Planning Nurses in Maternity Care: a Stochastic Assignment Problem

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Abstract. With 23 percent of all births taking place at home, The Netherlands have the highest rate of home births in the world. Also if the birth did not take place at home, it is not unusual for the mother and child to be out of hospital in a few hours after the baby was born. The explanation for both is the very well organised maternity care system. However, getting the right maternity care nurse available on time introduces a complex planning issue that can be recognized as a Stochastic Assignment Problem. In this paper an expert rule based approach is combined with scenario analysis to support the planner of the maternity care agency in his work.

1. Introduction

The main view in The Netherlands is that childbirth is not a medical condition and pregnant women should not be treated as patients. As a result pain relief is not encouraged and home births are encouraged.

The role of the doctor or gynaecologist in a normal pregnancy in The Netherlands is minor and in most cases they are not involved at all. The central person in the pregnancy is the midwife. With 23 percent of all births taking place at home (decreased from 38% in 1990), The Netherlands boasts the highest rate of home births in the world. In Britain home births account for 3 percent of total births, in Belgium and Germany this figure is closer to 1 percent. Similarly 99 percent of births in the United States take place in a hospital [1].

Most probably the main merit of giving birth in The Netherlands lies in the post-natal care [2]. Also if the birth did not take place at home, it is not unusual for the mother and child to be out of hospital in hours after the baby is born. There is a logical explanation for the short post natal care in Dutch hospitals: the maternity care system. The Dutch maternity care nurse is the envy of many women outside of the Netherlands. This type of maternity care is pretty much unique. For at least a week after the birth professional help is on hand. During a home birth the maternity care nurse supports the midwife and after a hospital birth the maternity care nurse is on your doorstep within hours of leaving hospital.

Maternity care duties range from care for the new mother and infant, light household duties, guidance on breast feeding and baby care and looking after other family members (such as other children). Every pregnant woman in the Netherlands has the right to post natal maternity care. The exact details of what a particular maternity nurse will deal with, as well as the frequency and length of her visits, will be determined before birth. This prenatal house-call takes place at around the 7th or 8th month and allows both parties to discuss the needs and expectations.

Therefore a pregnant woman has to register with a maternity care agency (MCA), preferably before the 12th week of pregnancy, to be sure to get this unique care.

When labour starts and the birth is planned at home, both the midwife and the MCA are warned. When the birth is planned at the hospital or moved to the hospital just before or during the childbirth, the MCA is warned when the mother and child leave the hospital. When the MCA is warned they will send a nurse to the home. Normally several nurses are stand-by or on duty. Here the question arises which nurse should be sent to the specific house.

2. Challenge

For the MCA it is important to provide adequate care during an adequate number of hours, and at the right time. The MCA needs an expert system providing an admissible solution in due time by assigning the right nurse to each upcoming demand, weighting the effect this assignment has on decisions in the future, under uncertainty. Nowadays, if there is a demand for a nurse, the planner of the agency should take into account a large number of variables in the decision of which of the available nurses has to be assigned, like:

- skills of the nurse should comply to the demand;
- the nurse should be able to work in a certain house, where people do or do not smoke, with or without other kids or pets, where are stairs etc.;
- the workload should be evenly distributed but nurses should work a number of hours as close to their contract as possible;
- meet health and safety standards;
- comply to work schedule agreements;
- perform high on quality standards like reaction time and number of changes in nurse.

Although most experienced planners succeed in this assignment in most cases, structural incorporation of the future effects of a decision is hard for a human. Computer assistance is welcome here. This expert system should work based on mathematical algorithms and use the already digitally available but continuously changing data on demand side (duration, size, location) and supply side (contract size, residence, utilization, deployment constraints, schedules). Such expert systems exist in other sectors (regular nurses, logistics, telecommunications, energy) but is not yet available in maternity care industry.

The planning methodology must find a balance between productivity of workers and the quality of care received. An important indicator of the quality are the number of hours received and the number of changes of nurses. More than one change (two different nurses) is not desirable. In this paper an approach is proposed for this problem.

3. Problem description

The key problem here is that a nurse should be assigned as soon as an incoming demand arrives. The planner has a number of possibilities here: the planner can

- Use one of the nurses available due to a scheduling mechanism; nurses have had some free days and are now available for a new task (on the 'bench');
- Replace an existing assignment by taking the nurse from another task to the new task and send a nurse from the 'bench' to the free coming task;
- Use an external nurse, on call-basis, with no contract based on a fixed number of hours.

Note that the nurses 'on the bench' are already paid and the external nurses have to be paid based on the hours they make. Their cost per hour will be higher. This assignment should be such that it optimizes the performance indicators of the agency, like profit, number of delivered hours, number of nurse changes etc. It should also comply with constraints that consider skills of the nurse and allergies.

As an example take a new task for which two nurses are available on the 'bench'. One of the nurses (1) is willing to serve in a house that has snakes as pets and needs hours to fulfil her contract. The other nurse (2) does not like snakes and is already high in her hours that month. The planner knows that there is a client, just passed her due date, that has snakes. What does he do, save nurse 1 for the client with a snake, creating the probability that she does not fulfil the hours in her contract or not, enlarging the probability on a nurse change (one of the performance indicators)?

From a mathematical point of view the problem can be seen as a special case of the sequential stochastic assignment problem as discussed in [3, 4]. This problem addresses the assignment of n IID sequentially-arriving tasks to n available workers (resources). Choosing a certain worker to perform the arriving task renders him unavailable for future assignments, with an expected reward associated with this assignment. The objective is to assign the n workers to n arriving tasks so as to maximize the expected total reward obtained from pairing workers with tasks. The difficulty in making the assignment decisions is that the assignments are performed in real-time. Once a task arrives and its value is revealed, it must be paired instantly with one of the available workers, without knowing any of the future task values. Although the main idea is the same in the nurse assignment problem, assign unknown arriving tasks to one of the available workers, several characteristics of the nurse assignment problem are different:

- The nurses come back in the system after their job finished.
- The nurse can stop the current job, start a different one, having another nurse replacing her in the first job.
- There are more tasks than nurses.
- A nurse can handle more than one job together on the same day (e.g., two duties of 3 hours).
- The nature of the future jobs are known, only the arrival time is stochastic.
- The problem is multi-objective.
- etcetera.

This makes the problem special and not discussed earlier.

4. Approach

The main idea of the approach presented here to assist the planner on this assignment decision is that of scenario analysis: determine for each possible assignment the expected effect on the performance indicators. For this, for every possible assignment a simulation is performed, where a huge number of possible realisations of the future (all the births) are generated. For each of these realisations a planning is created; which nurse is doing which task. The method that is used for this is a greedy rule based forward assignment model [5]. Next a score has to be assigned to each planning.

In Algorithm 1 the main procedure is described. For the assignment of a given task t, the arriving demand for a nurse, for all the available nurses that have the minimum skills for this task a set of simulation is performed. The available nurses are the nurses on the 'bench', all active nurses on another (interruptible) job and the set of external nurses. In other words, first only the nurses on leave (rest period, holiday) are not considered. Next, if a certain skill is demanded, the nurse have to fulfil this request. This can be some skills on breastfeeding, special care or the willingness to serve in a house with smokers, certain animals, other kids etc.

For each possible assignment a set of replications of the simulation ($NumberReplications$) is performed. In each simulation a realization is determined where the dates of all the delivery dates

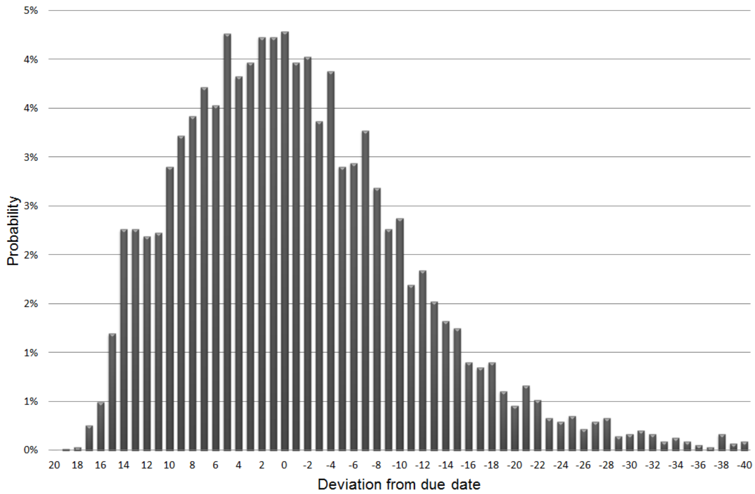

Figure 1. Probability deviation from due date

are fixed following the probability distribution, see the example in Fig. 1. For each realisation an assignment is calculated. This assignment is scored on the performance indicators as defined by the MCA.

Algorithm 1 Main Approach

Require:
Ensure: Assignment of task t
for $i \in$ AvailableNurses **do**
  if Nurse i can perform task t **then**
    $j = 1$
    $N = NumberReplications$
    while $j < N$ **do**
      Create dates for all deliveries resulting in tasks $t_1, ..., t_n$
      P_j=CreateGreedyPlanning($t_1, \ldots, t_n$)
      Calculate score $S_j(P_j)$
      j=j+1
    end while
    Score of nurse i: $TS_i = \frac{1}{N} \sum_{j=1}^{N} S_j$
  end if
  Assign task t to nurse $i = \text{argmin}_k\, TS(k)$
end for

How to create the planning is explained in Algorithm 2. Here a rule based assignment is chosen to get an acceptable calculation time. The exact quality of the solution is not the most important issue, where the planning should only reflect a picture of the effects of an initial assignment.

Based on expert opinion of the current planners of the agency three properties are translated to the rule base:

(i) Accomplishment: which part of the task (in hours) can be performed by nurse i. For example, if a nurse just started working and can work 50 hours until the next rest period and the task is 80 hours, the accomplishment equals $50/80 * 100\% = 62.5\%$.

(ii) Utilization: which part of the contract hours has not be assigned. For example, if a nurse works 140 hours in a period (4 week, month) and she has already worked 40 hours, the utilization equals $100/140 * 100\% = 71.5\%$

(iii) Distance: what is the distance of the nurse to the address of the task. Zero km equals a score of 100%, some maximum distance (e.g. 30 km) equals a score of 0%.

Here all remaining tasks, as drawn in the realization, have to be assigned. For each task, sorted in step 1 first on starting day and within the same starting day on the length of the task (longest first), again all available nurses are considered for assignment. Available has the same meaning as before, only now also rest periods are added. Given legal health and safety standards a rest period of two or three days is placed after a working period of a certain number of days and working hours.

For an available nurse the three properties, Accomplishment, Utilization and Distance, are calculated and added together to form a score. The weight (w_i) of this summation are adjustable. There are also minimum values on each property. This is done in step 9. Under that minimum the total score should be zero. This can also be realized by making the total score a product of the three value instead of a sum.

Now the nurse with the highest total score is assigned to the task.

Algorithm 2 CreateGreedyPlanning

1: Sort $\{t_i\}_{i=1}^n$
2: **for** j=1 to n **do**
3:   **for** $j \in availablenurses$ **do**
4:     Calculate $s_1 = accomplishment(t_i, n_j)$
5:     Calculate $s_2 = utilization(t_i, n_j)$
6:     Calculate $s_3 = distance(t_i, n_j)$
7:     $score[j] := w_1 * s_1 + w_2 * s_2 + w_3 * s_3$
8:     **for all** k=1 to 3 **do**
9:       **if** $s_k < min_k$ **then**
10:         $score[j] := 0$
11:       **end if**
12:     **end for**
13:   **end for**
14:   Assign task i to nurse $j = \text{argmax}_k\, score(k)$
15: **end for**

5. Conclusions

In this paper an approach was presented to support the planner of a MCA in assigning the right nurse to an incoming demand. Right means here that it optimizes the performance indicators in the long run. Especially this long run makes it hard for a human planner. For this, a scenario analysis based expert system was proposed where various assignment decisions are elaborated on a huge number of possible realisations of the future (the births). The first results of using the tool in practice seemed promising, for an agency with 260 expected deliveries and 180 nurses, the tool gives a proposal within 2 minutes. However, due to inaccessibility of data in other, related, systems, the fully automatic version could not be tested for a long period, this is future work. Also refinements of the expert rules and the effect of them on the outcome are open for future work.

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