Improvement of the Operational Planning of a Social Solidarity 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 to 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 in January by 96%, 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.

1 Introduction

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.

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 paper, 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. Still, 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. Given this, the main goal of this paper is 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 (at their homes) by whom and when.

The rest of the paper is structured as follows. Section 2 will summarise the literature review on the Home Health Care Scheduling and Routing Problem (HHCRSP) whose characteristics closely resemble those of the case study. Section 3 will define the proposed model, considering the main characteristics of the problem under study as well as its mathematical formulation. The discussion and analysis of the results will be presented in Section 4. Conclusions, limitations, and future steps will be explained in Section 5.

2 Literature Review

Home Health Care (HHC) offer a range of care, such as medical, paramedical, and social services, to be provided in patients' homes rather than in hospitals (Di Mascolo et al., 2021).

HHCRSP is an extension of the HHC concept and distinctive characteristics are identified in these models depending on if it concerns the HHC organisation, the patient, or the care worker (Cissé et al., 2017).

2.1 Characteristics related to the organisation

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. Another important feature which is increasingly being included by various authors is continuity of care. 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). 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). Due to this uncertainty, 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.

2.2 Characteristics related to the patient

Patients can be visited 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 (Grenouilleau et al., 2020). 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). 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. Regarding uncertainty, 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).

2.3 Characteristics related to the care worker

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). Grenouilleau et al. (2020) defined a maximum weekly working limit, while Yang et al. (2021) has defined a daily maximum limit. 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. 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). 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 Vehicle Routing Problem. 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)).

2.4 Objective Functions

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. 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).

3 Problem and Model Formulation

The purpose of this section is to present the mathematical model that outlines the case of ComDignitatis. In section 3.1 the problem is defined, as well as the assumptions made to the model. In section 3.2, the mathematical formulation is described.

3.1 Problem Definition

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. Each family requires a specific number of visits per month and those who require more than one must respect the minimum and maximum intervals between them. Besides, the organisation only has 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.

As mentioned in the previous section, the features between the articles reviewed and this case study, are quite similar. Nevertheless, some modelling aspects differ, as there are few visits per day (as visits take a long time and families are dispersed throughout the intervention area), which does not justify outlining a route for each technician. Thus, this problem can be reduced to an assignment and scheduling problem.

To simplify the model, 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 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. 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 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.

Therefore, the planning period is one month and the aim is to maximise the number of visits within this time period for 53 families. The result of this planning indicates which visits will occur, by which technicians and when.

3.2 Mathematical Formulation

This subchapter aims to present the mathematical formulation of the single-objective MILP model and all the notation required for its implementation. The model was developed in GAMS software.

<u>Sets and Indexes</u>

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 ($t \in T$)

<u>Parameters</u>

$ATS_{i,s,t}$ 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

$maxdis$ Maximum distance between families

$BigM$ Large number

<u>Decision Variables</u>

$b_{i,s,t}$ 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

Objective Function

$$Max \sum_{i \in I} \sum_{s \in S} \sum_{t \in T} b_{i,s,t} - 0{,}01 \sum_{i \in I} \sum_{t \in T} p_{i,t} \qquad (1)$$

Constraints

$$x_{i,a,s,t} \leq NV_{i,a} \qquad (2)$$

$$(\sum_{a} x_{i,a,s,t}) * 0.5 = b_{i,s,t} \quad \forall i \in I, s \in S, t \in T \qquad (3)$$

$$\sum_{t \in T} \sum_{s \in S} b_{i,s,t} \leq g_i \quad \forall i \in I \qquad (4)$$

$$b_{i,s,t} \leq ATS_{i,s,t} \quad \forall i \in I, s \in S, t \in T \qquad (5)$$

$$y_{a,s,t} \leq ATA_{a,s,t} \quad \forall a \in A, s \in S, t \in T \qquad (6)$$

$$\sum_{i \in I} b_{i,s,t} \leq 2 \quad \forall s \in S, t \in T \qquad (7)$$

$$\sum_{i \in I} x_{i,a,s,t} \leq 2 * y_{a,s,t} \quad \forall a \in A, s \in S, t \in T \qquad (8)$$

$$\sum_{a \in A} y_{a,s,t} \leq 2 \quad \forall s \in S, t \in T \qquad (9)$$

$$\sum_{tt=t}^{tt=t+Tmin_i} b_{i,s,tt} \leq 1 \quad \forall i \in I, t \in T - Tmin_i \qquad (10)$$

$$\sum_{t=tt}^{tt=t+Tmax_i} b_{i,s,t} + p_{i,t} \geq 1 \quad \forall i \in I, t \in T - Tmax_i \qquad (11)$$

$$-BigM * (2 - b_{i,s,t} - b_{j,s,t}) + d_{i,j} \leq maxdist \qquad (12)$$

$$\sum_{s \in S} \sum_{t \in T} b_{i,s,t} = 1 \quad \forall f(i) \in I \qquad (13)$$

$$b_{i,s,t} \in \{0,1\} \quad \forall i \in I, s \in S, t \in T \qquad (14)$$

$$x_{i,a,s,t} \in \{0,1\} \quad \forall i \in I, a \in A, s \in S, t \in T \qquad (15)$$

$$y_{a,s,t} \in \{0,1\} \quad \forall a \in A, s \in S, t \in T \qquad (16)$$

$$p_{i,t} \in \{0,1\} \quad \forall i \in I, t \in T \qquad (17)$$

The objective function is the maximisation of the number of visits undertaken, given by equation (1), and if there are visits that are not fulfilled, they are penalised. Equations (2) to (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 Results and Discussion

This section compares the current situation (what happened in reality in terms of visits) and the results obtained by the model (what was expected to happen). The data that served as input to the model refers to the months of January, February, and March 2022. Due to data confidentiality, technicians are represented by codes.

As mentioned in the previous section, the days were divided by slots, so the visits occur either in the morning or in the afternoon. Table 1 compares the two situations.

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. In the current situation, there were 22 visits in January, 17 in February and 27 in March. On the other hand, the results provided by the model guarantee 65 visits in January, 64 in February and 68 in March, which corresponds to the expected total number of visits per month. Therefore, it is possible to schedule 43 more visits in the 1st month (satisfying 95.6% of the total visits), 47 more in the 2nd month (94.1%) and 41 more in the 3rd (100%), with only one car.

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. Yet, each technician has enough free time to devote 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 (15). In February the model allowed for 13 families to be visited twice and in reality only one had. The interval between visits, for families who need to be visited twice a month, 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 1. 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 1, comparing it in the two situations, for the three months.

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, each technician has enough available slots to allocate her time to tasks other than visits (even with FRP visits included), 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.

Table 1. Comparison of results

KPI´s	Current Situation January	Current Situation February	Current Situation March	Proposed Solution January	Proposed Solution February	Proposed Solution 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%

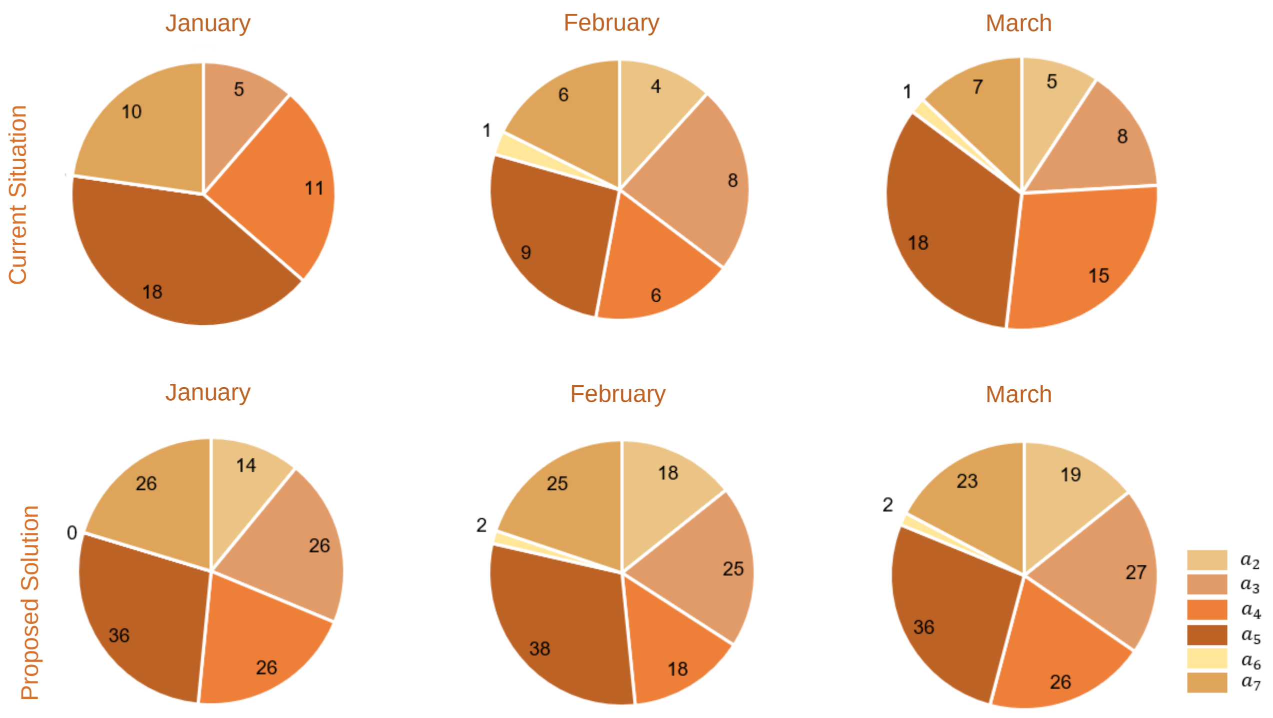

Figure 1. Comparison of the number of visits per technician

5 Conclusions

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, 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. Therefore, an assignment and scheduling model was developed and implemented in the GAMS software, which addresses the constraints of the case study.

The results suggest that with just one car, it is 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.

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). 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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