $i_{51}: a_2 + a_7$	22 MEETING	23 $i_{44}: a_4 + a_5$	24 $i_{22}: a_4 + a_5$	25 $i_8: a_5 + a_7$ $i_{45}: a_5 + a_7$
$i_{19}: a_1 + a_6$	$i_{26}: a_2 + a_4$	$i_{31}: a_2 + a_7$	v $i_{49}: a_5 + a_7$	$i_4: a_4 + a_7$ $i_{30}: a_4 + a_7$
28 $i_{20}: a_4 + a_5$ $i_{53}: a_4 + a_5$	29 MEETING	30 $i_2: a_2 + a_4$ $i_{42}: a_2 + a_4$	31 $i_{14}: a_2 + a_6$	1 $i_{46}: a_4 + a_5$
$i_{21}: a_4 + a_5$ $i_{50}: a_4 + a_5$	$i_{16}: a_3 + a_5$ $i_{33}: a_3 + a_5$	$i_9: a_3 + a_7$ $i_{34}: a_3 + a_7$	$i_{17}: a_3 + a_7$ $i_{24}: a_3 + a_7$	$i_{13}: a_3 + a_4$