ALCOM-Deliverable D9, WP 3.3
Production and Transportation Planning
Modeling Report

Torsten Fahle University of Paderborn
Fürstenallee 11 33102 Paderborn tef@upb.de

June 2001

Abstract

Home health care, i.e. visiting and nursing patients at their homes, is a strongly growing sector in the medical service business. The challenge of finding good working plans for home health companies is the combination of vehicle routing and staff rostering aspects. Both are well known combinatorial optimization problems. To obtain cost optimal solutions, however, it is crucial to solve the nurse scheduling problem as a whole due to the high interdependencies of optimized routes and the constraints from the rostering.

In this report we describe how we model data of a generic home health care software. Furthermore, we present an outline of the algorithmic methods planned to solve the home health care problem.

Report:	D9	**Resp.:**	Utrecht
WP:	3.3	**Resp.:**	Paderborn

Security: public
Delivery: month 12

1 Introduction

Home health care, i.e. visiting and nursing patients at their homes, is a strongly growing sector in the medical service business. More and more private companies are working in this area. As the nursing companies are getting larger, the problem arises of how to schedule the nursing staff. The challenge of this problem is to combine aspects of vehicle routing and staff rostering. Both are well known combinatorial optimization problems. To obtain cost optimal solutions, however, it is crucial to solve the nurse scheduling problem as a whole due to the high interdependencies of optimized routes and the constraints from the rostering. Rostering constraint include hard ones like qualification requirements or work time limitations, and soft ones. Especially soft constraints are difficult to model, but have to be considered for applicable schedules. Examples for typically soft constraints are:

- patients do not like frequent changes of nursing staff
- the right 'chemistry' between patients and staff has to be ensured
- staff satisfaction concerning e.g. work load and work time should be maximized

The vehicle routing part of the problem has to respect time windows and maintenance constraints, and inhomogeneous fleets (bicycles, public transport, cars).

In Figure 1 we present a more detailed view on constraints relevant for the home health care problem.

Among all solutions those with minimal costs are of interest for companies. Costs in this context may reflect expenses for fuel, etc. or costs for the staff. In Germany, a company gets a fixed amount of money for a given service independent from the income of the nurse providing the service. Hence, companies prefer schedules where highly qualifies staff is only assigned to patients that need that high qualification. Simple jobs should be assigned to less skilled employees. In concrete applications, costs for a working plan consists out of up to 20 different parameters.

The goal of the project is to model this problem and to develop suitable algorithms for finding good rosters respecting all hard and soft constraints mentioned above. Databases and GUI are developed by an industrial partner.

1.1 Literature Review

To our knowledge, there are only few publications on the topic of optimization and scheduling in home health care: Cheng and Rich describe a mixed-integer programming (MIP) approach [1]. In [3] a decission support system is proposed that is based in simple scheduling heuristics. Two related topics, however, have attracted more researchers: Planning systems for Hospitals model some aspects that are also needed for home health care. We only mention [2, 4, 13, 5] as an example. Most of them use constraint programming techniques in order to model and solve the nurse rostering problem. Vehicle Routing with Time Windows (see e.g. [10, 11]) reflects the mobility aspect in the problem, but ignores any further restriction. However, only a combination of time scheduling and route planning systems seems to be appropriated for the home health care problem as a whole.

In the next section we describe how we model the home health care problem. In section 3 we give a brief description of the approaches planned for the next phase of the project.

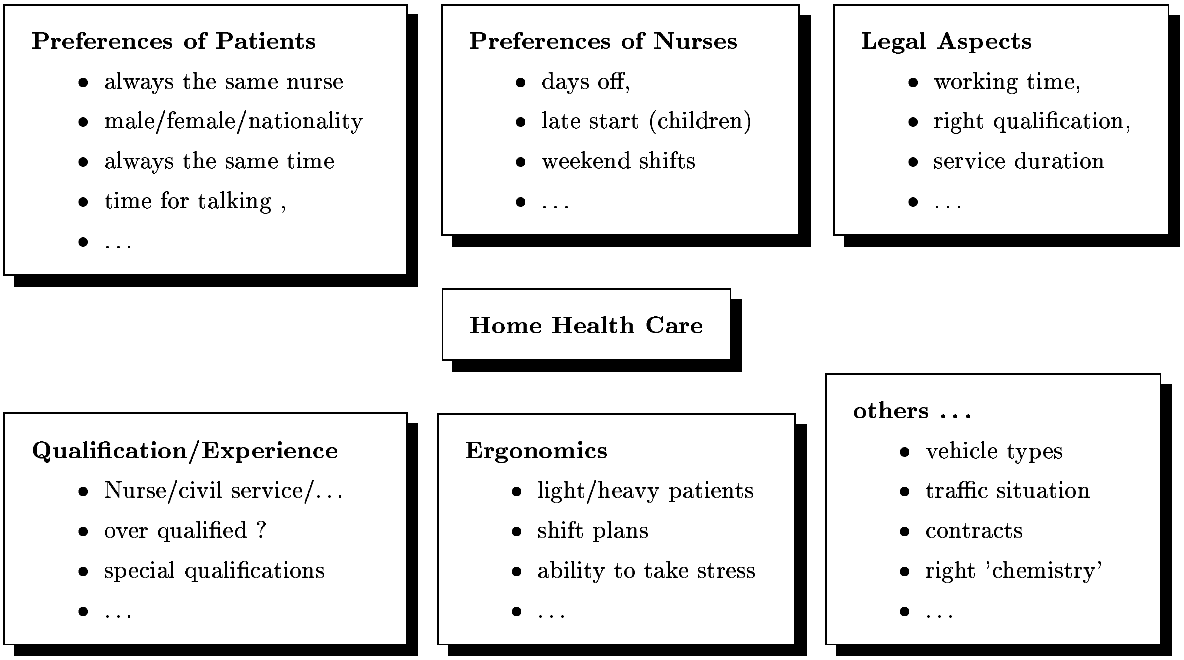

Figure 1: An overview on constraints relevant for the home health care problem.

2 Modeling the Home Health Care Problem

In co-operation with three home health care companies, a consulting company, and researchers from ergonomics we determined the important parameters that have to be respected for a generic home health care system. We shall briefly describe the key parameters in the following. For the exact modeling we refer to [9], a report on a grammar in BNF describing the data exchanged between GUI/database and optimization algorithms.[1]

2.1 Key Parameters For Home Health Care

The parameters for optimizing nurse schedules are grouped into five input, and one output exchange file. Additional output is generated into log files. Input files are

Nurses Contains information on the staff, their individual qualifications, working times, free days, special arrangements, driving licenses, etc.

Patients Consists of general information on the patients such as: Location, kind of services, duration and frequency for each service, dates, required skills

Location is the digital road and location information table

Vehicle lists all vehicles (cars, bike, public transport) available for serving the patients. Also contains information on availability, maintenance, typical working radius and typical speed.

[1] As the industrial co-operation only concerns partners from Germany, and involves non-english speaking persons as well, that report is currently available in german only.

Matching contains information on possible or forbidden combinations of patients and nurses due to personal relations or dislikes.

The output file represents a cost-optimized schedule, e.g. the assignment of nurses to patients and vehicles respecting all constraints. Also, additional information on the robustness of that solution can be provided.

3 Solving Home Health Care Problems

In this section we provide an outlook on the further development within the project. We restrict our presentation to two optimization modules.

One important point to be respected in the project is the design of generic algorithms that can be used for many different home health care companies without changing the general strategies. Home health care companies may differ in many organizational aspects like:

- single depot / multi depot
- working on demand / contract on working time
- one day planning period up to four weeks planning period
- ...

Laws and regulations are another source of frequent changes: In Germany, during the last 15 month there were 5 major changes in laws being important for the health care sector. Some of these changes only require changing of parameters (e.g. adapt some service times). Other require organizational changes, and thus also may influence the way schedules and working plans are calculated by the planning system.

In order to cope with this *need for flexibility* it was decided to adapt ideas and concepts from the area of constraint programming and to combine it with the strength of traditional optimization techniques.

3.1 Start Heuristics

It is planned to implement several simple start heuristics that are able to generate (not necessarily good) solutions for the home health care problem in short time. These heuristics typically are based on matching/assignment techniques that check all constraints involved in order to generate a schedule. Depending on the characteristics of the concrete home health care company different strategies will be used:

- Service within a city: usually short distances, but tight time tables $\Rightarrow$ Scheduling based heuristics.
- Service in the countryside: usually long distances $\Rightarrow$ heuristics for routing with time windows.

Given the typical sizes of home health care organizations, these heuristics will not run longer than up to 30 seconds on a standard PC. Such running times are well suited for a quick overview on the planning situation for the next week, or for recalculating a schedule in case of short term changes (new patients, failure of vehicles, illness of nurses, timing problems,...) that have to be scheduled quickly.

Γ' :=`columnsFromStartHeuristic()`
repeat
   $\lambda :=$ `solveLP`(Γ') {get new duals}
   $\{x_{j_1}, \ldots, x_{j_k}\} :=$ `solveSubproblem`(λ)
   $\Gamma' = \Gamma' \cup \{x_{j_1}, \ldots, x_{j_k}\}$
until $(\{x_{j_1}, \ldots, x_{j_k}\} = \emptyset)$

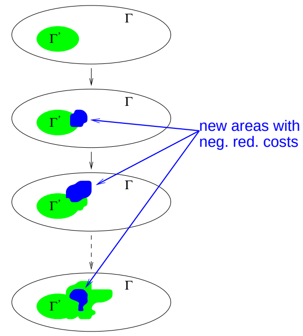

Figure 2: Outline of Column Generation

3.2 Optimization Components

In order to get working plans of good quality, more sophisticated approaches are needed. As the homes health care problem decomposes naturally in to the two stages: (a) generation of schedules for a nurse and (b) combining schedules in order to cover all patients demands, a column generation approach is planned to be implemented in the next phase of the project. Constraint Programming based Column Generation [12] has been shown to be quite generic while still preserving the ability of generating good quality solutions for crew rostering problems (see [8]). We will adapt this concept for the home health care problem.

Referring to the decomposition mentioned above, we can represent a possible working plan for a nurse by a vector $w^{(j)} = (w_1, \ldots, w_m) \in \{0,1\}^m$. In that coding, $w_i = 1 \iff$ a nurse has to cover the activity i (where activities are services for a given patient at a given time). Also, it is possible to assign costs $c^{(j)}$ to such a working plan.

Putting all possible working plans for all nurses into a matrix A, finding an cost-optimal solution to the home health care problem corresponds to solving the linear integer program $\min cx$ s.t. $Ax = 1^m$, where $x \in \{0,1\}^n$ and $A \in \{0,1\}^{n \times m}$. Such an integer LP is called a *set partitioning problem*. Relaxing the integrality constraint $x \in \{0,1\}^n$ to $0 \leq x_i \leq 1 \; \forall i = 1, \ldots, n$ allows to apply techniques from LP therory. Integrality than has to be achieved by a succeeding branch-and-bound or branch-and-price approach.

3.2.1 Column Generation

However, there are $O(2^m)$ potential workings plans. Column generation is a well-known technique in Operation Research dating back to the works of Dantzig and Wolfe [6]. It has been successfully applied to various types of vehicle routing, or crew rostering problems ([7]).

In brief, column generation allows solving huge linear programs by only considering a small number of initial columns. Reduced cost information is used to iteratively generate new columns that improve the objective value of the LP. As soon as all reduced cost values are non-negative, the optimal LP value is reached and the process terminates. Fig. 2 shows the process. Reduced cost values are obtained by adding the dual values λ.

We construct a directed graph G where nodes represent the activities to be served, and nodes i, j are connected iff it is possible for the nurse under consideration to serve the activity of node j directly after the activity of node i. We add a virtual start node s that is connected to all nodes representing activities. Furthermore, all activity nodes are connected to a virtual

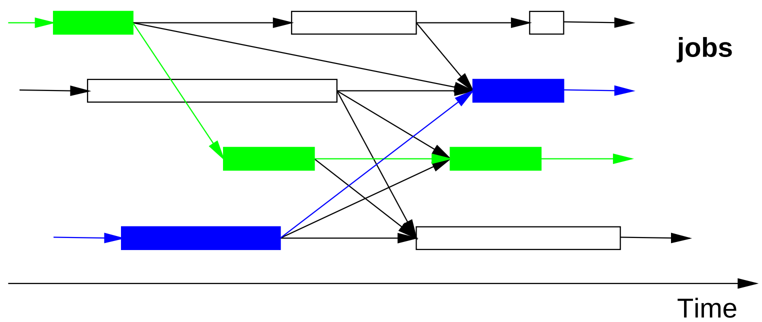

Figure 3: A possible working plan is a constraint shortest path in the task graph that minimizes reduced costs

end node t. When edge costs correspond to the dual values λ, finding a possible working plan then is equivalent to finding a constraint shortest (s, t)- path in G.

Constrained programming based column generation now models other constrains in such a way that if a service of activity j before activity i results in a removal of those edges of G that would allow a path from i to j.

References

[1] Cheng and Rich. *A Home Health Care Routing and Scheduling Problem*, Technical Report CAAM TR98-04, Rice University, 1998.

[2] Abdennadher, Schlenker *Nurse Scheduling using Constraint Logic Programming*, In Procs. of the 11th Conf. on Innovative Applications of Artificial Intelligence, 838–843. Menlo Park, Calif.: AAAI Press. 1999.

[3] Begur, Miller and Weaver. *An integrated spatial DSS for scheduling and routing home-health-care nurses.* Interfaces, vol.27, no.4, July-Aug. 1997, pp.35–48.

[4] Burke et al. *A Hybrid Tabu Search Algorithm for the Nurse Rostering Problem*, Lecture Notes in Artificial Intelligence 1585, Simulated Evolution And Learning, Selected Papers of SEAL ?98, Canberra, 187–194, 1999.

[5] Cheng, Lee, and Wu. *A Nurse Rostering System Using Constraint Programming and Redundant Modeling*, IEEE Transactions in Information Technology in Biomedicine, 1(1):44–54, 1997.

[6] G.B. Dantzig and P. Wolfe. The decomposition algorithm for linear programs. *Econometrica*, 29(4):767–778, 1961.

[7] J. Desrosiers, Y. Dumas, M.M. Solomon, F. Soumis, Time constrained routing and scheduling, in *Network Routing, Handbooks on Operations Research and Management Science 8*, M.O. Ball, T.L. Magnanti, C.L. Monma, G.L. Nemhauser eds., North-Holland, Amsterdam, 35–139, 1995.

[8] T. Fahle, U. Junker, S.E. Karisch, N. Kohl, M. Sellmann, B. Vaaben. Constraint programming based column generation for crew assignment. Technical Report tr-ri-99-212, University of Paderborn, 1999. *To appear in Journal of Heuristics Vol 8, No 1, 2001.*

[9] Fahle and Bertels. *Parpap AP2 Datenformat v0.2* internal project document, in german. see `http://www.uni-paderborn.de/cs/ag-monien/PERSONAL/TEF/datenformat.ps`

[10] M.L. Fisher, Vehicle routing, in *Network Routing, Handbooks on Operations Research and Management Science 8*, M.O. Ball, T.L. Magnanti, C.L. Monma, G.L. Nemhauser eds., North-Holland, Amsterdam, 1–33, 1995.

[11] M. Gendreau, G. Laporte, J.-Y. Potvin, Vehicle routing: modern heuristics, in *Local Search in Combinatorial Optimization*, E.H.L. Aarts and J.K. Lenstra eds., John Wiley & Sons, Chichester, 311–336, 1997.

[12] U. Junker, S.E. Karisch, N. Kohl, B. Vaaben, T. Fahle, M. Sellmann. A framework for constraint programming based column generation. *Proceedings of the CP'99*, Springer LNCS 1713:261–274, 1999.

[13] Mason, Smith. *A Nested Column Generator for solving Rostering Problems with Integer Programming*, n Int. Conf. on Optimisation : Techniques and Applications, Caccetta et al.(eds.), 1998.