MODELING AND ANALYSIS OF A HOME CARE ROUTING PROBLEM

by

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A HOME CARE ROUTING PROBLEM

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Abstract

This thesis proposes the Home Care Routing Problem with Time Windows (HCRPTW) which is an extension to the well-known Vehicle Routing Problem with Time Windows (VRPTW). Different than VRPTW, we solve the routing problem of the health care personnel of a Home Health Care (HHC) service provider when the patients require different types of services. In this problem, the patients may request different types of care which can be provided by two types of personnel: nurses and health care aides. Each patient must be visited exactly once even if her servicing requires both personnel and is associated with a strict time window during which the service must be provided. In order to solve this problem, we present the 0-1 mixed integer programming formulation of the problem. The problem can be modeled with three different objective functions which are to minimize the total distance travelled, to minimize the total number of personnel and to minimize the total number of vehicles. We randomly generate a set of instances based on Solomon's benchmark problems for the VRPTW and solve them using IBM ILOG CPLEX. We also study Crew Constrained Home Care Routing Problem with Time Windows (CC-HCRPTW) which is another extension of HCRPTW where the number of each type of personnel is limited.

EVDE BAKIM ROTALAMA PROBLEMİNİN MODELLENMESİ VE ANALİZİ

Başak Tozlu

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Anahtar Kelimeler: Evde Bakım; Sağlık Hizmetleri; Evde Sağlık Hizmetleri; Rotalama; Zaman Pencereli Araç Rotalaması Problemi

Özet

Bu tez, çokça bilinen Zaman Pencereli Araç Rotalama Problemi (ZARP)'nin genişletilmiş bir biçimi olan Evde Bakım Rotalama Problemi (EBRP)'ni sunmaktadır. ZARP'den farklı olarak biz, hastaların farklı tipte hizmetlere ihtiyaçları olduğu durumlar için Evde Sağlık Hizmetleri (ESH) sunan bir kurumun sağlık hizmetleri personelinin rotalanması problemini çözdük. Bu problemde hastalar, iki tip personel, hemşire ya da hastabakıcı, tarafından sağlanabilen farklı tipte hizmetleri talep edebilirler. Hastanın ihtiyacı her iki personeli gerektirse bile, her hasta günde kesinlikle bir kere ve hizmetin verilmesi gereken kendisi için belirlenmiş sıkı zaman pencereleri içinde ziyaret edilmelidir. Bu problemi çözmek için, problemin 0-1 karma tamsayılı programlama modelini sunduk. Bu problem üç farklı amaç fonksiyonu ile modellenebilir; ki bunlar toplam uzaklığı enazlamak, toplam personel sayısını enazlamak ve toplam araç sayısını enazlamaktır. Solomon'un ZARP referans problemlerini baz alarak rastgele örnek problemler ürettik ve bunları IBM ILOG CPLEX ile çözdük. Aynı zamanda ZARP'ın genişletilmiş bir başka biçimi olan, her tip personel sayısının kısıtlı olduğu Personel Kısıtlı Evde Bakım Rotalama Problemi (PK-EBRP) üzerine de çalıştık.

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Chapter 1

INTRODUCTION

Home Health Care (HHC) covers a wide range of services that are provided at the homes of the patients as an alternative to the traditional hospitalization. HHC mainly addresses the needs of the patients who are over aged, who have disabilities or who have chronic diseases. The main purpose of HHC is providing medical, paramedical and social services to the at-home patients in order to assist them to hold on to their best medical, psychological and social conditions. HHC includes services such as nursing, medical visits, home life aids, psychological support, old people assistance, house cleaning etc. The HHC services are usually less expensive, more convenient and as effective as the care that is in a medical care institution. The demand for HHC services is growing rapidly due to the congestion of hospitals, ageing of populations, increase in the number of people who have chronical diseases and economic factors (Shepperd & Iliffe, 2005). Therefore, effective planning of HHC operations has become very important for the governments and private organizations providing such services. The efficient planning helps us to reduce the number of patients in the medical care institutions, to keep track of the medical records of the patients regularly, to improve the quality of care, and to minimize the costs of health care services (Chahed, Matta, Sahin, & Dallery, 2006). There are many papers that are concerned with the HHC and its advantages (see e.g. (Van den Berg & Wolter HJ, 2008)). There are a number of studies related to staff planning, scheduling and routing for HHC operations such as the study of Cappanera and Scutella (2014) and the study of Mankowska et al. (2014).

Each of these papers tackles a variation of the problem with different properties and assumptions.

This thesis deals with the vehicle routing problem of the HHC personnel where different types of care are provided to patients within specific time windows. We refer to this problem as the Home Care Routing Problem with Time Windows (HCRPTW). This problem is motivated by a real life case of a company that provides such services to a district municipality in Istanbul. This company routes nurses and home health aides (we will refer to as aides in the remainder of this thesis) in vehicles that carry at most two people excluding the driver from a central office on a daily basis. It can be argued that it would be more efficient if one of the home care crew could drive the car. Yet this is not feasible in a city like Istanbul where parking is a huge problem and the driver needs to stay in the car while the personnel give their service. It is the policy of the company that each patient is visited exactly once in a day. The patients to be visited in any day are finalized in the evening of the previous day.

The current practice of the company is to have one nurse and one aide in each vehicle, in spite of the fact that some patients do not need both a nurse and an aide. In fact, the services to be provided to the patients can be categorized in two major groups. The first group includes the services such as nursing, vaccination, blood sugar measurement, blood pressure measurement, etc. These services are provided by a nurse. The second group includes old people assistance, home life aids, bathing, etc. These are provided by an aide. On the other hand, some of the patients are in need of both of these services; hence, they should be serviced by a nurse and an aide. It is also possible that the service that a patient requires must be provided by two people simultaneously, e.g. the patient cannot move but needs a bath.

The patients may require any type of service depending on their health conditions. It is possible that a vehicle carries just a nurse or just an aide and utilizes the resources more effectively. If a vehicle carries both a nurse and an aide, it can satisfy the requirements of any patient whereas a vehicle carrying either a nurse or an aide can satisfy the requirements of certain patients depending on their needs. In the vehicle routing literature, customers requiring different types of services is also applicable in the technician routing problem where technicians with different types of skill levels are considered.

In this thesis, we introduce and study the problem of minimizing the costs while satisfying the particular needs of the patients in the required time windows. We have three main sources of costs that provide us three different objective functions to work on. The first objective is to minimize the total distance travelled by the vehicles. The second is to minimize the total number of personnel employed. And the third objective is to minimize the total number vehicles used. Obviously, the total number of personnel is at most twice the total number of vehicles but in general minimizing one does not necessarily imply minimizing the other. We have worked on the problem with these three objectives separately. To the best of our knowledge, this particular vehicle routing problem (VRP) variant which has the property of routing two personnel in one vehicle has not been studied in the literature. In this thesis, we also introduce the Crew Constrained Home Care Routing Problem with Time Windows (CC-HCRPTW) which is a variant of HCRPTW with additional constraints. In CC-HCRPTW, the number of each type of personnel is limited. In this case, a reasonable objective is to minimize the total distance travelled.

The remainder of the thesis is organized as follows: Chapter 2 reviews the related literature. Chapter 3 describes the problem and presents the mathematical programming formulation. The computational study is provided in Chapter 4. Finally, Chapter 5 concludes the thesis with some remarks and directions for future research.

Chapter 2

LITERATURE REVIEW

There is a vast amount of research related to the Vehicle Routing Problem with Time-Windows (VRPTW) and its variants but the literature on HCC routing is rather scant. Cappanera and Scutella (2014) propose an integrated approach that jointly addresses: (i) the compatibility of the skills, (ii) not violating the time windows, and (iii) the determination of the routes daily. By introducing a concept called *pattern*, which specifies possible schedule for skilled visits, the assignment, scheduling and routing decisions are jointly addressed. The objective proposed in this model is mainly related to the operator utilization.

Kergosien et al. (2009) formulated the routing problem of the HHC workers as a Multiple Travelling Salesman Problem with Time Windows (MTSPTW). The objective is to minimize the total travelling cost while not violating the time windows constraints, and synchronized (some cares requires more than one worker) and disjunctive (come workers cannot work at the same time) services constraints. The model is tested by solving randomly generated instances using a commercial solver. In the problem presented in this thesis, one or more workers with different skills may be assigned to each route. If a crew of workers covering all skills can be assigned to each vehicle, the problem becomes MTSPTW as shown in the work of in Kergosien et al. (2009).

In the work of Begur et al. (1997), not only the scheduling and routing of home health care nursing is studied, but also a spatial decision support system is developed. Taking unavailabilities constraints into account, they have built a heuristic that combines some procedures for constructing the daily routes of care providers. The objective is to minimize the total time of travelling while respecting the constraints of the route construction, time windows and skills requirements. Eveborn et al. (2006) minimized the travel time and the waiting time of the patients for an application in Sweden. The problem is solved by using a set partitioning model with two types of variables (some for assigning a staff member to a schedule and some for to a visit with a vehicle) and for finding a solution a matching approach is used. A decision support system called LAPS CARE, which eliminates the manual planning of assignments, is developed. In the paper of Eveborn et al. (2009), the authors discussed the experiences and the results from LAPS Care and from two governmental organizations. They have stated that operational efficiency and the quality of home care for elderly people have been improved. Other studies on intelligent home care of the elderly

Cheng and Rich (1998) have worked on a daily scheduling problem and developed a multi-depot vehicle routing problem with time windows and the compatibility information. They have studied the problem of routing home health care staff by taking two types of nursing, part time and full time, with different costs respectively into consideration. A mixed integer program is introduced as well as a basic heuristic considering the lunch breaks and the maximum nurse shift length with the objective of minimizing the total cost while visiting each patient exactly once, assigning each nurse at least one patient and starting and ending at his/her home. The proposed heuristic has two phases, where the first phase builds the tours and the second phase attempts to make improvements on those.

In the paper of Rasmussen et al. (2012), a daily scheduling problem is addressed as a multi-depot vehicle routing problem with time windows. In their model, there are connections between visits and a multi-criteria objective. Bredström and Rönnqvist (2007) have proposed a very similar formulation with a difference: a visit is allowed to be uncovered. Thus, one part which has a higher priority than the other parts of their multi-criteria objective is minimization of uncovered visits. In this paper, they have developed a branch-and-price algorithm to solve the model without including any precedence constraints whereas they have later developed a mathematical model that incorporates synchronization and precedence constraints (Bredström & Rönnqvist. 2008).

Bertels and Fahle (2006) present a problem with nurses having different skills and a heuristic to solve it. Here, the objective is to minimize a weighted sum of the total travel time, while maximizing the satisfaction of patients, plus a sum of several penalties like the violation of patients' preferences or of time windows. The developed heuristic consists of two phases: (i) building a set of patients to be served by each nurse and (ii) finding an optimal sequence for each set of patients. Different than our problem, the violation of patients' preferences and of time windows are allowed in this paper so there are both soft and hard constraints included in the formulation. In the paper of Allaoua et al. (2013), a similar problem is considered where different types of services are required by the patients. But different than our problem, the services can be provided separately at different times of the day. In the problem presented in this thesis, it is a must to visit the patients once a day. So even though a patient needs two types of care, two types of personnel are assigned to visit him/her at the same time, thus with the same vehicle. In the work of Thomsen (2006), a daily scheduling problem is addressed as a VRP with time windows and shared visits. The objective is to minimize the total travelling cost and the number of visits. The constraints include satisfying the time windows, serving all of the patients and starting and ending a shared visit of two service providers at the same time.

Bachouch et al. (2008) proposed the VRPTW as a mixed integer linear programming model with the objective of minimizing the total distance travelled. The defined constraints are related to time windows, meal breaks, care continuity, and the restriction on the workers' maximum travel limit. Another paper respecting care continuity is the work of Elbenani (2008). In this paper, a model for determining routes for operators with the objective to minimize the total distance travelled by the operators. Additionally, for each patient and each nurse, an assignment to a region policy is applied in this work. A nurse is also allowed to visit a different region but with a certain penalty.

The main problem is a problem of not routing but allocating resources within a given budget in the paper of De Angelis (1998). A linear program model is developed with the objective to maximize the number of patients delivered. The same problem is addressed in other sectors as well. Another linear program model is formulated by Borsani et al. (2006) in order to address the human resource short term planning. This model tries to satisfy each patient on time.

The problem of vehicle routing and staff rostering aspects in home health care is studied and solved by Fahle (2001).

Our problem has a resemblance with technician routing problem where technicians with different skill levels are considered (see e.g. (Kovacs, Parragh, Doerner, & Hartl, 2012)). Yet a typical assumption in technician routing problem is that a technician with a certain skill level can be assigned to any task that requires lower skill levels. In our problem, we have two types of personnel that perform different types of tasks. Thus our problem has some flavors of the VRPTW and the Technician Routing Problem. The crew constrained version of our problem can be considered within the context of the Resource Constrained Vehicle Routing Problem introduced by Paraskevopoulos et al. (2005). This problem is more general in many aspects but the time window constraints are not included.

Torres-Ramors et al. (2014) has conducted one of the recent studies on Home Health Care Routing and Scheduling Problem. They have integrated Nurse Rostering Problem (NRP) and VRP. They have presented a mixed integer programming model for not only planning the schedules of the health care personnel, but also for routing them to the patients while considering time windows, workload and attention capacity constraints. Their objective considered not only the costs but also the quality. Like our problem, they have considered the skills of the personnel and coverage of the different cares of the patients.

Another recent study by Braekers et al. (2015) proposes a metaheuristic to solve the home care routing and scheduling problem while embracing a multi-objective approach. They have concentrated on the trade-off relationship between two objectives which are to minimize the operating costs and to maximize the service level by taking the preferences of the patients into consideration. The metaheuristic algorithm they have proposed is a variation of large neighborhood search heuristic in a multi-directional local search framework.

For more details about different versions of the VRP, please refer to the book of Toth and Vigo (2002). The solution algorithms for VRP were firstly proposed by Solomon (1987), but developed drastically since then. A taxonomic review of the VRP is provided in the paper of Eksioglu et al. (2009) and a general review on human resources scheduling and routing can be found in the paper of Yalçındağ et al. (2011). A short review of the heuristics and metaheuristics developed in order to address home care routing and scheduling problems can also be found on the work of Braekers et al. (2015).

Chapter 3

PROBLEM DESCRIPTION AND FORMULATION

In this chapter, we first describe the HCRPTW and then provide its 0-1 mixed-integer linear programming model.

3.1 Problem Definition

We are given a set of patients and a central office. The patients are classified as type 1, type 2 or type 3, where type 1 patients need a nurse, type 2 patients need an aide, and type 3 patients need both. The service time for a patient depends of the type of the patient. Each patient is assigned a time window that describes the earliest and latest time to start the service for that patient. The time window constraint is not only due to better quality of service but because some tasks like injection or blood taking must be performed at a certain time of the day. A vehicle is referred to as type 1, type 2 or type 3, if it carries a nurse, a home health care aide, or both, respectively. As mentioned before, a type 3 vehicle can serve all patients where as a type 1 (2) vehicle can only serve type 1 (2) patients. Each vehicle starts its tour at the central office, serves a set of patients, and returns to the central office before the shift ends. In the CC-HCRPTW version of the problem, we assume that the numbers of nurses and aides available are limited. In this respect, we have two types of resources that are both limited.

The goal is to determine the type of vehicles and route the vehicles such that each patient receives the service she requires within her time window. For the HCRPTW formulation, we set three different objective functions. One of them is to minimize the total distance travelled, another one of them is to minimize the total number of personnel and the last one of them is to minimize the total number of vehicles used. For the CC-HCRPTW formulation, we use the distance minimization objective.

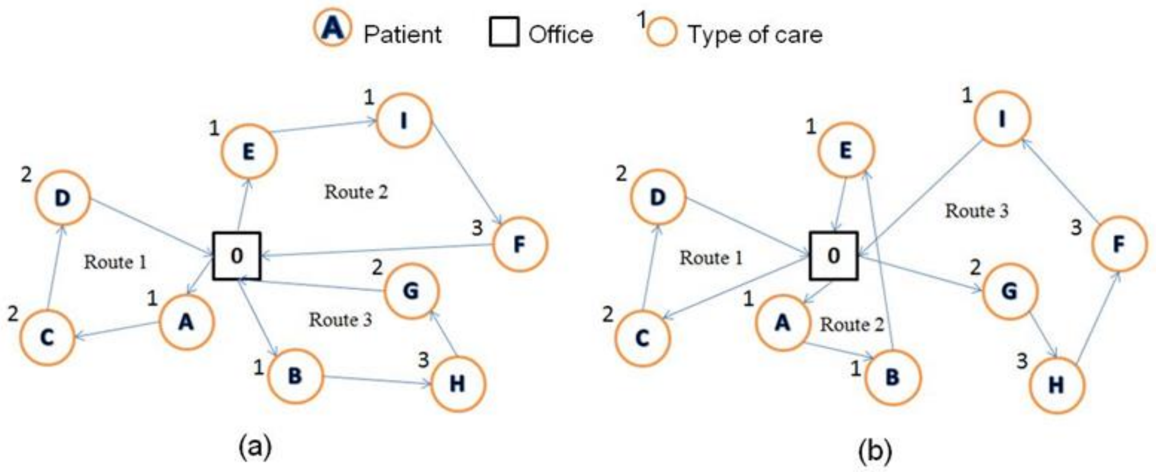

Figure 3.1: An example of HCRPTW

Figure 3.1 illustrates the problem on an example. The solution in Figure 3.1(a) utilizes three vehicles, each carrying both a nurse and an aid since each vehicle visits either a type 3 patient or at least one type 1 and one type 2 patients. So, three nurses and three aides are required in total. In Figure 3.1(b), the same service can be provided with again three vehicles but less number of personnel. An aide is assigned to Route 1 (Route 2) as all the patients are type 2 (type 1) patients. A nurse and an aide are assigned to Route 3 since that vehicle serves all type of patients. So, the patients are served by two nurses and two aides in this solution, saving two personnel compared to the solution depicted in Figure 3.1(b).

3.2 Mathematical Formulation

The set of patients is denoted by $V = \{1. \dots . N\}$. Vertices 0 and $N + 1$ denote the depot and every route starts at 0 and ends at $N + 1$. The sets including the depot are denoted as $V_0 = V \cup \{0\}$ and $V_{N+1} = V \cup \{N + 1\}$. The set containing all of the nodes is denoted as $V_{0.N+1} = V \cup \{0\} \cup \{N + 1\}$. Thus, the complete directed graph of this problem is denoted as $G = (V_{0.N+1}. A)$ with the set of arcs $A = \{(i.j) |\ i.j \in V_{0.N+1}. i \neq j\}$. Each arc is associated with distance d_{ij} and travel time t_{ij}. Each patient $i \in V$ is of type r_i, where $r_i \in \{1.2.3\}$ has a service time s_i and time window $[e_i. l_i]$. The time window states that the earliest time to start the care of patient i is e_i and the latest time to start the care of patient i is l_i. The start time of service from depot and the latest time to arrive the depot at the end of the services are denoted with time window $[e_0. l_o]$. The set of patients of type r is denoted as n_r and $n_{r.0} = n_r \cup \{0\}$. If a nurse (aide) is assigned to a vehicle, it is called a type 1 (type 2) vehicle. If a nurse and an aid are both assigned to a vehicle, it is called a type 3 vehicle. The binary decision variable x_{ijr} takes value of 1 if arc $(i.j)$ is traversed by a vehicle of type r, and 0 otherwise. The decision variable q_i keeps track of the arrival time to the vertex i.

$$\min \sum_{i \in V_{0,N+1}} \sum_{j \epsilon V_{N+1}, j \neq i} \sum_{r \epsilon R} d_{ij} x_{ijr} \tag{1}$$

s.t.

$$\sum_{i \in V_0, i \neq j} x_{ij1} + \sum_{i \in V_0, i \neq j} x_{ij3} = 1, \forall j \in n_{10} \tag{2}$$

$$\sum_{i \in V_0, i \neq j} x_{ij2} + \sum_{i \in V_0, i \neq j} x_{ij3} = 1, \forall j \in n_{20} \tag{3}$$

$$\sum_{i \in V_0, i \neq j} x_{ij3} = 1\,, \forall j \in n_{30} \tag{4}$$

$$\sum_{i \in V_0, i \neq j} x_{ijr} = \sum_{i \in V_{N+1}, i \neq j} x_{jir}\,, \forall j \in V, \forall r \in R \tag{5}$$

$$q_i + x_{ijr}\left(t_{ij} + s_i\right) - L\left(1 - x_{ijr}\right) \leq q_j, \forall i \in V_0, \forall j \in V_{N+1}, j \neq i, \forall r \in R \tag{6}$$

$$e_j \leq q_j \leq l_j, \forall j \in V_{0,N+1} \tag{7}$$

$$x_{ijr} \in \{0,1\}, \forall i \in V_0, \forall j \in V_{N+1}, j \neq i, \forall r \in R \tag{8}$$

$$q_i \geq 0, \forall i \in V_{0,N+1} \tag{9}$$

The objective function (1) minimizes the total distance travelled. Constraints (2)-(4) make sure that the care is provided to the patient exactly once by a vehicle that has the appropriate personnel. Type 1 care is provided by a vehicle of type 1 or type 3 in Constraints (2) whereas type 2 care is provided by a vehicle of type 2 or type 3 in Constraints (3). Constraints (4) ensure that type 3 care is given by only a vehicle of type 3. Constraints (5) enforce that the number of outgoing arcs equals to the number of incoming arcs at each vertex other than the depot. Constraints (6) ensure the time feasibility of the arcs leaving the patients and the depot. Constraints (7) enforce the time windows of the patients and the depot. Constraints (6) and (7) eliminate the sub-tours by maintaining the schedule feasibility with respect to time considerations. Constraints (8) define the binary decision variables. Finally, Constraints (9) are the non-negativity restrictions of the decision variables.

The model can be easily modified to handle other relevant objective functions. If the objective function was to minimize the total number of health care personnel, (1) would have been replaced with (10). If the objective function was to minimize the total number of vehicles, (1) would have been replaced with (11).

$$\min \sum_{j \in V_{N+1}} (x_{0j1} + x_{0j2} + 2x_{0j3}) \tag{10}$$

$$\min \sum_{j \in V_{N+1}} \sum_{r \in R} x_{0jr} \tag{11}$$

In this paper, we also introduce the Crew Constrained Home Care Routing Problem with Time Windows (CC-HCRPTW). In order to propose the mathematical formulation of the CC-HCRPTW, we define the available number of nurses and aides as h_1 and h_2, respectively, and refer them as the personnel (resource) constraints. In order to complete the mathematical formulation, in addition to the constraints (2)-(9) we add the constraints (12) and (13). These constraints make sure that the crew assigned to the vehicles does not exceed the available number of nurses and aids, respectively. In this case, we consider the objective function as minimizing the total distance travelled. This makes sense in the following scenario; the vehicles are provided by another company and the cost is by the total distance travelled.

$$\sum_{j \in V_{N+1}} x_{0j1} + \sum_{j \in V_{N+1}} x_{0j3} \leq h_1 \tag{12}$$

$$\sum_{j \in V_{N+1}} x_{0j2} + \sum_{j \in V_{N+1}} x_{0j3} \leq h_2 \tag{13}$$

Chapter 4

COMPUTATIONAL STUDY

4.1. Experimental Design

To solve our HCRPTW problem, we used a selection of 25-node and 50-node Solomon instances that we can solve using CPLEX and adapted them to our problem. We chose two instances of each problem class (C1, C2, R1, R2, RC1, and RC2), namely C101, C106, C207, C208, R103, R108, R201, R210, RC101, RC105, RC201, and RC205. We used the same coordinates and time windows, and ignored the demands. In order to use this data in our problem, we needed to assign each customer a type and corresponding service time. For each instance, we randomly generated new data in three different groups with the following three care types:

(i) the patients are equally likely to be of each of the three types (33.3% for each type)
(ii) the probability of a patient being type 1 or type 2 is 40% percent and type 3 is 20%
(iii) the probability of a patient being type 1 is 60%, and type 2 or type 3 is 20%

We refer to these categories as G1, G2 and G3, respectively. We generated two instances of each setting, thus twelve instances for each Solomon problem and a total of 72 instances for 25-node instances. In the same manner, we generated a total of 72 instances for 50-node instances. The service times of the instances are set as 10 minutes for care of type 1, 40 minutes for care of type 2, and 45 minutes for care of type 3.

We also had to determine the number of nurses and aides for each instance for CC-HCRPTW. This is not a straightforward task because if we set the crew constraints too tight we may end up with infeasible problem instances. On the other hand, if these constraints are too loose, the instances may no longer become challenging examples.

In order to determine meaningful crew sizes, we solved the CC-HCRPTW problems using CPLEX with two different objective functions by relaxing the crew constraints (12) and (13). We first solved the model to minimize the total distance, which provided us a guideline to find the number of nurses and aides. Intuitively (but not theoretically), these serve as “upper bounds” for our crew sizes h_1 and h_2. This is because in a typical instance (not always), minimizing total distance and minimizing total personnel are conflicting objectives. In the same manner, we also solved the model which minimizes the total number of crew without the crew constraints and obtained “lower bounds” for our crew sizes. Then, we determine four different crew settings for each instance following these lower and upper bounds for the nurses and aids. In the first, we set the crew sizes h_1 and h_2 equal to the optimal number of vehicles achieved when total distance traveled is minimized. In the second, both h_1 and h_2 are set equal to the average of the number of nurses and aides needed (rounded up to integer) when the objective function is to minimize the total number of crew. We refer to these two data types with loose and tight crew constraints L and T, respectively. For the third and fourth settings, each of h_1 and h_2 is determined between the two values set above. These provide medium tight (or medium loose) crew constraints and we refer to this instances as M1 and M2 types. The total number of problem instances $72 \times 4 = 288$; however, we omitted two instances which have loose and tight crew constraints equal to each other thus provide us no medium tight crew constraints. In the end, we obtained 280 test instances.

4.2. Results

We solved all of the instances using CPLEX by setting the run time limit to two hours. The time results are given in seconds. The results of 25-node sized instances with different objective functions are as follows. CPLEX obtained the optimal solution of all 72 instances with distance minimization objective. The average distance, number of personnel, number of vehicles and solving time with respect to each problem class are shown in Table 4.1. The problem type R1 took the longest time and the problem type C1 took the shortest time to solve on average.

Table 4.1: Average optimal results of 25-node instances with distance minimization objective

Problem	Count	Distance	Personnel	Vehicles	Time
C1	12	191.387	5.7	2.8	0.04
C2	12	215.127	4	2	5.51
R1	12	515.048	12.5	6.5	1043.22
R2	12	447.163	7.2	3.6	12.61
RC1	12	681.502	15.3	7.9	5.04
RC2	12	354.474	5.9	3	5.41
All	72	400.783	8.4	4.3	178.64

When the objective function is to minimize the total number of personnel, CPLEX was able to obtain the optimal solution of 51 instances out of 72. The average distance, number of personnel, number of vehicles and solving time for the 51 optimal instances with respect to each problem class are shown in Table 4.2. For the remaining 21 instances, we obtained the best solution found in two hours and reported the gap in Table 4.3. As the complexity of the problem increases when the objective function is to minimize integer values, only for 70% percent of the instances CPLEX was able to find the optimal solution in two hours.

Table 4.2: Average optimal results of 25-node instances with personnel minimization objective

Problem	Count	Distance	Personnel	Vehicles	Time
C1	12	470.313	3.5	2	0.78
C2	11	435.070	2	1	55.12
R2	6	799.655	4.2	2.5	11.21
RC1	12	819.260	12.5	8.4	30.76
RC2	10	760.979	3.7	2	978.25
All	51	640.556	5.4	3.4	212.44

Let us remind that there are 12 instances of each problem class. If all 12 of them were solved optimally, then they take place in the tables related to the optimal solutions only, e.g. a row of C1 is not present on the Table 4.3 because all of the C1 class instances are solved optimally and the results related to them take place in Table 4.2. As far as we see on Table 4.2, the RC2 class instances were the ones which took the most time on average to solve. All of the C1 class and RC1 class instances were solved optimally, whereas none of the R1 class instances were as shown on Table 4.3. The R1 class instances are the ones with the highest average gap with respect to the average gap of other instances. This is not a surprise as the R1 class instances took nearly 16 minutes on average to solve with the easier objective, which is to minimize the total distance, as well. The average gap of all the instances which cannot be solved optimally is 258%.

Table 4.3: Average best feasible results of 25-node instances with personnel minimization objective

Problem	Count	Distance	Personnel	Vehicles	GAP
C2	1	418.910	2	1	100%
R1	12	738.544	10	7.2	279%
R2	6	873.797	3.8	2.2	265%
RC2	2	856.993	4	2.5	192%
All	21	773.248	7.3	5	258%

When the objective function is to minimize the total number of vehicles, CPLEX was able to obtain the optimal solution of 49 instances out of 72. All of the results for the optimally solved instances are shown on Table 4.4. For the remaining 23 instances, we obtained the best solution found in two hours and the results of these instances are reported on Table 4.5 with the related gap data. Likewise the other results, R1 class instances are hardest to solve and the gap of them is a huge number, 264%. In this objective, the RC2 class instances were hard to solve as an interesting fact.

Table 4.4: Average optimal results of 25-node instances with vehicles minimization objective

Problem	Count	Distance	Personnel	Vehicles	Time
C1	12	445.550	4	2	0.28
C2	12	445.267	2	1	7.96
R2	6	787.973	5	2.5	5.51
RC1	12	765.253	14.7	7.8	41.61
RC2	7	767.443	4	2	160.17
All	49	611.689	6.2	3.2	35.76

Table 4.5: Average best feasible results of 25-node instances with vehicles minimization objective

Problem	Count	Distance	Personnel	Vehicles	GAP
R1	12	694.157	12.6	6.5	264%
R2	6	821.157	4	2	100%
RC2	5	785.070	3.8	2	100%
All	23	747.174	8.4	4.3	186%

For 50-node sized instances, CPLEX obtained the optimal solution of 43 instances when the objective function is to minimize the total distance travelled. The average distance, number of personnel, number of vehicles and solving time with respect to each problem class are shown in Table 4.6. The optimal solutions were always provided in less than half a minute time. For the other 29 instances, the best feasible results obtained in two hours are reported in Table 4.7. The gaps are not as high as we obtained with other objectives. The results also show once more that R1 class instances are the hardest ones to solve.

Table 4.6: Average optimal results of 50-node instances with distance minimization objective

Problem	Count	Distance	Personnel	Vehicles	Time
C1	12	361.728	10	5	0.22
C2	12	356.287	5	2.5	23.31
R2	6	813.328	12.7	6.3	4.3
RC1	6	1368.737	28.3	14.3	2.32
RC2	7	689.732	10	5	28.92
All	43	617.132	11.5	5.8	12.20

Table 4.7: Average best feasible results of 50-node instances with distance minimization objective

Problem	Count	Distance	Personnel	Vehicles	GAP
R1	12	978.127	24.8	12.6	44%
R2	6	677.430	10	5	19%
RC1	6	1239.468	25.2	13.3	18%
RC2	5	643.136	10	5	21%
All	29	912.227	19.2	9.9	29%

When the objective function is to minimize the total number of personnel on 50-node instances, CPLEX was able to obtain the optimal solution of only 18 instances out of 72. The average distance, number of personnel, number of vehicles and solving time with respect to each problem class are shown in Table 4.8 for the problem classes which can be solved optimally. The solution time is quite low. For the remaining 54 instances, we obtained the best solution found in two hours and reported the results and the gap in Table 4.9. CPLEX performed extremely poor on some instances as the gaps are huge.

Table 4.8: Average optimal results of 50-node instances with personnel minimization objective

Problem	Count	Distance	Personnel	Vehicles	Time
C1	12	1250.548	6	3.4	11.96
RC1	6	1659.007	22.5	15.3	24.75
All	18	1386.701	11.5	7.4	16.22

Table 4.9: Average best feasible results of 50-node instances with personnel minimization objective

Problem	Count	Distance	Personnel	Vehicles	GAP
C2	12	1398.545	2.8	1.8	200%
R1	12	1480.886	22.1	14.3	924%
R2	12	1839.548	8	4.9	438%
RC1	6	1649.148	20.7	14.7	84%
RC2	12	2020.170	7.9	4.8	431%
All	54	1680.828	11.4	7.4	452%

When the objective function is to minimize the total number of vehicles, CPLEX was able to obtain the optimal solution of 25 instances out of 72 for 50-node sized instances. All of the results for the optimally solved instances can be found on Table 4.10. For the remaining 47 instances, we obtained the best solution found in two hours and the results of these instances are reported on Table 4.11 with the related gap data. For the instances which are listed in Appendix B, the lower bound CPLEX obtained were so low that the gap became so high. In order to get out of this situation, we added a new constraint which makes sure that the number of vehicles used is at least one. The results reported for those instances are the results out of the model with this new constraint.

Table 4.10: Average optimal results of 50-node instances with vehicles minimization objective

Problem	Count	Distance	Personnel	Vehicles	Time
C1	12	1220.625	6.3	3.2	5.71
C2	6	1268.713	2	1	2415.51
R2	1	1614.090	8	4	592.62
RC1	6	1508.912	26.2	13.8	15.25
All	25	1317.094	10.1	5.2	609.63

Table 4.11: Average best feasible results of 50-node instances with vehicles minimization objective

Problem	Count	Distance	Personnel	Vehicles	GAP
C2	12	1513.942	3.8	2.2	117%
R1	12	1418.492	25.4	13.8	711%
R2	11	1691.316	8.5	4.5	268%
RC1	6	1443.170	25.8	13.3	94%
RC2	12	1826.180	8	4.2	237%
All	47	1601.770	14.3	7.6	332%

For the CC-HCRPTW, we have obtained the solutions of all instances using CPLEX by setting the run time limit to two hours. As we have mentioned before, for this problem we have provided 25-node sized 280 instances which can be classified by problem types, data groups and crew constraints types. CPLEX obtained the optimal solution of 263 instances out of 280. For the remaining 17, we have provided the best feasible solution found in two hours.

As it may be expected the R1 class of instances were the ones which took the longest time to solve again as shown on Table 4.10. On Table 4.11. it is seen that all of the instances for which the optimal solution cannot be obtained in two hours are R1 class instances. The gap is

15%. On the other hand. C1 instances are the fastest to solve again and the average solving time of the other instances are 202.91 seconds.

Table 4.12: The optimal results of CC-HCRPTW classified by problem types

Problem	Count	Distance	Personnel	Vehicles	Time
C1	40	211.229	4.7	2.4	0.08
C2	48	231.315	2.6	1.3	49.23
R1	31	532.523	12	6.5	1142.76
R2	48	476.976	5.3	2.8	20.67
RC1	48	696.775	14.1	7.9	139.34
RC2	48	437.691	4.8	2.5	164.45
All	263	431.216	7	3.8	202.91

Table 4.13: The best feasible results of CC-HCRPTW classified by problem types

Problem	Count	Distance	Personnel	Vehicles	GAP
R1	17	529.207	10.5	6.3	15%

When we observe the results by the classification of data groups on Table 4.12, we do not see any distinctive details. The average solving time of G1 and G2 are really close. The instances which cannot be solved optimally seem spread on Table 4.13.

Table 4.14: The optimal results of CC-HCRPTW classified by data groups

Data Group	Count	Distance	Personnel	Vehicles	Time
G1	92	439.044	7.4	3.9	229.06
G2	88	428.953	7	3.8	220.61
G3	83	424.938	6.6	3.6	155.17
All	263	431.216	7	3.8	202.91

Table 4.15: The best feasible results of CC-HCRPTW classified by data groups

Data Group	Count	Distance	Personnel	Vehicles	GAP
G1	4	523.981	10.8	6.3	14%
G2	8	568.609	11.5	7.1	15%
G3	5	470.344	8.8	5	17%
All	17	529.207	10.5	6.3	15%

We can classify the data by crew constraints types as well. The optimal solutions were easily obtained for all of the tight (T) constraints as shown on Table 4.14. For the other types of crew constraints, there are just a few number of instances for which the optimal solution cannot be obtained in two hours as shown on Table 4.15.

Table 4.16: The optimal results of CC-HCRPTW classified by crew constraints types

Type	Count	Distance	Personnel	Vehicles	Time
T	70	406.826	8.5	4.4	164.15
L	63	449.274	5.9	3.3	323.32
M1	64	430.610	6.7	3.7	50.59
M2	66	440.433	6.8	3.7	276.80
All	263	431.216	7	3.8	202.91

Table 4.17: The best feasible results of CC-HCRPTW classified by crew constraints types

Type	Count	Distance	Personnel	Vehicles	GAP
L	7	538.433	10.3	6.4	18%
M1	6	539.819	11.3	6.5	11%
M2	4	497.142	9.8	5.8	17%
All	17	529.207	10.5	6.3	15%

As mentioned before, determining the number of nurses and aides for each instance for CC-HCRPTW is not an easy task. We wanted to show the trade-off between setting the crew constraints tight and loose. We have chosen two of our instances, namely RC105 of the G2 data set and R103 of the G3 data set as they seemed to be challenging examples. The first value in the parenthesis indicates the crew constraint for nurses and the second value indicates the crew constraint for aides. For the sample of RC105 when the crew constraints are set to be (6, 6) or (7, 6), the solutions are infeasible. When the crew constraints are set to be (6. 7) and further, CPLEX can obtain feasible solutions. The distance decreases for a while as the number of available personnel changes in different combinations. Whereas, after some point having more personnel on workforce does not decrease the total distance travelled any more. The marginal cost of hiring one worker is high, whereas it does not worth it after the critical point. The observation of this fact can be seen on Figure 4.2 for instance RC105 of the G2 data set and on Figure 4.3 for instance R103 of the G3 data set.

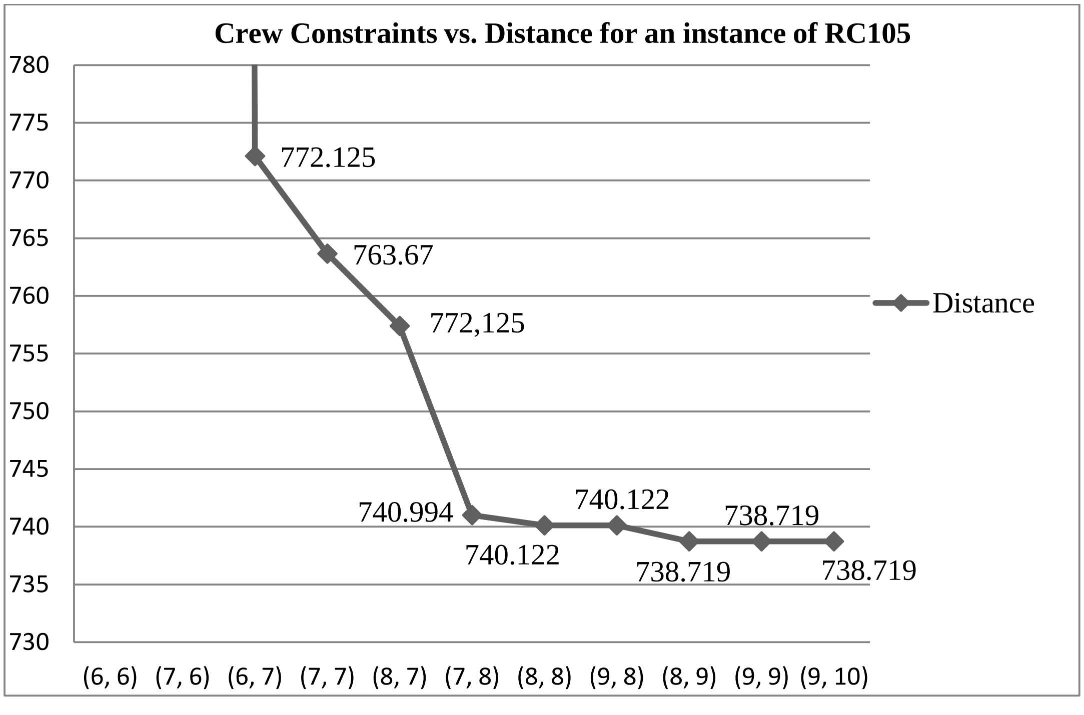

Figure 4.2: Distance change with increasing levels of crew constraints on instance RC105

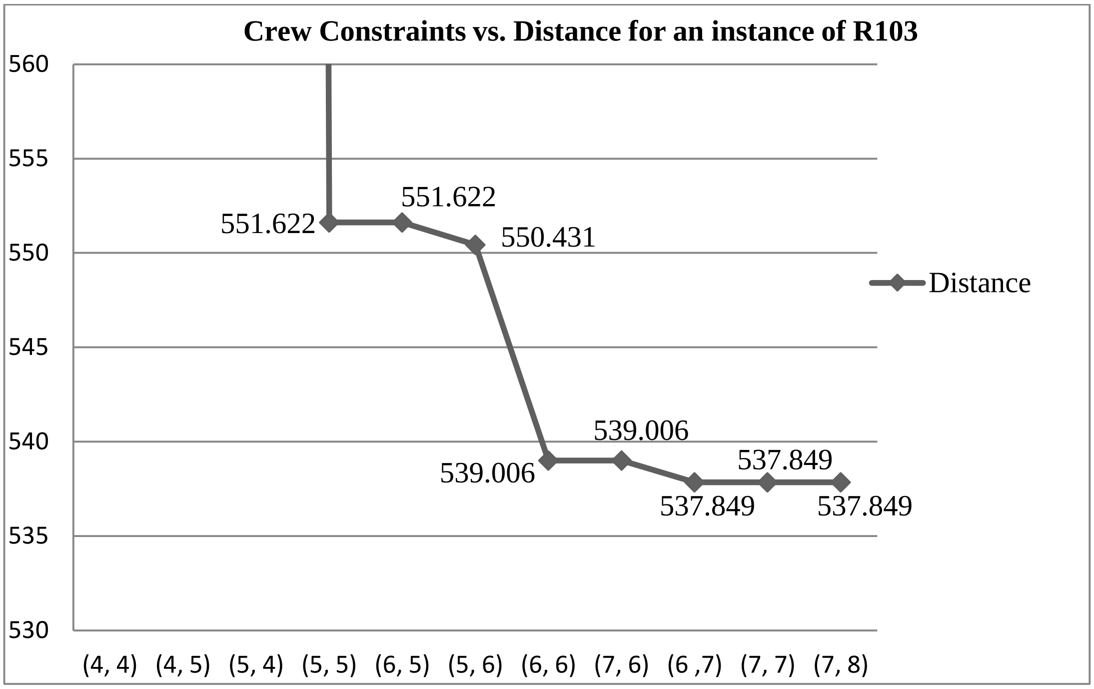

Figure 4.3: Distance change with increasing levels of crew constraints on instance R103

Chapter 5

CONCLUSION AND FUTURE WORK

In this study, we presented the Home Care Routing Problem with Time Windows and crew constrained version of the same problem. We formulated their mathematical programming models and obtained the solutions on CPLEX. For most of the instances, CPLEX was unable to find good feasible solutions in two hours. For the experimental tests, we randomly generated a data set using Solomon's benchmark problems and determined different personnel resource limitations for the crew constrained version.

For this study, we have created feasible instances with 25 and 50 patients by solving the model with different objectives. Creating challenging and interesting instances with larger number of instances is a relevant problem. The final goal here should be creating a set of benchmark problems for a more general framework that considers different types of limited resources.

Since the problem is NP-Hard, the next future step has to be building a heuristic to work on the problem. Starting with Solomon (1987), there are a lot of proposed algorithms available in the literature. In order to get familiar with some route construction heuristics and solution improvement methods, the paper of Braysy and Gendreau (2005) would be very useful. Another collection of heuristics for the vehicle routing problem are presented in the paper of Laporte et al. (2000).

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APPENDIX A: RESULTS OF ALL PROBLEM INSTANCES

In the following tables, all of the results are provided. “TD”, “#Veh”, “#Pers”, “#Nurses”, and “#Aides” denote the total distance travelled, the total number of vehicles, the total number of personnel, the total number of nurses employed, and the total number of aides employed, respectively.

Table A.1: The results of 25-node sized instances with distance minimization objective

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1	191.808	3	6	3	3	0.05	0%
C101-G1-2	191.808	3	6	3	3	0.03	0%
C101-G2-1	191.808	3	6	3	3	0.02	0%
C101-G2-2	191.808	3	6	3	3	0.03	0%
C101-G3-1	191.808	3	6	3	3	0.02	0%
C101-G3-2	191.808	3	6	3	3	0.03	0%
C106-G1-1	191.808	3	6	3	3	0.11	0%
C106-G1-2	191.808	3	6	3	3	0.03	0%
C106-G2-1	191.808	3	6	3	3	0.03	0%
C106-G2-2	191.808	3	6	3	3	0.05	0%
C106-G3-1	189.281	2	4	2	2	0.03	0%
C106-G3-2	189.281	2	4	2	2	0.06	0%
C207-G1-1	214.926	2	4	2	2	11.75	0%
C207-G1-2	214.926	2	4	2	2	6.74	0%
C207-G2-1	214.926	2	4	2	2	3.35	0%
C207-G2-2	214.926	2	4	2	2	3.07	0%
C207-G3-1	214.926	2	4	2	2	2.26	0%
C207-G3-2	214.926	2	4	2	2	10.50	0%
C208-G1-1	215.327	2	4	2	2	2.73	0%
C208-G1-2	215.327	2	4	2	2	2.65	0%
C208-G2-1	215.327	2	4	2	2	4.74	0%
C208-G2-2	215.327	2	4	2	2	11.28	0%
C208-G3-1	215.327	2	4	2	2	2.85	0%
C208-G3-2	215.327	2	4	2	2	4.15	0%
R103-G1-1	571.922	8	16	8	8	67.89	0%
R103-G1-2	588.521	8	16	8	8	10.80	0%
R103-G2-1	548.523	7	13	6	7	22.12	0%

R103-G2-2	555.926	7	13	6	7	1708.60	0%
R103-G3-1	496.069	6	9	6	3	52.29	0%
R103-G3-2	537.849	7	14	7	7	99.03	0%
R108-G1-1	483.726	6	12	6	6	179.68	0%
R108-G1-2	491.952	6	12	6	6	2674.57	0%
R108-G2-1	523.945	7	14	7	7	2194.14	0%
R108-G2-2	491.324	6	12	6	6	3233.70	0%
R108-G3-1	451.292	5	9	5	4	1701.16	0%
R108-G3-2	439.521	5	10	5	5	574.66	0%
R201-G1-1	470.830	4	8	4	4	0.17	0%
R201-G1-2	498.416	4	8	4	4	0.22	0%
R201-G2-1	495.906	4	8	4	4	0.23	0%
R201-G2-2	483.665	4	8	4	4	0.11	0%
R201-G3-1	482.398	4	8	4	4	0.09	0%
R201-G3-2	482.398	4	8	4	4	0.25	0%
R210-G1-1	415.300	4	8	4	4	18.99	0%
R210-G1-2	412.320	3	6	3	3	16.46	0%
R210-G2-1	408.300	3	6	3	3	62.51	0%
R210-G2-2	405.473	3	6	3	3	12.43	0%
R210-G3-1	405.473	3	6	3	3	23.10	0%
R210-G3-2	405.473	3	6	3	3	16.79	0%
RC101-G1-1	759.749	9	18	9	9	0.06	0%
RC101-G1-2	747.281	9	17	8	9	0.05	0%
RC101-G2-1	747.313	9	17	8	9	0.09	0%
RC101-G2-2	787.112	9	18	9	9	0.03	0%
RC101-G3-1	668.479	8	15	8	7	0.19	0%
RC101-G3-2	638.329	7	14	7	7	0.13	0%
RC105-G1-1	685.711	7	14	7	7	5.48	0%
RC105-G1-2	654.088	8	14	8	6	4.85	0%
RC105-G2-1	618.139	7	14	7	7	3.45	0%
RC105-G2-2	738.719	9	18	9	9	37.25	0%
RC105-G3-1	535.048	6	11	5	6	4.31	0%
RC105-G3-2	598.053	7	14	7	7	4.62	0%
RC201-G1-1	367.237	3	6	3	3	0.20	0%
RC201-G1-2	368.272	3	6	3	3	0.08	0%
RC201-G2-1	370.286	3	6	3	3	0.09	0%
RC201-G2-2	362.597	3	6	3	3	0.23	0%
RC201-G3-1	361.235	3	5	3	2	0.14	0%
RC201-G3-2	368.272	3	6	3	3	0.09	0%
RC205-G1-1	344.768	3	6	3	3	0.67	0%
RC205-G1-2	338.925	3	6	3	3	2.82	0%

RC205-G2-1	342.755	3	6	3	3	5.52	0%
RC205-G2-2	349.479	3	6	3	3	53.04	0%
RC205-G3-1	338.925	3	6	3	3	0.73	0%
RC205-G3-2	340.938	3	6	3	3	1.25	0%

Table A.2: The results of 25-node sized instances with personnel minimization objective

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1	423,897	2	4	2	2	0,36	0%
C101-G1-2	535,015	2	4	2	2	0,70	0%
C101-G2-1	446,177	2	4	2	2	0,72	0%
C101-G2-2	464,290	2	3	1	2	0,30	0%
C101-G3-1	469,174	2	4	2	2	0,66	0%
C101-G3-2	457,270	2	3	1	2	0,98	0%
C106-G1-1	543,690	2	3	1	2	0,09	0%
C106-G1-2	414,106	2	4	2	2	0,61	0%
C106-G2-1	474,624	2	3	1	2	1,22	0%
C106-G2-2	490,812	2	3	1	2	1,09	0%
C106-G3-1	405,857	2	4	2	2	0,53	0%
C106-G3-2	518,839	2	3	2	1	2,14	0%
C207-G1-1	419,213	1	2	1	1	0,83	0%
C207-G1-2	447,999	1	2	1	1	2,96	0%
C207-G2-1	383,939	1	2	1	1	10,75	0%
C207-G2-2	430,897	1	2	1	1	4,21	0%
C207-G3-1	455,630	1	2	1	1	5,35	0%
C207-G3-2	469,726	1	2	1	1	112,94	0%
C208-G1-1	431,890	1	2	1	1	3,12	0%
C208-G1-2	351,588	1	2	1	1	20,69	0%
C208-G2-1	418,910	1	2	1	1	7200,30	100%
C208-G2-2	527,740	1	2	1	1	2,22	0%
C208-G3-1	507,446	1	2	1	1	131,21	0%
C208-G3-2	359,702	1	2	1	1	312,05	0%
R103-G1-1	770,746	8	12	6	6	7205,45	100%
R103-G1-2	767,591	9	14	7	7	7206,06	46%
R103-G2-1	840,490	8	11	5	6	7209,81	80%
R103-G2-2	807,851	8	10	4	6	7209,82	150%
R103-G3-1	666,996	6	7	5	2	7210,40	133%
R103-G3-2	745,876	7	9	4	5	7204,19	157%
R108-G1-1	785,460	8	10	4	6	7212,38	233%

R108-G1-2	756,212	7	10	5	5	7217,03	558%
R108-G2-1	685,652	7	11	4	7	7214,03	440%
R108-G2-2	735,961	7	9	4	5	7209,96	800%
R108-G3-1	570,087	5	8	5	3	7217,82	300%
R108-G3-2	729,603	6	9	5	4	7220,15	350%
R201-G1-1	926,660	3	4	2	2	10,09	0%
R201-G1-2	752,139	3	5	2	3	4,54	0%
R201-G2-1	737,523	3	4	2	2	9,11	0%
R201-G2-2	722,465	2	4	2	2	6,90	0%
R201-G3-1	801,598	2	4	2	2	23,65	0%
R201-G3-2	857,545	2	4	2	2	12,98	0%
R210-G1-1	848,606	2	4	2	2	7210,79	552%
R210-G1-2	809,049	2	4	2	2	7212,39	300%
R210-G2-1	907,445	3	4	2	2	7212,57	300%
R210-G2-2	868,403	2	4	2	2	7211,88	300%
R210-G3-1	925,968	2	3	2	1	7208,29	38%
R210-G3-2	883,313	2	4	2	2	7205,75	100%
RC101-G1-1	897,074	10	16	6	10	0,58	0%
RC101-G1-2	768,100	9	15	6	9	0,66	0%
RC101-G2-1	869,801	9	13	5	8	0,78	0%
RC101-G2-2	898,677	10	16	7	9	0,89	0%
RC101-G3-1	904,749	9	12	5	7	1,42	0%
RC101-G3-2	741,417	8	10	5	5	2,45	0%
RC105-G1-1	811,193	8	13	6	7	16,44	0%
RC105-G1-2	910,325	8	11	6	5	16,05	0%
RC105-G2-1	740,264	8	12	5	7	27,99	0%
RC105-G2-2	832,718	8	12	5	7	62,17	0%
RC105-G3-1	579,249	6	8	4	4	80,01	0%
RC105-G3-2	877,552	8	12	6	6	159,70	0%
RC201-G1-1	737,901	2	4	2	2	3,87	0%
RC201-G1-2	719,963	2	4	2	2	5,04	0%
RC201-G2-1	681,921	2	4	2	2	8,99	0%
RC201-G2-2	742,260	2	4	2	2	73,46	0%
RC201-G3-1	845,183	2	3	2	1	61,17	0%
RC201-G3-2	853,432	2	4	2	2	63,26	0%
RC205-G1-1	732,402	2	4	2	2	771,46	0%
RC205-G1-2	733,895	2	4	2	2	4874,61	0%
RC205-G2-1	778,874	2	3	1	2	3491,33	0%
RC205-G2-2	927,880	3	4	2	2	7207,50	284%
RC205-G3-1	783,959	2	3	2	1	429,30	0%
RC205-G3-2	786,106	2	4	2	2	7204,16	100%

Table A.3: The results of 25-node sized instances with vehicles minimization objective

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1	486,857	2	4	2	2	0,06	0%
C101-G1-2	394,052	2	4	2	2	0,14	0%
C101-G2-1	448,534	2	4	2	2	0,11	0%
C101-G2-2	443,89	2	4	2	2	0,05	0%
C101-G3-1	478,533	2	4	2	2	0,06	0%
C101-G3-2	379,561	2	4	2	2	1,23	0%
C106-G1-1	456,569	2	4	2	2	0,33	0%
C106-G1-2	501,664	2	4	2	2	0,48	0%
C106-G2-1	423,909	2	4	2	2	0,17	0%
C106-G2-2	428,805	2	4	2	2	0,19	0%
C106-G3-1	439,918	2	4	2	2	0,19	0%
C106-G3-2	464,31	2	4	2	2	0,30	0%
C207-G1-1	523,713	1	2	1	1	2,07	0%
C207-G1-2	441,176	1	2	1	1	1,33	0%
C207-G2-1	472,856	1	2	1	1	0,45	0%
C207-G2-2	426,491	1	2	1	1	0,53	0%
C207-G3-1	454,011	1	2	1	1	0,41	0%
C207-G3-2	466,319	1	2	1	1	62,81	0%
C208-G1-1	482,971	1	2	1	1	1,26	0%
C208-G1-2	354,311	1	2	1	1	8,24	0%
C208-G2-1	427,998	1	2	1	1	9,69	0%
C208-G2-2	381,585	1	2	1	1	3,96	0%
C208-G3-1	486,944	1	2	1	1	1,31	0%
C208-G3-2	424,824	1	2	1	1	3,46	0%
R103-G1-1	740,595	7	14	7	7	7225,95	75%
R103-G1-2	763,679	8	16	8	8	7239,77	50%
R103-G2-1	702,731	7	14	7	7	7215,16	75%
R103-G2-2	817,781	7	13	6	7	7233,05	133%
R103-G3-1	670,788	6	10	6	4	7225,29	200%
R103-G3-2	735,722	7	12	6	6	7212,43	133%
R108-G1-1	741,395	7	14	7	7	7272,16	250%
R108-G1-2	597,489	6	12	6	6	7202,77	500%
R108-G2-1	701,006	7	14	7	7	7229,71	465%
R108-G2-2	643,136	6	12	6	6	7249,32	488%
R108-G3-1	642,538	5	10	5	5	7297,48	400%
R108-G3-2	573,018	5	10	5	5	7220,32	400%
R201-G1-1	743,875	3	6	3	3	6,99	0%
R201-G1-2	883,771	3	6	3	3	0,81	0%

R201-G2-1	756,559	3	6	3	3	3,56	0%
R201-G2-2	790,09	2	4	2	2	2,98	0%
R201-G3-1	806,18	2	4	2	2	6,66	0%
R201-G3-2	747,365	2	4	2	2	12,08	0%
R210-G1-1	920,436	2	4	2	2	7235,47	100%
R210-G1-2	832,782	2	4	2	2	7238,04	100%
R210-G2-1	725,182	2	4	2	2	7225,31	100%
R210-G2-2	790,238	2	4	2	2	7213,07	100%
R210-G3-1	823,511	2	4	2	2	7250,72	100%
R210-G3-2	837,619	2	4	2	2	7208,92	100%
RC101-G1-1	852,787	9	17	8	9	0,11	0%
RC101-G1-2	834,47	9	17	8	9	0,06	0%
RC101-G2-1	870,834	9	17	8	9	0,16	0%
RC101-G2-2	800,672	9	18	9	9	0,16	0%
RC101-G3-1	787,619	8	14	7	7	0,27	0%
RC101-G3-2	749,112	7	13	7	6	0,14	0%
RC105-G1-1	701,718	7	14	7	7	3,79	0%
RC105-G1-2	708,818	7	14	7	7	9,39	0%
RC105-G2-1	674,792	7	13	6	7	6,69	0%
RC105-G2-2	822,844	8	15	7	8	147,81	0%
RC105-G3-1	609,489	6	11	6	5	286,34	0%
RC105-G3-2	769,881	7	13	6	7	44,44	0%
RC201-G1-1	807,813	2	4	2	2	1,19	0%
RC201-G1-2	759,96	2	4	2	2	0,56	0%
RC201-G2-1	711,413	2	4	2	2	1,67	0%
RC201-G2-2	840,125	2	4	2	2	0,47	0%
RC201-G3-1	791,836	2	4	2	2	4,42	0%
RC201-G3-2	682,925	2	4	2	2	1,20	0%
RC205-G1-1	778,028	2	4	2	2	1111,66	0%
RC205-G1-2	809,018	2	4	2	2	7200,44	100%
RC205-G2-1	748,356	2	4	2	2	7202,55	100%
RC205-G2-2	749,706	2	4	2	2	7200,68	100%
RC205-G3-1	917,119	2	3	2	1	7205,08	100%
RC205-G3-2	701,149	2	4	2	2	7200,30	100%

Table A.4: The results of 50-node sized instances with distance minimization objective

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1	361,574	5	10	5	5	0,17	0
C101-G1-2	362,037	5	10	5	5	0,17	0
C101-G2-1	362,037	5	10	5	5	0,16	0
C101-G2-2	362,037	5	10	5	5	0,14	0
C101-G3-1	361,574	5	10	5	5	0,22	0
C101-G3-2	362,037	5	10	5	5	0,19	0
C106-G1-1	361,574	5	10	5	5	0,23	0
C106-G1-2	361,574	5	10	5	5	0,20	0
C106-G2-1	361,574	5	10	5	5	0,28	0
C106-G2-2	361,574	5	10	5	5	0,27	0
C106-G3-1	361,574	5	10	5	5	0,27	0
C106-G3-2	361,574	5	10	5	5	0,34	0
C207-G1-1	360,216	3	6	3	3	25,41	0
C207-G1-2	360,79	3	6	3	3	31,92	0
C207-G2-1	360,216	3	6	3	3	22,17	0
C207-G2-2	360,79	3	6	3	3	16,40	0
C207-G3-1	360,79	3	6	3	3	42,29	0
C207-G3-2	360,216	3	6	3	3	47,39	0
C208-G1-1	352,07	2	4	2	2	9,17	0
C208-G1-2	352,07	2	4	2	2	19,05	0
C208-G2-1	352,07	2	4	2	2	8,42	0
C208-G2-2	352,07	2	4	2	2	13,32	0
C208-G3-1	352,07	2	4	2	2	31,81	0
C208-G3-2	352,07	2	4	2	2	12,40	0
R103-G1-1	1498,4	15	30	15	15	0,58	0
R103-G1-2	1338,72	14	27	13	14	2,68	0
R103-G2-1	1446,53	16	31	16	15	0,95	0
R103-G2-2	1403,31	15	30	15	15	1,25	0
R103-G3-1	1213,92	13	26	13	13	1,59	0
R103-G3-2	1311,54	13	26	13	13	6,85	0
R108-G1-1	1392,27	15	29	14	15	7204,27	7
R108-G1-2	1277,47	14	26	12	14	7213,13	23
R108-G2-1	1290,51	14	26	13	13	7211,44	26
R108-G2-2	1287,58	14	26	12	14	7203,56	3
R108-G3-1	1052,41	11	21	11	10	7207,57	26
R108-G3-2	1136,57	12	23	11	12	7202,55	25
R201-G1-1	707,105	5	10	5	5	1,69	0
R201-G1-2	698,721	5	10	5	5	2,42	0

R201-G2-1	701,986	5	10	5	5	3,68	0
R201-G2-2	691,972	5	10	5	5	2,81	0
R201-G3-1	695,477	5	10	5	5	3,25	0
R201-G3-2	692,713	5	10	5	5	2,43	0
R210-G1-1	640,148	5	10	5	5	186,19	0
R210-G1-2	648,362	5	10	5	5	7215,97	15
R210-G2-1	638,624	5	10	5	5	7214,13	16
R210-G2-2	645,416	5	10	5	5	7221,64	25
R210-G3-1	639,39	5	10	5	5	7227,49	26
R210-G3-2	643,888	5	10	5	5	7222,39	22
RC101-G1-1	1078,71	15	30	15	15	7230,65	23
RC101-G1-2	1080,61	14	28	14	14	7247,98	18
RC101-G2-1	1070,55	14	28	14	14	7256,74	17
RC101-G2-2	1069,87	14	28	14	14	7250,15	23
RC101-G3-1	1011,07	13	26	13	13	7225,50	26
RC101-G3-2	988,088	13	24	13	11	7233,06	35
RC105-G1-1	1003,92	13	26	13	13	7221,74	71
RC105-G1-2	963,008	12	24	12	12	7235,95	77
RC105-G2-1	924,323	12	23	11	12	7214,41	59
RC105-G2-2	912,172	11	22	11	11	7227,26	69
RC105-G3-1	819,424	10	19	10	9	7229,16	53
RC105-G3-2	815,773	10	19	10	9	7284,72	58
RC201-G1-1	816,209	6	12	6	6	5,57	0
RC201-G1-2	831,14	6	12	6	6	2,46	0
RC201-G2-1	814,339	7	14	7	7	4,35	0
RC201-G2-2	812,271	6	12	6	6	4,29	0
RC201-G3-1	800,832	6	12	6	6	4,21	0
RC201-G3-2	805,175	7	14	7	7	4,88	0
RC205-G1-1	669,807	5	10	5	5	7250,22	16
RC205-G1-2	692,388	5	10	5	5	7328,23	20
RC205-G2-1	678,963	5	10	5	5	7229,63	20
RC205-G2-2	678,299	5	10	5	5	7270,47	19
RC205-G3-1	663,319	5	10	5	5	7251,44	16
RC205-G3-2	681,801	5	10	5	5	7223,91	21

Table A.5: The results of 50-node sized instances with personnel minimization objective

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1	1475,630	4	6	3	3	2,09	0
C101-G1-2	1362,560	4	7	3	4	3,23	0
C101-G2-1	1199,040	3	6	3	3	1,14	0
C101-G2-2	1337,260	4	6	3	3	1,33	0
C101-G3-1	1206,440	3	6	3	3	2,95	0
C101-G3-2	1193,360	3	6	3	3	0,55	0
C106-G1-1	1179,180	3	6	3	3	23,18	0
C106-G1-2	1422,450	4	7	3	4	5,68	0
C106-G2-1	1154,520	3	5	2	3	21,45	0
C106-G2-2	1088,660	4	6	3	3	62,23	0
C106-G3-1	1174,130	3	5	2	3	13,99	0
C106-G3-2	1213,350	3	6	3	3	5,71	0
C207-G1-1	1640,400	3	4	2	2	7216	200
C207-G1-2	1386,020	2	3	1	2	7240,74	300
C207-G2-1	1258,430	1	2	1	1	7202,30	300
C207-G2-2	1775,140	3	4	2	2	7219,41	200
C207-G3-1	1655,060	2	3	2	1	7223,75	200
C207-G3-2	1272,090	1	2	1	1	7202,80	100
C208-G1-1	1075,070	1	2	1	1	7209,24	100
C208-G1-2	1062,590	1	2	1	1	7204	100
C208-G2-1	1440,630	2	3	1	2	7230,10	200
C208-G2-2	1412,510	2	3	2	1	7250,19	300
C208-G3-1	1340	2	3	2	1	7214,49	200
C208-G3-2	1406,060	2	3	2	1	7218,54	200
R103-G1-1	1359,350	15	26	12	14	7216,39	333
R103-G1-2	1496,680	15	24	12	12	7219,80	200
R103-G2-1	1559,780	16	23	9	14	7217,96	283
R103-G2-2	1653,520	16	20	7	13	7219,38	186
R103-G3-1	1529,530	14	22	12	10	7210,41	450
R103-G3-2	1440,750	13	19	10	9	7202,69	850
R108-G1-1	1512,560	15	23	9	14	7207,76	2200
R108-G1-2	1398,810	14	22	9	13	7204,59	2100
R108-G2-1	1502,080	14	25	11	14	7204,11	733
R108-G2-2	1513,170	14	20	8	12	7203,78	1900
R108-G3-1	1413,950	13	21	10	11	7205,73	950
R108-G3-2	1390,450	12	20	11	9	7204,30	900
R201-G1-1	1807,940	5	8	4	4	7217,14	33
R201-G1-2	1763,260	5	8	3	5	7211,08	58

R201-G2-1	1703,750	5	7	3	4	7222,27	125
R201-G2-2	1758,120	5	7	3	4	7213,75	91
R201-G3-1	1365,590	3	6	3	3	7212,69	50
R201-G3-2	1846,370	4	6	4	2	7213,36	100
R210-G1-1	1737,260	4	8	4	4	7241,66	700
R210-G1-2	1815,740	5	9	5	4	7206,14	800
R210-G2-1	1957,710	6	10	5	5	7204,30	900
R210-G2-2	2167,450	6	10	5	5	7224,44	900
R210-G3-1	2208,490	6	9	5	4	7232,61	800
R210-G3-2	1942,900	5	8	3	5	7209,76	700
RC101-G1-1	1814,470	17	24	10	14	4,68	0
RC101-G1-2	1474,610	14	24	11	13	39,62	0
RC101-G2-1	1816,330	18	25	10	15	9,14	0
RC101-G2-2	1749,750	16	22	9	13	7,02	0
RC101-G3-1	1537,460	13	21	12	9	72,67	0
RC101-G3-2	1561,420	14	19	9	10	15,40	0
RC105-G1-1	1838,940	17	26	10	16	7222,28	58
RC105-G1-2	1659,240	15	21	9	12	7216,64	75
RC105-G2-1	1808,760	16	19	7	12	7217,40	105
RC105-G2-2	1668,100	15	21	8	13	7211,15	48
RC105-G3-1	1414,600	12	18	9	9	7213,53	80
RC105-G3-2	1505,250	13	19	9	10	7218,12	138
RC201-G1-1	1639,180	4	8	4	4	7218,51	100
RC201-G1-2	1506	4	6	3	3	7225,58	50
RC201-G2-1	2054,810	5	7	3	4	7220,62	250
RC201-G2-2	1934,780	5	7	3	4	7224,88	195
RC201-G3-1	1552,290	4	7	3	4	7223,64	247
RC201-G3-2	1732,790	4	7	4	3	7212,97	75
RC205-G1-1	1978,720	5	9	4	5	7220,26	800
RC205-G1-2	2297,410	5	9	4	5	7207,04	800
RC205-G2-1	2036,630	5	9	5	4	7217,82	800
RC205-G2-2	2459,930	6	10	5	5	7212,99	900
RC205-G3-1	1869,140	4	7	4	3	7209,27	600
RC205-G3-2	2666,190	6	9	5	4	7217,04	350

Table A.6: The results of 50-node sized instances with vehicles minimization objective

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1	1093,520	3	6	3	3	0,75	0
C101-G1-2	1370,610	4	8	4	4	1,50	0
C101-G2-1	1191,030	3	6	3	3	0,92	0
C101-G2-2	1224,080	3	6	3	3	0,42	0
C101-G3-1	1270,810	3	6	3	3	1,00	0
C101-G3-2	1274,870	3	6	3	3	0,48	0
C106-G1-1	1017,720	3	6	3	3	12,47	0
C106-G1-2	1256,810	4	7	3	4	1,30	0
C106-G2-1	1080,340	3	6	3	3	33,49	0
C106-G2-2	1284,170	3	6	3	3	9,80	0
C106-G3-1	1336,890	3	6	3	3	4,27	0
C106-G3-2	1246,650	3	6	3	3	2,09	0
C207-G1-1	1241,110	2	4	2	2	7255,25	100
C207-G1-2	1536,360	2	4	2	2	7200,59	100
C207-G2-1	1530,160	2	3	1	2	7233,58	100
C207-G2-2	1312,220	2	4	2	2	7202,32	100
C207-G3-1	1325,490	2	4	2	2	7230,69	100
C207-G3-2	1457,890	1	2	1	1	163,54	0
C208-G1-1	1044,820	1	2	1	1	201,93	0
C208-G1-2	1055,590	1	2	1	1	371,00	0
C208-G2-1	1330,220	1	2	1	1	6543,93	0
C208-G2-2	1375,530	1	2	1	1	249,65	0
C208-G3-1	2138,310	3	4	2	2	7218,34	200
C208-G3-2	1348,230	1	2	1	1	6963,04	0
R103-G1-1	1368,960	15	28	13	15	7218,48	275
R103-G1-2	1379,510	14	28	14	14	7227,62	180
R103-G2-1	1408,700	15	26	12	14	7227,85	275
R103-G2-2	1473,910	14	26	12	14	7222,68	133
R103-G3-1	1332,700	13	24	12	12	7220,77	500
R103-G3-2	1466,600	13	23	13	10	7222,75	1200
R108-G1-1	1421,470	15	28	13	15	7205,19	1400
R108-G1-2	1381,670	14	24	11	13	7205,76	1300
R108-G2-1	1451,930	14	25	12	13	7216,75	367
R108-G2-2	1481,800	14	27	13	14	7226,08	1300
R108-G3-1	1400,260	12	24	12	12	7203,28	500
R108-G3-2	1454,390	12	22	12	10	7218,40	1100
R201-G1-1	1359,750	4	8	4	4	7218,93	100
R201-G1-2	1614,090	4	8	4	4	592,62	0

R201-G2-1	1591,050	4	8	4	4	7233,78	100
R201-G2-2	1586,370	4	8	4	4	7213,39	100
R201-G3-1	1642,790	4	8	4	4	7254,69	100
R201-G3-2	1398,460	3	6	3	3	7231,01	50
R210-G1-1	1999,090	6	10	5	5	7223,11	500
R210-G1-2	1685,400	4	8	4	4	7223,53	300
R210-G2-1	1656,440	5	9	5	4	7215,84	400
R210-G2-2	1883,490	6	10	4	6	7249,07	500
R210-G3-1	1936,620	5	9	5	4	7226,37	400
R210-G3-2	1865,020	5	9	5	4	7219,88	400
RC101-G1-1	1610,660	15	27	12	15	2,65	0
RC101-G1-2	1537,190	14	27	13	14	9,08	0
RC101-G2-1	1589,400	15	30	15	15	3,07	0
RC101-G2-2	1488,730	14	26	12	14	4,17	0
RC101-G3-1	1309,910	12	23	12	11	33,88	0
RC101-G3-2	1517,580	13	24	13	11	38,64	0
RC105-G1-1	1504,770	15	30	15	15	7217,14	65
RC105-G1-2	1493,030	14	26	13	13	7215,87	100
RC105-G2-1	1591,360	14	27	13	14	7221,29	133
RC105-G2-2	1536,900	14	28	14	14	7222,94	81
RC105-G3-1	1240,330	11	21	10	11	7216,56	83
RC105-G3-2	1292,630	12	23	11	12	7218,79	100
RC201-G1-1	1709,890	4	8	4	4	7217,95	100
RC201-G1-2	1703,250	4	8	4	4	7210,40	100
RC201-G2-1	2039,930	4	8	4	4	7210,52	100
RC201-G2-2	1358,550	4	8	4	4	7224,09	289
RC201-G3-1	1286,170	3	6	3	3	7208,10	50
RC201-G3-2	1841,990	4	8	4	4	7211,08	100
RC205-G1-1	1788,360	4	8	4	4	7212,92	300
RC205-G1-2	2049,650	5	9	4	5	7243,72	400
RC205-G2-1	1867,110	4	8	4	4	7248,84	300
RC205-G2-2	2176,730	5	10	5	5	7250,76	400
RC205-G3-1	2268,950	5	9	5	4	7227,29	400
RC205-G3-2	1823,580	4	8	4	4	7229,54	300

Table A.7: The results of CC-HCRPTW

Instance	TD	#Veh	#Pers	#Nurses	#Aides	Time	GAP
C101-G1-1-1	191,808	3	6	3	3	0,05	0
C101-G1-1-2	218,120	2	4	2	2	0,09	0
C101-G1-1-3	218,120	2	4	2	2	0,22	0
C101-G1-1-4	198,850	3	5	2	3	0,06	0
C101-G1-2-1	191,808	3	6	3	3	0,05	0
C101-G1-2-2	237,273	2	4	2	2	0,06	0
C101-G1-2-3	237,273	2	4	2	2	0,06	0
C101-G1-2-4	220,439	3	5	2	3	0,09	0
C101-G2-1-1	191,808	3	6	3	3	0,05	0
C101-G2-1-2	211,943	2	4	2	2	0,08	0
C101-G2-1-3	211,943	2	4	2	2	0,06	0
C101-G2-1-4	211,943	2	4	2	2	0,09	0
C101-G2-2-1	191,808	3	6	3	3	0,05	0
C101-G2-2-2	218,120	2	4	2	2	0,27	0
C101-G2-2-3	200,212	3	5	2	3	0,06	0
C101-G2-2-4	218,120	2	4	2	2	0,33	0
C101-G3-1-1	191,808	3	6	3	3	0,06	0
C101-G3-1-2	229,842	2	4	2	2	0,08	0
C101-G3-1-3	221,801	3	5	2	3	0,06	0
C101-G3-1-4	220,103	3	5	3	2	0,06	0
C101-G3-2-1	191,808	3	6	3	3	0,05	0
C101-G3-2-2	229,842	2	4	2	2	0,06	0
C101-G3-2-3	229,842	2	4	2	2	0,06	0
C101-G3-2-4	220,103	3	5	3	2	0,05	0
C106-G1-1-1	191,808	3	6	3	3	0,17	0
C106-G1-1-2	217,903	2	4	2	2	0,05	0
C106-G1-1-3	217,903	2	4	2	2	0,08	0
C106-G1-1-4	217,903	2	4	2	2	0,09	0
C106-G1-2-1	191,808	3	6	3	3	0,05	0
C106-G1-2-2	214,611	2	4	2	2	0,08	0
C106-G1-2-3	214,611	2	4	2	2	0,06	0
C106-G1-2-4	214,611	2	4	2	2	0,05	0
C106-G2-1-1	191,808	3	6	3	3	0,08	0
C106-G2-1-2	211,943	2	4	2	2	0,05	0
C106-G2-1-3	211,943	2	4	2	2	0,08	0
C106-G2-1-4	211,943	2	4	2	2	0,06	0
C106-G2-2-1	191,808	3	6	3	3	0,05	0
C106-G2-2-2	214,611	2	4	2	2	0,06	0

C106-G2-2-3	214,611	2	4	2	2	0,06	0
C106-G2-2-4	214,611	2	4	2	2	0,06	0
C207-G1-1-1	214,926	2	4	2	2	4,29	0
C207-G1-1-2	245,961	1	2	1	1	26,86	0
C207-G1-1-3	245,961	1	2	1	1	21,90	0
C207-G1-1-4	241,552	2	3	2	1	33,21	0
C207-G1-2-1	214,926	2	4	2	2	2,47	0
C207-G1-2-2	245,961	1	2	1	1	28,88	0
C207-G1-2-3	243,240	2	3	1	2	29,17	0
C207-G1-2-4	245,961	1	2	1	1	30,64	0
C207-G2-1-1	214,926	2	4	2	2	3,23	0
C207-G2-1-2	245,961	1	2	1	1	1483,57	0
C207-G2-1-3	245,961	1	2	1	1	25,82	0
C207-G2-1-4	245,961	1	2	1	1	27,49	0
C207-G2-2-1	214,926	2	4	2	2	3,71	0
C207-G2-2-2	245,961	1	2	1	1	23,99	0
C207-G2-2-3	245,961	1	2	1	1	36,47	0
C207-G2-2-4	245,961	1	2	1	1	27,38	0
C207-G3-1-1	214,926	2	4	2	2	11,92	0
C207-G3-1-2	245,961	1	2	1	1	28,50	0
C207-G3-1-3	245,193	2	3	1	2	53,07	0
C207-G3-1-4	245,961	1	2	1	1	27,41	0
C207-G3-2-1	214,926	2	4	2	2	19,34	0
C207-G3-2-2	245,961	1	2	1	1	22,73	0
C207-G3-2-3	245,961	1	2	1	1	67,24	0
C207-G3-2-4	245,961	1	2	1	1	30,25	0
C208-G1-1-1	215,327	2	4	2	2	2,54	0
C208-G1-1-2	228,900	1	2	1	1	5,46	0
C208-G1-1-3	228,900	1	2	1	1	9,33	0
C208-G1-1-4	228,900	1	2	1	1	7,68	0
C208-G1-2-1	215,327	2	4	2	2	3,21	0
C208-G1-2-2	228,900	1	2	1	1	19,91	0
C208-G1-2-3	228,900	1	2	1	1	8,89	0
C208-G1-2-4	228,900	1	2	1	1	7,05	0
C208-G2-1-1	215,327	2	4	2	2	4,07	0
C208-G2-1-2	228,900	1	2	1	1	21,45	0
C208-G2-1-3	228,900	1	2	1	1	22,93	0
C208-G2-1-4	228,900	1	2	1	1	28,75	0
C208-G2-2-1	215,327	2	4	2	2	4,26	0
C208-G2-2-2	228,900	1	2	1	1	16,79	0
C208-G2-2-3	228,900	1	2	1	1	22,73	0

C208-G2-2-4	228,900	1	2	1	1	9,53	0
C208-G3-1-1	215,327	2	4	2	2	5,63	0
C208-G3-1-2	228,900	1	2	1	1	7,29	0
C208-G3-1-3	228,900	1	2	1	1	16,57	0
C208-G3-1-4	228,900	1	2	1	1	13,31	0
C208-G3-2-1	215,327	2	4	2	2	6,80	0
C208-G3-2-2	226,692	1	2	1	1	25,96	0
C208-G3-2-3	226,692	1	2	1	1	18,36	0
C208-G3-2-4	215,327	2	3	2	1	5,20	0
R103-G1-1-1	571,922	8	15	7	8	65,65	0
R103-G1-1-2	587,407	7	12	6	6	652,32	0
R103-G1-1-3	582,216	7	13	6	7	170,74	0
R103-G1-1-4	573,980	7	14	7	7	90,39	0
R103-G1-2-1	588,521	8	16	8	8	11,98	0
R103-G1-2-2	640,632	8	14	7	7	2478,89	0
R103-G1-2-3	609,131	8	15	8	7	25,29	0
R103-G1-2-4	626,876	8	15	7	8	413,67	0
R103-G2-1-1	548,523	7	13	6	7	21,11	0
R103-G2-1-2	620,085	8	12	6	6	7201,30	15
R103-G2-1-3	548,523	7	13	6	7	19,64	0
R103-G2-1-4	613,422	7	13	7	6	7200,24	6
R103-G2-2-1	555,926	7	12	5	7	1166,08	0
R103-G2-2-2	627,967	8	10	5	5	7201,44	30
R103-G2-2-3	588,849	8	12	7	5	7201,26	20
R103-G2-2-4	555,926	7	13	6	7	897,77	0
R103-G3-1-1	496,069	6	9	6	3	71,37	0
R103-G3-1-2	509,142	5	9	5	4	2153,38	0
R103-G3-1-3	496,069	6	10	6	4	51,59	0
R103-G3-1-4	509,142	5	10	5	5	1358,30	0
R103-G3-2-1	537,849	7	13	6	7	67,17	0
R103-G3-2-2	551,622	6	10	5	5	3794,38	0
R103-G3-2-3	539,006	7	12	6	6	83,18	0
R103-G3-2-4	550,431	6	11	5	6	280,49	0
R108-G1-1-1	483,726	6	12	6	6	190,43	0
R108-G1-1-2	489,780	6	11	5	6	247,65	0
R108-G1-1-3	489,780	6	11	5	6	3939,76	0
R108-G1-1-4	551,678	7	10	4	6	7201,08	22
R108-G1-2-1	491,952	6	12	6	6	3744,57	0
R108-G1-2-2	527,973	6	11	6	5	7208,96	14
R108-G1-2-3	496,138	6	11	5	6	7200,32	3
R108-G1-2-4	520,136	6	11	6	5	7201,24	16

R108-G2-1-1	523,945	7	13	6	7	1301,98	0
R108-G2-1-2	533,629	7	12	5	7	7201,91	5
R108-G2-1-3	523,945	7	13	6	7	1299,01	0
R108-G2-1-4	546,971	7	12	6	6	7201,27	18
R108-G2-2-1	491,324	6	12	6	6	2688,22	0
R108-G2-2-2	515,422	6	10	5	5	7201,22	20
R108-G2-2-3	492,753	6	11	5	6	5285,95	0
R108-G2-2-4	502,525	6	11	6	5	7202,74	4
R108-G3-1-1	451,292	5	9	5	4	1432,48	0
R108-G3-1-2	488,197	5	8	4	4	7201,41	23
R108-G3-1-3	464,282	5	9	4	5	7202,21	17
R108-G3-1-4	451,292	5	9	5	4	1056,72	0
R108-G3-2-1	439,521	5	10	5	5	365,29	0
R108-G3-2-2	459,176	5	9	5	4	7200,24	4
R108-G3-2-3	476,471	5	9	4	5	7201,19	23
R108-G3-2-4	463,592	5	9	5	4	7201,38	15
R201-G1-1-1	470,830	4	8	4	4	0,09	0
R201-G1-1-2	781,808	3	4	2	2	6,60	0
R201-G1-1-3	489,374	3	6	3	3	0,41	0
R201-G1-1-4	601,980	3	5	3	2	2,15	0
R201-G1-2-1	498,416	4	8	4	4	0,17	0
R201-G1-2-2	518,444	3	6	3	3	0,62	0
R201-G1-2-3	518,444	4	7	3	4	0,69	0
R201-G1-2-4	514,469	4	7	4	3	0,44	0
R201-G2-1-1	495,906	4	8	4	4	0,27	0
R201-G2-1-2	655,240	3	4	2	2	5,93	0
R201-G2-1-3	543,315	3	5	2	3	0,58	0
R201-G2-1-4	517,603	3	6	3	3	0,50	0
R201-G2-2-1	483,665	4	8	4	4	0,33	0
R201-G2-2-2	582,653	2	4	2	2	1,93	0
R201-G2-2-3	494,589	3	6	3	3	0,70	0
R201-G2-2-4	577,045	3	5	3	2	1,45	0
R201-G3-1-1	482,398	4	8	4	4	0,34	0
R201-G3-1-2	553,186	2	4	2	2	1,17	0
R201-G3-1-3	553,186	2	4	2	2	1,05	0
R201-G3-1-4	486,859	3	6	3	3	0,31	0
R201-G3-2-1	482,398	4	8	4	4	0,22	0
R201-G3-2-2	573,317	2	4	2	2	0,98	0
R201-G3-2-3	552,390	3	5	2	3	1,00	0
R201-G3-2-4	547,688	3	5	3	2	0,98	0
R210-G1-1-1	415,300	4	8	4	4	19,20	0

R210-G1-1-2	427,007	2	4	2	2	67,49	0
R210-G1-1-3	423,472	3	5	2	3	62,34	0
R210-G1-1-4	418,228	3	6	3	3	24,40	0
R210-G1-2-1	412,320	3	6	3	3	14,98	0
R210-G1-2-2	414,456	2	4	2	2	17,66	0
R210-G1-2-3	414,456	2	4	2	2	20,84	0
R210-G1-2-4	414,456	2	4	2	2	22,04	0
R210-G2-1-1	408,300	3	6	3	3	48,53	0
R210-G2-1-2	414,456	2	4	2	2	71,82	0
R210-G2-1-3	414,456	2	4	2	2	76,11	0
R210-G2-1-4	414,456	2	4	2	2	68,89	0
R210-G2-2-1	405,473	3	6	3	3	22,18	0
R210-G2-2-2	410,599	2	4	2	2	20,75	0
R210-G2-2-3	410,599	2	4	2	2	17,47	0
R210-G2-2-4	410,599	2	4	2	2	21,12	0
R210-G3-1-1	405,473	3	6	3	3	25,13	0
R210-G3-1-2	413,441	2	4	2	2	74,44	0
R210-G3-1-3	413,441	2	4	2	2	67,75	0
R210-G3-1-4	413,441	2	4	2	2	68,05	0
R210-G3-2-1	405,473	3	6	3	3	13,18	0
R210-G3-2-2	413,255	2	4	2	2	44,46	0
R210-G3-2-3	413,255	2	4	2	2	52,00	0
R210-G3-2-4	413,255	2	4	2	2	22,26	0
RC101-G1-1-1	759,749	9	18	9	9	0,08	0
RC101-G1-1-2	766,780	9	17	8	9	0,44	0
RC101-G1-1-3	766,780	9	17	8	9	0,14	0
RC101-G1-1-4	789,048	9	16	7	9	0,23	0
RC101-G1-2-1	747,281	9	18	9	9	0,09	0
RC101-G1-2-2	748,684	9	16	7	9	0,34	0
RC101-G1-2-3	747,281	9	17	8	9	0,11	0
RC101-G1-2-4	753,370	9	15	6	9	0,14	0
RC101-G2-1-1	747,313	9	17	8	9	0,12	0
RC101-G2-1-2	802,097	9	14	6	8	0,36	0
RC101-G2-1-3	796,721	9	15	7	8	0,27	0
RC101-G2-1-4	796,721	10	17	9	8	0,25	0
RC101-G2-2-1	787,112	9	18	9	9	0,34	0
RC101-G2-2-2	822,576	9	16	8	8	0,16	0
RC101-G2-2-3	822,576	9	17	8	9	0,30	0
RC101-G2-2-4	798,325	9	17	9	8	0,11	0
RC101-G3-1-1	668,479	8	15	8	7	0,23	0
RC101-G3-1-2	668,479	8	15	8	7	0,17	0

RC101-G3-1-3	711,799	8	13	6	7	0,36	0
RC101-G3-1-4	669,945	8	14	7	7	0,16	0
RC101-G3-2-1	638,329	7	14	7	7	0,30	0
RC101-G3-2-2	727,336	8	10	5	5	0,28	0
RC101-G3-2-3	657,228	7	11	6	5	0,31	0
RC101-G3-2-4	639,899	7	13	6	7	0,25	0
RC105-G1-1-1	685,711	7	14	7	7	5,29	0
RC105-G1-1-2	692008,000	7	13	6	7	6068,00	0
RC105-G1-1-3	692,008	7	13	6	7	6,38	0
RC105-G1-1-4	685,711	7	14	7	7	7,50	0
RC105-G1-2-1	654,088	8	16	8	8	7,71	0
RC105-G1-2-2	671,886	7	12	6	6	12,75	0
RC105-G1-2-3	671,886	7	12	6	6	8,86	0
RC105-G1-2-4	655,457	8	13	7	6	6,83	0
RC105-G2-1-1	618,139	7	13	6	7	2,37	0
RC105-G2-1-2	631,164	7	12	5	7	6,47	0
RC105-G2-1-3	618,139	7	13	6	7	4,79	0
RC105-G2-1-4	618,139	7	13	6	7	3,71	0
RC105-G2-2-1	738,719	9	17	8	9	59,20	0
RC105-G2-2-2	772,125	9	13	6	7	133,55	0
RC105-G2-2-3	743,702	9	14	6	8	64,16	0
RC105-G2-2-4	756,534	9	16	9	7	39,16	0
RC105-G3-1-1	535,048	6	11	5	6	6,33	0
RC105-G3-1-2	557,446	6	8	4	4	51,65	0
RC105-G3-1-3	535,048	6	11	5	6	5,51	0
RC105-G3-1-4	543,507	6	9	5	4	11,65	0
RC105-G3-2-1	598,053	7	14	7	7	6,55	0
RC105-G3-2-2	670,679	7	12	6	6	113,68	0
RC105-G3-2-3	655,278	7	13	6	7	38,69	0
RC105-G3-2-4	610,823	7	13	7	6	12,11	0
RC201-G1-1-1	367,237	3	6	3	3	0,16	0
RC201-G1-1-2	548,583	2	4	2	2	1,58	0
RC201-G1-1-3	548,583	2	4	2	2	1,61	0
RC201-G1-1-4	490,817	3	5	3	2	0,94	0
RC201-G1-2-1	368,272	3	6	3	3	0,13	0
RC201-G1-2-2	523,284	2	4	2	2	1,30	0
RC201-G1-2-3	516,103	3	5	2	3	1,62	0
RC201-G1-2-4	520,882	3	5	3	2	1,62	0
RC201-G2-1-1	370,286	3	6	3	3	0,19	0
RC201-G2-1-2	525,730	2	4	2	2	0,81	0
RC201-G2-1-3	525,730	3	5	2	3	0,87	0

RC201-G2-1-4	492,563	3	5	3	2	0,76	0
RC201-G2-2-1	362,597	3	6	3	3	0,41	0
RC201-G2-2-2	501,923	2	4	2	2	1,89	0
RC201-G2-2-3	501,923	3	5	2	3	2,12	0
RC201-G2-2-4	413,489	3	5	3	2	0,87	0
RC201-G3-1-1	361,235	3	5	3	2	0,45	0
RC201-G3-1-2	483,752	2	4	2	2	3,96	0
RC201-G3-1-3	483,752	2	4	2	2	5,13	0
RC201-G3-1-4	361,235	3	5	3	2	0,20	0
RC201-G3-2-1	368,272	3	6	3	3	0,14	0
RC201-G3-2-2	491,948	2	4	2	2	1,34	0
RC201-G3-2-3	491,948	2	4	2	2	1,86	0
RC201-G3-2-4	456,538	3	5	3	2	0,76	0
RC205-G1-1-1	344,768	3	6	3	3	1,00	0
RC205-G1-1-2	480,305	2	4	2	2	1473,82	0
RC205-G1-1-3	480,305	2	4	2	2	276,61	0
RC205-G1-1-4	480,305	2	4	2	2	105,00	0
RC205-G1-2-1	338,925	3	6	3	3	4,21	0
RC205-G1-2-2	443,074	2	4	2	2	205,42	0
RC205-G1-2-3	443,074	2	4	2	2	164,49	0
RC205-G1-2-4	443,074	2	4	2	2	175,33	0
RC205-G2-1-1	342,755	3	6	3	3	2,45	0
RC205-G2-1-2	451,902	2	4	2	2	349,86	0
RC205-G2-1-3	414,636	3	5	2	3	282,19	0
RC205-G2-1-4	449,187	3	5	3	2	331,30	0
RC205-G2-2-1	349,479	3	6	3	3	43,31	0
RC205-G2-2-2	430,499	2	4	2	2	2372,31	0
RC205-G2-2-3	430,499	2	4	2	2	470,47	0
RC205-G2-2-4	405,856	3	5	3	2	436,18	0
RC205-G3-1-1	338,925	3	6	3	3	1,50	0
RC205-G3-1-2	442,110	2	4	2	2	532,99	0
RC205-G3-1-3	442,110	2	4	2	2	456,79	0
RC205-G3-1-4	399,288	3	5	3	2	30,14	0
RC205-G3-2-1	340,938	3	6	3	3	4,63	0
RC205-G3-2-2	414,271	2	4	2	2	53,21	0
RC205-G3-2-3	414,271	2	4	2	2	53,85	0
RC205-G3-2-4	411,916	3	5	3	2	35,80	0

APPENDIX B: THE LIST OF THE INSTANCES WHICH HAS HUGE GAP

CPLEX cannot obtain a reasonable lower bound for the instances, of which the names provided below in two hours. So we have provided the results of these instances with an additional constraint.

Table B.1. The list of the instances

Instance
C207-G1-1
C207-G1-2
C207-G2-1
C207-G2-2
C207-G3-1
C207-G3-2
C208-G1-1
C208-G1-2
C208-G2-1
C208-G2-2
C208-G3-1
C208-G3-2
R210-G1-1
R210-G1-2
R210-G2-1
R210-G2-2
R210-G3-1
R210-G3-2
RC205-G1-2
RC205-G2-2
RC205-G3-1