# Managing Personnel through Staff Scheduling Algorithms

Kiranmai D. Naidu
Dept. of Electrical and Computer Engineering
Box 90291, Duke University
Durham, NC 27708-0291
kdn@ee.duke.edu

Keith M. Sullivan
Division of Medical Oncology and Transplantation
Duke University Medical Center
Durham, NC 27710
sulli025@mc.duke.edu

Paul P. Wang and Yi Yang
Dept. of Electrical and Comp. Engineering
Box 90291, Duke University
Durham, NC 27708-0291
{ppw, yy}@ee.duke.edu

**Abstract**

*This article presents a literature review of the current state of staff scheduling, in particular nurse scheduling. In current health care service, the critical problem in nurse scheduling in a hospital is how to determine day-to-day shift assignments of each nurse for a period of time in a way that satisfies the given requirements of a hospital. As a basis, the formal analysis of the problem is performed and a general scheduling procedure was established. Based on the method, a word processing template or software system which produces a scheduling program for a given institution was developed. Another objective of scheduling is optimization. Optimization of personnel scheduling consists of the selection of those work patterns that meet total work requirements at the lowest cost. Various approaches to alleviate the scheduling quagmire while attaining optimization are presented in this paper. Analysis of each of these approaches along with their effectiveness is presented. We anticipate that one of these approaches researched will provide the backbone to develop a system suitable for use at Duke University's medical oncology department.*

## 1 Introduction

### 1.1 Why Scheduling?

In today's medical environment of cost containment and restricted reimbursement, importance is placed on the maximum use of facility and personnel resources. [1] One of the most obvious areas in a hospital environment is the automation of appointment and resource scheduling. In our case, resources will refer to nurses. It is not always realized that nursing costs account for 50 percent of total hospital costs. It is even more rarely appreciated that the manner in which nurses are deployed has a significant impact on a hospital's operating budget. Scheduling has a significant impact not only on costs but also on nurses' job satisfaction. [2] In scheduling nurses, a variety of factors, including the following must be satisfied simultaneously, 1) night shifts must be assigned to each nurse equally, 2) individual preferences should be taken into account as much as possible, 3) a proportionate number of skilled and unskilled nurses must be in attendant at any given shift. Cyclical scheduling has its own merits [3]~[6] but its applicability is very limited. The concept of this methodology is to design a working pattern that may be repeated for every scheduling period. This reduces the amount of time spent on arranging the schedule, however, the scheduling of nurses involves many circumstances that cannot be confined in such a rigid pattern. The inflexibility of this method limits it applicability. Miller et al. and Warner et al. have applied mathematical programming models [7]~[9] and Arthur and Ravindran and Musa and Saxena have proposed a goal programming model [10, 11]. Ozkarahan developed a methodology to obtain flexible work schedules through alternative mathematical models [12]. Smith et al. adopted a heuristic approach to the problem [13, 14].

### 1.2 Why Automate?

Nursing administrators consistently bemoan the time-consuming process of manual scheduling. It is inefficient and economically unsound for the head nurse to spend so much time and effort to arrange the schedule. [15] To begin the discussion on current approaches we must recognize overwhelming need for automation and widespread use of automation. Nowadays, nursing managers practice enterprise-wide automated resource management across networked departments. This is a tool that saves time, money, and headaches. [16] Implementing an automated scheduling system can:

- dramatically decrease in the amount of paperwork and record keeping.
- improve information flow.
- alert management to necessary staffing adjustments.
- categorize staff by position and qualification, blending information from an enterprise perspective.
- allow managers to use their own "mission-trained" staff throughout their network of facilities.

Automated scheduling system can be integrated with clinical information systems to provide up-to-the-minute staffing requirements based on patient census and acuity. [16]~[18] Enterprise-wide resource management systems contain a variety of components, but the component we axe most interested in is the scheduling component. When selecting an enterprise-wide resource management system, the scheduling component must:

- have a flexible, user-friendly design with point-and-click simplicity.
- apply staff's schedule preferences and requests automatically
- track staffing totals and targets simply and clearly.
- work to meet staffing targets.

By beginning to reduce the time spent each day on scheduling and making changes to staffing, nurse managers can better use the strengths of their vast health care networks. Ultimately it has been found that automated staff scheduling is one of the most desired components of management information systems.

### 1.3 Implementation

Implementation begins with a thorough detailed system design, consultation with the users and finally, planning, development and implementation of the system. Nurse administrators axe vital from beginning to end in terms of the decision making about installation of computerized systems in facilities, knowing the manual system, analyzing data and identifying and differentiating systems. Some critics warn that the human touch associated with medicine will be gone, and it will become stale and impersonal. Others believe the exact opposite is true, where computers are assigned only for the laborious time-consuming tasks such as scheduling and this will not change. In the next sections, we will discuss the prevalent methods used in the medical environment for scheduling nurses while taking into account preferences, patient census, and how different scheduling practices affect nurses' satisfaction and retention.

## 2 Current Approaches

The approaches we will discuss in the paper are automated in some way shape or form based on the institution's needs. Jelinek describes staffing as the process of determining the appropriate number and the mix of nursing resources necessary to meet workload demand for nursing care at the unit or departmental level. [19] Taxonomy of nurse staffing approaches has been identified. This includes, 1) consensus approaches, including the use of intuitive and consultative method, 2) top-down management approaches, including the use of nursing interventions and patient dependency approaches. Each approach has its own advantages and disadvantages and can be used in combination with each other. In some cases time and motion studies were employed for calculating hours of nursing care associated with each patient category to determine the number of hours of nursing care needed to meet nursing care requirements. As scheduling systems have been used over time, they have not been updated with regard to the number of hours of nursing care needed to care for patients in different categories based on new technology and approaches to nursing practices. [17] Scheduling approaches that focus on a single index of productivity should be avoided because of the inability of most systems to capture the complex interacting nature of scheduling situations.

## 2.1 Mathematical Programming Models

### 2.1.1 Linear Programming

Linear Programming (LP), a powerful mathematical tool has been the topic of several papers [2, 15, 20] for scheduling optimization. It has long been used in industry to maximize benefits and minimize costs. This process can maximize employee satisfaction and minimize costs when applied to nursing scheduling in a two-stage process of optimization. [21]~[23] Previous attempts have failed to accommodate the varying requirements of different hospital settings or the diverse preferences of nurses. The first step in optimization is to determine the preferred work patterns of individual wards. Harmeier says the first step in optimization is to construct a matrix that describes the objective of the optimization as well as the constraints that apply. [20] The second step of optimization, employees bid for the patterns of their choice on the basis of a Seniority Performance Indexes, which can be assigned permanently or rotated among different employees.

Harmeier's paper used an LP optimizer named OPTIMUM that runs on a standard IBM or IBM compatible microcomputer having at least 512K of RAM. The LP optimizer works in conjunction with Lotus 1-2-3 for manipulation of input data and report writing of results. He uses the matrix to lay out a plan for each of the problem constraints to be modeled as linear equations. According to his paper, the LP optimizer OPTIMUM met all staffing requirements and yielded a significant cost savings. Both studies have touted LP as not only a cost effective procedure but also as having the ability to be flexible enough to respond to changes in census and staffing levels.

### 2.1.2 Expert-System Based

Chen developed a hybrid expert system entitled NURSE-HELP to achieve flexible and effective scheduling for nurses. [15] It is designed for decentralized scheduling of nurses, where each unit is responsible for its own scheduling task. So far we have talked about mathematical models using linear programming and heuristic based models. Chen delves into a new approach that combines these two methods discussed. Most of the previous systems do not consider ergonomic criteria, which Chen believes is essential when developing a computer nurse scheduling system. The hybrid expert system developed combines the expert system together with the linear zero-one goal programming to solve the nurse scheduling problem. Goal programming is a technique that solves multiple-objective programming problems. Linear zero-one goal is a particular type of programming in which all the decision variables axe either zero or one and where all the goals in the model are represented by linear equations. Most hybrid expert systems work in two phases. The results obtained from the first part will be transferred as input for the second part. Knowledge acquisition for the expert system is from mainly the public domain, Le, books and articles and a series of interviews with head nurses at the Veterans Administration Hospital in Houston. Knowledge representation in NURSE-HELP adopts a rule-based system, which is the most popular and straightforward approach. NURSE-HELP, after system performance validation, has proven itself to be able to design quick and accurate nurse schedules, while incorporating all the ergonomics guidelines into the hybrid expert system. Advantages and disadvantages will be discussed in the next section.

## 3 Heuristic Approach

In the case of Okada, a heuristic approach was presented which was thought to be more appropriate than mathematical models. [24, 25] Various types of constraints were integrated in the scheduling problem, and among them, constraints on role patterns and individual preferences were two of the most important factors which often conflict with one another. Okada made a formal analysis of the problem, applied language theory, and established a general procedure which controls the generation of the role sequences under given constraints on role patterns where individual preferences are reflected as constraints on role sequences. A software system which allows the user to declare institution-specific requirements involved in scheduling was developed. A large number of studies have explored the effects of shift work on people's well-being and health [26]~[28], and there is now convincing evidence that biological clocks reset with difficulty [29, 30] and long-term exposure to variable work schedules results in an increased risk of various disorders. For example, the initial constraint declaration is as follows: Let $\Sigma$ denote the set of symbols which stand for the possible roles. Let the roles night shift, evening shift, day shift, day off, and official trip be denoted n, e, d, o, t; respectively. Then we have Σ=n, e, d, o, t. day-to-day role sequences may then be represented as strings consisting of symbols in Σ. In the formulation of language theory, the set of all the possible sequences forms a language L, and L is specified by the gram max G corresponding to the constraints on the role patterns. Given multiple requirements each is represented as a binary relation (a rule in Prolog) which determines, for two given nurses, which is preferred over the other. Individual preferences and best team member criteria are configured into role sequences, which are then implemented into the software system. The system passed the initial validation stage, which was a 5-month period in one unit of a hospital. All requirements, including individual preferences, equality of workload, composition of staff members were met.

## 4 Analysis

In this paper we have discussed the various systems that exist in the market for the sole purpose of scheduling [31]. Since the 1970s widespread computer use has given experts new insight into tackling the problem. Mathematical modeling was tackled by one group (e.g. linear programming), [7, 10, 11] to obtain an "optimal solution". Another group tackled heuristic models to obtain good, but non-optimal solutions [24, 32]. Both mathematical and heuristic models improve the flexibility of the scheduling process as compared with the cyclical scheduling method. There are, however, limitations to both of these approaches. Mathematical models ignore ergonomics criteria (e.g. forward rotation, shift preferences). Those scheduling models concern only guidelines such as meeting minimum staff level and minimizing overtime work. One has to consider human physical limitations [15], and lack of consideration for these ergonomic criteria can lead to overall job dissatisfaction. For example the zero-one goal programming developed by Musa and Saxena consider the minimum staff level, contracted working hours, three consecutive days off, and weekends off only. [11] The quality of the schedule is reduced despite giving us the optimal solution. It is also difficult to define the concept of "optimal solution" in a strict sense. Experts claim that some constraints are ambiguous and may be different from one nurse to another. Therefore, it is not clear to what extent they should be satisfied. The heuristic solutions have no benchmark to test their solutions. The ergonomics approach discussed by Chen doesn't integrate full-time and part-time nurses. [15] It's also decentralized so that resources cannot be shared by different units unless explicitly notified. With the various scheduling techniques available, each is tailored to a specific institution. We can safely say that it is up to that institution's Resource Management team to find a suitable approach which will yield the best results for them based on their resources and requirements. The approaches we have discussed in the paper are overwhelmingly computer-based. Some are as simple as using a spreadsheet type format, while others integrate expert system with linear programming techniques. Computer-based scheduling saves time in planning and budgeting. Although it may take some time to format the original program, once the initial format is complete, it can be copied for other units or departments, or even for an entire nursing division. Many elements still exist outside of implementing computerized scheduling, like training the staff, and dealing with glitches.

## References


[1] J. Enterline et al, *Integrated Ambulatory Care Services in Oncology.* JONA, 1993, 197-200.

[2] H. Loevinsohn, *A New Perspective on Scheduling: Freedom and Cost Control.* Nursing Management, 1992, 23(7): 56-61.

[3] H. Ahuja, R. Sheppard, *Computerized nurse scheduling.* Ind. Eng., 1975, 7: 24.

[4] J. Howell, *Cyclical Scheduling of Nursing Personnel*, J. Am. Hops. Assoc. 1966, 40: 77.

[5] L. Smith, *The Application of an interactive algorithm to develop cyclical rotational schedules for nursing personnel.* INFOR., 1976, 14: 53.

[6] C. Maier-Roth, H. Wolfe, *Cyclical Scheduling and allocation of nursing staff.* Socio-Econ.Plan.Sci., 1973, 7: 471.

[7] D. Warner, *Scheduling nursing personnel according to nursing preference: a mathematical programming approach.* Operations Research, 1976, 24: 842-856.

[8] D. Warner, J. Prawda, *A mathematical programming model for scheduling nursing personnel in a hospital.* Manage. Sci., 1972, 19: 411.

[9] P. Miller, G. Folse, *Patient Classification and staffing in ambulatory care.* Nurs. Manag., 1989, 20(8): 29-31.

[10] L. Arthur, A. Ravindran, *A multiple objective nurse scheduling model.* AIIE Transaction, 1981, 13: 55-60.

[11] A. Musa, U. Saxena, *Scheduling nurses using goal-programming techniques.* HE Transactions, 1984, 16: 216-221.

[12] I. Ozkarahan, *A disaggregation model of a flexible nurse scheduling support system.* Socio-Econ.Plan.Sci., 1991, 25: 9.

[13] L. Smith, A. Wiggins, *A computer-based nurse scheduling system.* Comput.Ops.Rev., 1977, 4: 195.

[14] L. Smith, A. Wiggins, D. Bird, *Post implementation experience with computer- assisted nurse scheduling in a large hospital.* INFOR, 1979, 17: 309.

[15] J. Chen, T. Yeung, *Hybrid Expert System Approach to Nurse Scheduling.* Computers in Nursing, 1993, 11(4): 183-90.

[16] S. Tandy, *Want Simple, Superior Resource Management?.* Nursing Management, 1999, 40-1.

[17] M. Dunn et al, *Expert Panel Method for Nurse Staffing and Resource Management.* JONA, 1995, 25(10): 61-67.

[18] L. Walts, A. Kapadia, *Patient Classification System: An Optimization Approach.* Health Care Manage Review, 1996, 21(4): 75-82

[19] R. Jelinek, J.Kavios, *Nurse staffing and Scheduling: past solutions and future directions.* J. Soc. Health Syst. 1992, 3(4): 75-82.

[20] P. Haxmeier, *Linear programming for optimization of nurse scheduling.* Computers in Nursing, 1991, 9: 149-151.

[21] R. Bland, *The Allocation of Resources by L.P. for Maximum Benefit and Minimum Cost.* Scientific American, 1981, 126-144.

[22] In *Scientific and the Citizen: Simplex Algorithms for Determining Optimum Way of Deploying Resources, Including Scheduling for Flight Crews. Sc*ientific American, 1985, 54.

[23] In *Science and the Citizen Explaining the Nature of the Algorithm and its Ability to Solve Problems Involving the Allocation of ManPower and Resources at Minimum Cost and Maximum Benefits.* Scientific American, 1980, 80-84.

[24] M. Okada, *An Approach to the Generalized Nurse Scheduling Problem-Generation of a Declarative Program to Represent Institution-specific knowledge.* Computers and Biomedical Research, 1992, 25: 417-34.

[25] M. Okada, M. Okada, *Prolog-based system for nursing staff scheduling implemented on a personal computer.* Computers and Biochemical Research, 1988, 21: 5363.

[26] K. Dahlgren, *Temporal patterns in psychophysiological activation in rotation shift workers-A follow-up field study one year after an increase in nighttime work.* Scand. J. Work Environ. Health, 1981, 7: 131.

[27] D. Minors, J. Waterhouse, *Circadian rhythms in deep body temperature, urinary excretion and alertness in nurses on night work.* Ergonomics, 1985, 28: 1523.

[28] D. Baker, *The Use and health consequences of shift work.* Int.J.Health Serv., 1980, 10: 405.

[29] M. Mooreede, C. Czeisler, G. Richardson, *Circadian timekeeping in health and disease. PartI. Basic properties of circadian pacemakers.* N.Engl.J.Med., 1983, 309: 469.

[30] M. Mooreede, C. Czeisler, G. Richardson, *Circadian timekeeping in health and disease. PartIl. Basic properties of circadian pacemakers.* N.Engl.J.Med., 1983, 309: 530.

[31] P. Waterhouse, *Cost Benefit Analysis of an automated nurse scheduling and staffing system.* Department of Veterans Affairs, Contract Report No.V101-93-P-1098, 1989.

[32] L. Smith, A. Bird, A. Wiggins, *A computerized system to schedule nurses that recognizes staff preferences.* Hospital and Health Services Administration, 1935.

[33] Institute of Medicine, *Physician staffing for the* VA. Volume I and summary of study. Washington, DC: National Academy Press, 1991.

[34] H. Degroot, *Patient Classification systems and staffing part I.- problems and promise.* J. Nurs. Admin., 1994;24(9):43-51.

[35] T. Arthur, N. James, *Determining nurse staffing levels: a critical review of literature.* J. Adv. Nurs., 1994;19:558-565.

[36] J. Palmer, *Eight-and 12-Hour Shifts: Comparing Nurses 'Behavior Patterns.* Nursing Management, 1991, 22(9): 42-44.

[37] J. Bracken et al, *A Strategy for Adaptive Staffing of Hospitals under Varying Environmental Conditions.* Nurse Care Management Review, 1985, 10(4): 43-53.

[38] G. Velianoff, *Establishing a 10-hour Schedule.* Nursing Management, 1991, 21(9): 36-38.

[39] H. Addams, L. Bracci, *Bar Coding, An Effective Productivity Concept.* JONA, 1991, 21(10): 54-60.

[40] C. Bergmann, J. Johnson, *Managing Staffing with a Personal Computer-Part 11.* Nursing Management, 1988, 55-61.

[41] M. Brady, *Evaluating Personnel with Automated Management Systems.* Nursing Management, 1988, 19(3): 38-39.

[42] B. Bross, B. Gamblin, S. Holtzclaw, Us*ing a Computerized Scheduling System to Predict Procedure Lengths.* 1995, 61(6): 1054-61.

[43] D. Fisher, *Method to Assist in the Scheduling of Add-On Surgical cases-Upper Prediction bounds for Surgical Case Durations Based on the Log-normal distribution.* Anesthesiology, 1998, 89(5): 1228-32.

[44] J. Gray, D. McIntire, H.J.Doller, *Modeling Shift Workers' Scheduling Desires: An Application Involving Nursing Personnel.* AMIA, 1992, 315-319.

[45] J. Hall. *Step-by-step.* Nursing Times. 1991, 87(21): 62-65.

[46] E. Halloran, P. Vermersch, *Variability in Nurse Staffing Research.* JONA, 1987, 17(2): 26-32.

[47] F. Hiltz, J. Teich, *Coverage List: A Provider-Patient Database Supporting Advanced Hospital Information Services.* AMIA, 1994, 80913.

[48] J. Kinley, L. Cronenwett. *Multiple Shift Patient Classification: Is it necessary?* JONA, 1987, 17(2): 22-25.

[49] M. Kirby et al, *Improving Staffing with a Resource Management Plan.* JONA, 1987, 17(l): 3943.

[50] F. Marks, *Refining a Classification System for Fiscal and Staffing Management.* JONA, 1987, 17(l): 39-43.

[51] R. Martorelli, *Nurse Manager's Use of Lotus 12-3 Template as Support for Decision Making for Nursing Hours, Staffing and Direct Nursing Costs per Day.* AMIA, 1994, 963-5.

[52] W. Pierskalla, D. Woods, *Computers in Hospital Management and Improvements in Patient Care-New Trends in the United States.* Journal of Medical Systems, 1988, 12(6): 4211-28.

[53] M. Shaffre et al, *Clinical Engineering Development of Computer Applications for an Anesthesiology Department.* Biomedical Instrumentation and Technology, 1995, 12(5): 109-119.

[54] C. Taylor, C. Burdis, D. Ferguson, *Workload Management in A and E: Counting the uncountable and predicting the unpredictable.* J Accid. Emerg. Med., 1997, 14: 88-91.

[55] S. Kokkotos, E. Ioannidis, C. Spyropoulos, *A System for efficient scheduling of patient tests in hospitals.* Medical Informatics, 1997, 22(2): 179-90.

[56] K. Lawson et al, *Redefining the Purpose of Patient Classification.* Nursing Economics, 1993;11(5):298-302.

[57] A. Roth, *New Physicians: A Natural Experiment in Market Organization.* Science, 1990, 250: 1524-1528.

[58] J. Baker, *A Spreadsheet Method for Calculating Maximum Caseload and Intake Capacity for CMHC Psychiatrists.* Psychiatric Services, 1997, 48(12): 1578-81.

[59] D. Eaves, *Computerise your Ward.* Nursing Times, 1989, 23(85): 43-44.

[60] L. Day, *Automated Staff Scheduling in Long-Term Care Facilities.* Nursing Management, 1989, 20(3): 76-78.

[61] D. Charletta, *Microcomputer-Assisted Residency Data Management.* Invest. Radiol, 1988, 23: 224-226.

[62] B. Oppenheim, *Computer-Assisted Radiology Resident Rotation Scheduling.* Invest Radiol 1989, 24: 163-66.

[63] J. Aram, P. Salipante, J. Knauf, Hu*man Resource indicators for hospital managers.* Health Care Manage Rev, 1987, 12(2): 15-22.

[64] T. Choi et al, *Effects on Nurse Retention.* Medical Care, 1986, 24(11): 1029-43.

[65] M. Kirby, *Moving to Computerized Scheduling: A Smooth Transition.* Nursing Management, 1997, 28(8): 42-44.

[66] D. Diers, J. Bozzo, *Nursing Resource Definition in DRGs.* Nursing Economics, 1997, 15(3): 124-130.

[67] M. Kostreva, K. Jennings, *Computer Takes Note of Shift Preferences.* Computers Operational Research, 1991, 18(8): 731-39.

[68] J. Watts, *Workload measurement systems: their applications and limitations.* Dimensions, 1986, 44-46.

[69] S. Kokkotos, C. Spyropoulos, *A ReActive Scheduling System based on TGS kernel.* Proceedings of the Artificial Intelligence in Engineering AIENG-90 Conference, Boston, MA, *Applications of AI in Engineering, Manufacturing and Planning,* Computation Mechanics Publications. 2:52333.

[70] A. Kumar, P. Ow, M. Prietula. *Organizational simulation and information systems design: an operations level example.* Management Science, 1993, 39(2): 218-40.

[71] M. Frances, *Implementing a program of cyclical scheduling of nursing personnel.* 1966, 40: 108-125.

[72] P. Knauth, J. Rutenfranz, *Development of criteria for the design of shiftwork systems,* Journal of Human Ergology, 1982, 11: 337-367.

[73] H. Miller, W. Pierskalla, G. Rath, *Nurse scheduling using mathematical programming.* Oper. Res. 1976, 24: 857.

[74] Y. Sigemura et al., *A Study of designed nursing subsystem by computer under THINK.* Proceedings, 5th Joint Conference on Medical Informatics(JCMI), 1985, 83-86.

[75] M. Anzai, Y. Miura, *Computer program for quick work scheduling of nursing staff.* Med-Inf., 1987, 12: 43.

[76] J. Ladou, *Health effects of shift work.* West.J.Med., 1982, 137: 525.

[77] S. Folkhard, D. Minors, J. Waterhouse, *Chronobiology and shift work: Current issues and trends.* Chronobiologia, 1985, 12: 31.

[78] K. Behner et al, *Nursing Resource Management: Analyzing the Relationship between Costs and Quality in Staffing Decisions.* Healthcare Management Review, 1990, 15(4): 63-71.