DEVELOPING A DECISION SUPPORT SYSTEM FOR NURSE SCHEDULING AT A PUBLIC HOSPITAL IN SOUTH AFRICA

S. Friedrich and L. van Dyk

1Department of Industrial Engineering
University of Stellenbosch, South Africa
lvd@sun.ac.za

ABSTRACT

Stellenbosch Hospital is situated in the Western Cape of South Africa. It is an 85-bed public facility and serves a community of 170,000 people. Based on a root cause analysis the conclusion was made that nurse utilization and employee morale at the hospital could be improved by granting nurses more control over schedules. The purpose of this project is to develop a nurse scheduling Decision Support System (DSS). This system allows nurses to be more involved in the annual day-and-night shift scheduling and ward preferences, as these factors have the most significant impact on nurses at work. The day-and-night schedule is solved with an integer programming model. The results are utilized as an input to the custom-made algorithm, which imitates the thought process of the unit managers’ scheduling process, in arriving at a basic feasible solution for ward assignments. A flowchart supporting the documentation and understanding of the code has been developed along with a testing table to verify the results of the code. Finally, a user validation of the DSS at Stellenbosch Hospital confirms its usefulness and effectiveness to support nurse scheduling decision making, enhance nurse utilization and improve employee morale by including nurses in the scheduling process.
1 INTRODUCTION

The provision of health care to all its citizens is of great concern to any government, South Africa is no exception. One of the goals of the South Africa government is to “create a long and healthy life for all South Africans”[1]. The South African health care system faces several challenges which make health care improvement difficult. According to Harrison [2], one of the central concerns lies in the management of health systems.

Stellenbosch Hospital is a typical district hospital, founded in 1942. It is an 85-bed, non-profit public facility that serves a community of 170 000 people. Approximately 5000 patients are treated monthly, comprising an equal number of outpatients and inpatients. The government subsidizes Stellenbosch Hospital with about R95 million annually in an attempt to reach national goals for the health sector.

Primary health care, at no cost to all citizens, is the ultimate aspiration of a government hospital. The nurses are the providers of this service and they ensure the quality of care [3]. Health care and nursing services were thus identified as the focal point for this project. A cause-and-effect analysis (Error! Reference source not found.) was executed to determine the root causes of the problems at Stellenbosch Hospital.

Considering Harrison’s [2] work, as well as personal observations, the quality of health care and nursing services at Stellenbosch Hospital is affected by four major causes. These causes are (Error! Reference source not found. - main bones): 1. the lack of authority of management, 2. low employee morale, 3. limited and inept management of finances and general ineffectiveness and 4. absenteeism of staff.

Utilizing industrial engineering tools to upgrade the nurse scheduling process yields potential opportunities for improving the quality of health care and nursing services at Stellenbosch Hospital, and possibly other health care facilities in South Africa.

2 PURPOSE AND METHODOLOGY

The most common root causes of substandard health care identified at Stellenbosch Hospital are; the complexity of scheduling and incorporating nurses’ preferences in schedules, inadequate nurse utilization and shift coverage, and nurses’ lack of authority and control over schedules. Resolving these root causes could ultimately alleviate the main predicament of insufficient quality of health care and nursing services at Stellenbosch Hospital.

The purpose of this project is to develop a nurse scheduling Decision Support System (DSS). The following objectives are pursued to achieve this purpose:

- Provide decision makers with a DSS,
- Improve and enhance nurse utilization,
- Involve nurses in the scheduling process and
- Improve employee morale.

The methodology is a combination of the strategies developed by Turban et al[4] and Winston [1], as follows:

- Decide on a scope of decisions that need to be integrated into the programme in order to incorporate the most relevant factors,
- Observe the system and decide on which data to use,
- Decide which development software to use,
- Choose an algorithm,
- Define a mathematical model that describes the real-world problem and
- Find possible solutions to the modelled problem and evaluate them.

3 THE DECISION SUPPORT SYSTEM
“Decision Support Systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions.... It is a computer-based support system for management decision makers who deal with semi-structured problems”[4].

The most important DSS inputs for Stellenbosch Hospital were identified as; the different types of nurses (sister, staff nurse, and assistant nurse), nurses’ preferences, nurses’ availability, day or night shift assignment, nurse requirements and nurses’ qualifications. The process was the scheduling process, which would transform the input information into a feasible assignment of nurses, and thus form the output. The decision makers are the unit managers who ensure the feasibility of the schedule and give comments on how it may be improved. This is transferred as inputs and an improved schedule is then created. Furthermore, due to the fact that the public has no insight into scheduling procedures, the hospital scheduling process can be classified as a closed system.

3.1 Nurse scheduling algorithms

The nurse scheduling problem is semi-structured, as it requires human judgment combined with structured elements, or known variables, for instance the number of wards. The scheduling problem furthermore supports operational activities which call for regular decision making. A DSS is a possible solution to this type of problem[4].

Nurse scheduling models have been of interest to operations researchers for decades, for example Bailey’s [5]shift personnel scheduling model, which focuses mainly on the day-to-day scheduling. This involves work patterns, off days, weighing nurse preference against cost (which includes patient inconvenience due to understaffing) and taking different constraints into account, for instance maximum day shifts allowed per week. This model takes the day-and-night assignments and ward assignments as given inputs.

Ozkarahan[6] uses Bailey’s [5]work and expands on it. He “allocates optimum work patterns to individual nurses based on their desires and compatibilities”. In contrast to Bailey’s work, Ozkarahan’s model takes note of the ward/unit allocations in the day-to-day scheduling system. His model assigns a nurse to a specific work pattern in a specific ward. Aickelin and Dowsland[7] on the other hand take day-and-night scheduling into account, but ignore nurse type and applicable ward assignments.

Nurse scheduling is also addressed locally, as mentioned in Bester et al[8] in which a Nurse Rostering Decision Support System (NURODSS) was developed for Stikland Hospital, in the Western Cape, using metaheuristics. Similar to Bailey’s [5]model, this DSS takes day-and-night, as well as the ward assignments as given inputs.

Numerous models assume day-and-night shift, as well as ward assignments, as given inputs. Other models only cater for day-and-night scheduling, and further models address ward assignments but ignore day-and-night scheduling. Incorporating all factors into one algorithm makes the problem very complex. Consequently, in this project the DSS caters for these neglected but important scheduling areas that could be used as a possible input to the other models described.
4.2. Inputs and outputs to the system

- Nurse qualifications information
- Names of nurses to be assigned
- Nurse availability information
- Nurse shift type information
- Nurse hierarchy type information
- Ward's nurse requirements information
- Wards information
- Current quarter time information
- Hospital rules
- Judgement and common sense

In the current scheduling system, unit managers meet once a month to manually schedule day-and-night, as well as ward assignments, of different nurses with diverse skills, to seven wards. This is the bulk of the work. Subsequently, shifts are recorded in a shift book according to the fixed; three on-, three off-, two on-, two off- days shift pattern. One shift is 12 hours from 7 pm to 7 am or from 7 am to 7 pm. Nurses are always scheduled in pairs, thus the second nurse follows a pattern; three off-, three on-, two off-, and two on- days. The unit managers call it the “exchange”-shift, this particular pattern was developed by Stellenbosch Hospital. According to the unit manager, there is no specific reason for this pattern except that it reduces complexity of scheduling. The five unit managers themselves and some of the assistant nurses follow a stretch shift which is a normal working day shift from 7 am to 4 pm from Monday to Friday. The unit managers decide on the shift type for each nurse.

Day-and-night shift assignments are currently done each month, and each nurse has to work three consecutive months of night shifts. This arrangement is part of hospital regulations. Currently, no input from nurses is given and nurses do not know when they have to commence night shifts. In the DSS, day-and-night shift assignments are assigned on an annual basis. As the day-and-night schedules have a crucial impact on the nurses working lives, their preference is used as an input when creating a schedule. Nurses are able to select specific quarters of the year during which they prefer to work night shifts. In terms of the monthly ward assignments, unit managers give their preferences during the current quarter.

Nurse hierarchy is a parameter used by the DSS to identify nurse qualifications. It consists of four levels, with unit managers at the highest level. The second level consists of the sisters (a term used for higher qualified nurses), followed by staff nurses and then assistant nurses. The nurse hierarchy is recorded as a fixed input into the DSS. Unit managers enter the names of the nurses to be assigned, as well as the hierarchy status of each nurse. Shift patterns of unit managers are fixed and not ward specific, therefore unit managers are not included in the scheduling system. Nurses are ranked and promoted according to training and experience. Currently the hospital has 24 sisters, 37 assistant nurses and 23 staff nurses, all of whom have varying skills and availability which changes over time. Up to ten additional nurses per nurse type may be added, making the model moderately flexible(?). In the case of
Stellenbosch Hospital, nurse numbers are not likely to increase significantly due to the restricted budget.

**Figure 1: Inputs and outputs to the decision support system**

In the DSS, the number of sisters, staff nurses as well as assistant nurses, and their skills required per ward, are taken as a variable input by unit managers. Ward assignments are done once a month as indicated by the time trigger in Error! Reference source not found.. Nurses have the option to give a preferred ward assignment input. The Hospital has seven wards: the Pediatric ward, Ward A (chronic patients), Ward B (women), Ward C (men), Theatre, the Trauma/Accidents ward and the Maternity ward. Each of these wards needs a mix of sisters, assistant nurses and staff nurses as specified by the unit managers. The mix, as well as the availability of nurses, is a variable input supplied by unit managers. Nurses who are on study-, normal-, maternity-or sick leave during a scheduling month may be highlighted(?). For the DSS, the wards are a fixed input, as it is unlikely that an additional ward will be added to the hospital.

Nursing costs per shift are not included as an input, because all the nurses are usually assigned, and as indicated in the cause-and-effect diagram, high nursing costs are a result of insufficient schedules, absenteeism and resulting overtime. The DSS’s objective is to improve schedules and involve nurses, and thus reduce costs due to a more efficient approach and solution.

Patient admission data is not directly incorporated in the system but they do follow clear trends which the experienced unit managers are aware of. For instance, admissions increase at the end of the month after people have received their salaries, as well as on Friday nights (Linders & Skippers, personal communication, 31 May 2011). In the DSS, unit managers manually adjust the number of nurses required per month per ward, and assign extra nurses on daily shifts as required. This practice makes patient forecasting redundant.

The basic feasible solution, as indicated as an output of the DSS process in Error! Reference source not found., is similar to the current output report of the manual nurse scheduling process. This is done so that the unit managers may adapt more comfortably to the new scheduling method. The DSS’s output sheet includes the different ward assignments, day-and-night assignments and identifies nurses who are not available for periods of the month. Unit managers manually document, in the output sheet, the reasons why nurses are not available. Furthermore, nurse pool sections are added, which indicate the nurses that have not been assigned for various reasons. Based on these facts, unit managers apply their own judgment to the output sheet, adjusting the computer generated day-and-night schedule and ward assignments, as to obtain a good basic feasible solution.

### 4 LINEAR PROGRAMME FOR NURSE SCHEDULING AT STELLENBOSCH HOSPITAL

Linear programming and a custom-made algorithm were determined to be the best options according to the Analytical Hierarchy Process (AHP). Consequently, these methods were used to develop the day-and-night assignment, as well as the ward assignments. Although metaheuristics is a strong contender, the approach was not pursued for the purposes of this project. However, a study that was done parallel to this project, used a genetic algorithm (metaheuristic) to solve a scheduling problem, specifically adapted for Stellenbosch Hospital [9]).

#### 5.1. Day-and-Night Integer Programming Model

The day-and-night scheduling is separated into three parts: sister scheduling, assistant nurse scheduling and staff nurse scheduling. Each one of these is solved in the same manner. The first constraint is implemented in the structure of the model. Nurses have to work at least three consecutive months of night shifts per year. Thus, the year is separated into four quarters.
If the objective function is maximized, the system assigns more shifts than needed by the shift coverage constraints. Consequently, in this model the objective function minimizes the dissatisfaction of nurses.

\( J_{ij} \) = Nurse \( i \) preference for quarter \( j \). \( J \) is a matrix with four columns for four nurses and a number of rows respective to the number of nurses that need to be assigned to a night shift. Nurses may choose \( J_{ij} \) as 0 (most preferred quarter for night shift), 5 (if nurses do not care to work night shifts during a specific quarter) or 10 (if nurses do not want to work night shifts during a specific quarter).

\( S_{ij} \) = Assigned shift of nurse \( i \) for quarter \( j \). \( S \) is a matrix of ones (assigned shift) and zeros (no shift) with four columns for four nurses and a number of rows respective to the number of nurses that need to be assigned to a night shift.

\( R \) = Coverage - nursing requirements for three months to cover needs as specified by unit managers. It is assumed that the basic night shift nursing requirements are the same each quarter. This is realistic as wards are assigned fixed numbers of each nurse type each day.

\[
\text{min } z = \sum_{i} \sum_{j} J_{ij} \cdot S_{ij}
\]

Subject to:

Nursing requirements to be satisfied each quarter:

\[
\sum_{i} S_{ij} \geq R_{...Quarter1}
\]

\[
\sum_{i} S_{i2} \geq R_{...Quarter2}
\]

\[
\sum_{i} S_{i3} \geq R_{...Quarter3}
\]

\[
\sum_{i} S_{i4} \geq R_{...Quarter4}
\]

Minimum shifts to be assigned per nurse per year, where each nurse has to work at least one quarter:

\[
S_{i1} + S_{i2} + S_{i3} + S_{i4} \geq 1 \text{...Nurse}_1
\]

\[
S_{i2} + S_{i3} + S_{i4} \geq 1 \text{...Nurse}_2
\]

\[
\vdots
\]

\[
\sum_{i} S_{ij} \geq 1 \text{...Nurse}_i
\]

Where:

\( R \geq 0, J_{ij} = 0, 5 \text{ or } 10 \text{ and } S_{ij} \) are integers
The model was solved using Excel Solver. Theoretically the integer programming model should converge to the optimal solution but, due to the complexity of the model, and computational constraints of Solver, it was necessary to apply a rounding heuristic. Consequently, the solution is not necessarily optimal. Nonetheless, comparing the solution to the nurses’ preferences showed satisfactory results of up to 90% of the cells positively corresponding to nurses’ preferences and the coverage constraint was also adhered to. Unit managers may adjust the schedule by shifting assignments. All three models reacted similarly and it could thus be said that the objective of creating a point of departure for the day-and-night schedule has been achieved.

Limitations of this model are as mentioned, the necessity of a rounding heuristic, which leads to suboptimal solutions. Additionally, this model is rigid as nurses may only choose different quarters if their months are pre-set. Finally, solving with Excel Solver limits the size of the model. It cannot work with more than 200 variables and thus, the problem cannot be solved for considerably larger models than the one presented, except if different software is used, which usually means more cost.

5 SYSTEM VALIDATION

The DSS validation underwent several iterations during its development phase. The system was tested with the users and then taken back to introduce improvements.

6.1. Final user validation

The final user validation was performed on 19/09/2011 with actual nurse data for the month. The staff manager and two unit managers were present. Although these users were sceptical about the outcomes and the use of the DSS during its development phase, the feedback received about the latest version of the model was positive and enthusiastic.

The interview was conducted in Afrikaans, the language which the unit managers were most comfortable with, in order to get optimal feedback. They were asked the following pre-design questions:

6.1.1. Is the DSS useful to you?

The unit managers stated that the DSS is useful to them, as it performs the same computations they carry out in a time consuming process, in a few seconds. They said that starting from an already pre-solved problem speeds up the scheduling process considerably and relieves them of the tedious iterations of preparing the schedule, which often results in inadequate schedules and underutilized nurses. Furthermore, arguments among unit managers over where specific resources should be allocated could be prevented. In their opinion the system supports unit manager’s decision making, without compromising control.

6.1.2. Does DSS solve the problem?

According to the unit managers, the DSS does solve problems for them at the hospital. They said that documentation of all the nurses, the “Unassigned Pool” and the “Unavailable Pool” aids them in enhancing nurse utilization. Unit managers, with the help of DSS, have an overview of all staff and their attributes, and they can thus assign them in an optimal way. This ultimately reduces overtime for nurses, as unit managers can plan schedules in advance.

Scheduling the night shifts one year in advance provides fairer schedules and presents nurses with the opportunity to be aware of upcoming night shift periods, so that they may organize private matters in advance. A more convenient schedule for nurses will improve employee morale and reduce absenteeism in the future.

6.1.3. Do you understand how this DSS works?

The DSS and its basic workings were explained to the sisters. As the system emulates the nurses’ scheduling process, they understood how the system works. They were pleased that their input was used so extensively in the development of the DSS.
6.1.4. Is the DSS user-friendly?
The nurses understood the process of executing the DSS. They enjoyed the colourful design of the programme and appreciated the data validation function which prevents them from entering invalid data. However, all of them, being beginners with handling computers, requested a training session in using the DSS and especially Solver.

6 CONCLUSION
In this project a problem at Stellenbosch Hospital was solved by defining the problem and developing and validating the solution with the input of its future users. More specifically, the purpose of this project was to resolve root causes at a specific public hospital (name removed for peer review purposes) by designing a DSS related to the scheduling of nursing resources.

The following objectives were set to achieve the purpose of the project:
- Provide decision makers with a DSS,
- Improve and enhance nurse utilization,
- Involve nurses in scheduling and
- Improve employee morale.

The system has not been implemented yet, and the impact on employee morale and absenteeism rates was not quantified. Nevertheless, unit managers stated that including nurses in the scheduling process is of significant importance to the nurses, as knowing their day-and-night schedule well in advance enables them to plan their personal lives according to their work shifts and thus attend work more regularly. This potentially minimizes overtime for nurses and reduces friction with management. Nurses are allowed to gain control over their schedules, and consequently a more comfortable work environment may be created, which will potentially lead to improved employee morale. These results can be extrapolated to other health care institutions in South Africa.

7 REFERENCES


