CHAPTER 3

A GOAL PROGRAMMING MODEL FOR NURSE SCHEDULING

Section 3.1. DRGs: A New Incentive for Cost Containment in Hospitals

Since World War II, government policy has encouraged the tremendous rise in health costs. Government legislation, such as the Hill-Burton Act of 1946, has subsidized the construction of hospital facilities. The Medicare and Medicaid legislation of the mid-1960s and the growth of third party insurance companies such as Blue Cross have had a significant effect on medical costs. The patients are not concerned about the costs because they do not pay them directly. Similarly, because the doctors know they will not be placing a financial burden on their patients, expensive and unnecessary tests may be performed.

The current level of health care expenditures reflects this trend. During 1982, the USA's bill rose 11.8 percent to $322.4 billion or $1265 per person.[3] As the nation's largest industry, health care accounted for 10.5 percent of the Gross National Product and at 42 percent, hospital care accounted for the largest single share of this expense. By comparison, in 1965 health care cost the USA $41.7 billion or $211 per person and accounted for 6 percent of the GNP.[4] Health costs have increased 773 percent since 1965 while the consumer price index has risen 306 percent. If health costs continue to rise at about 12 percent annually, by 1992 they will reach $1 trillion.

Medical costs also are taking an increasing bite out of tax dollars. The Medicare bill has increased from $4.5 billion in 1967 to $50.9 billion in 1982.[5] Hospitals received 71.3 percent of the Medicare payments in 1982. Because of the concern caused by increases in medical costs, state legislatures passed 285 bills in 1983 that were designed to reduce costs. The most significant legislation, however, was approved by Congress.

On April 20, 1983, President Reagan signed the Social Security Amendments of 1983, HR 1900 (PL 28-21), into law. Included in this bill was the mandate that beginning on October 1, 1983, the federal government would pay hospital medicare bills by the Diagnostic Related Groups (DRG) method.

DRGs were introduced in an attempt to control hospital costs. Patients are classified into 467 DRG categories. Instead of being compensated on a per diem basis, hospitals will be reimbursed according to a predetermined amount, based on the costs that a patient in a given category is supposed to incur. This new system of funding will mean major changes for hospitals because Medicare patients constitute more than 30 percent of a hospital's expenses. More importantly, over the next three years, private insurance companies are expected to adopt the DRG method. One thousand hospitals, those which are least efficient, will be forced to close by 1990.[6]

DRGs were originally developed at Yale University and implemented by the state of New Jersey. The hospital is paid the same amount of money regardless of the actual costs. If the hospital can treat the patient for less than that amount it will realize a profit, but if it exceeds the predetermined amount, the hospital will suffer a loss. This will motivate hospitals to avoid unnecessary care and become more efficient in all phases of their operation.

The DRG method of funding will be phased in over a four year period. During the first year, 25 percent of the government's payments will be based on regional averages and 75 percent on the historical costs at the actual hospital. During the second year, 50 percent of the payments will be based on a combination of national and regional averages and 50 percent on historical costs of the hospital. During the third year, 75 percent will be based on a combination of national and regional averages and 25 percent on the historical cost. In the fourth year, the entire remuneration will be based on a standardized national DRG rate.

Nursing costs usually account for more than 40 percent of a hospital's expenses. Nursing costs may be excessive for several reasons: (1) a hospital may have a higher proportion of RNs to LPNs and Techs than neighboring hospitals, (2) there may be overstaffing, (3) salaries may be too high, relative to other hospitals, (4) scheduling may not be adjusted for decreases in patient occupancy, (5) and professional nurses may spend too much time on indirect duties such as transporting patients and making beds. Factors 1, 3 and 5 can be corrected only if there is a change in hospital policy. Factors 2 and 4 can be improved through a more efficient scheduling process however. Increased efficiency is the goal of the following model.

Section 3.2: The General Model for Sacred Heart Hospital

Hospitals make three basic types of decisions on nurse scheduling. A staffing decision is made annually in order to determine the correct number of permanent nurses for the hospital. A scheduling decision is made every 2-6 weeks in order to determine the shifts for each nurse. This will generally not change significantly. If a nurse needs certain days off, she will be asked to trade shifts with another nurse. Finally, an allocation decision is made each day. "Float nurses" will be moved from one unit to another since the demand may be high or low in certain units on any given day. In addition, specific tasks are assigned to each nurse on duty.

This model deals with the scheduling decision. A good model will be useful, with small modifications, to the hospital for at least a year. Although the model was developed for Sacred Heart Hospital in Eugene, Oregon, the system and goal constraints will be relevant for most hospitals. The hospital requested that the specific units that are under investigation remain confidential in order to preserve the anonymity of the nurses. The nurses will be assigned to a fourteen day cyclical schedule.

The system constraints are based on the collective bargaining agreement between the hospital and the Oregon Nurses Association. All of these constraints are absolute and therefore must be given equal weight in the model:

1. Each nurse must work at least as many shifts as he/she is scheduled to work.

2. Each nurse must work for at least as long as the shift length indicated.

3. Nurses must get at least every other weekend off.

4. There is to be no shift rotation.

5. Part-time nurses (those who normally work less than 32 hours/week) should never work more than 40 hours in one week.

6. Nurses cannot work more than five days in a row.

The hospital also has four goals; these are listed in descending order of importance:

Goal 1: Meet the hospital's minimum staffing requirement.

Goal 1A: Meet the hospital's minimum staffing requirement for each skill level of nurse.

Goal 2: Avoid overtime (nurses who work more than forty hours per week must be paid time-and-a-half).

Goal 3: Schedule no more nurses on weekend than the minimum staffing level.

Goal 4: Achieve the desired staffing level if this figure is above the minimum.

In addition to these goals, the hospital would like to avoid day off/day on/day off patterns. However, this goal can be achieved by adjusting the computer based solution once these other goals are attained.

Scheduling nurses at Sacred Heart Hospital currently is a difficult and time-consuming task. Each month administrators start from scratch with a new schedule that is printed by the main computer. None of these schedules fulfills the hospital's management goals. They violate goals 2, 3, 4 and the day off/day on/day off avoidance goal, although the current form cannot be compared directly to this formulation. This model will save the hospital time and produce a superior schedule.

The problem requires a zero-one algorithm. All decision variables will be of the form $X_{i,j}$ where i is the nurse and j is the day of the week.

$X_{i,j} = 0$ indicates that nurse i does not work on day j, while

$X_{i,j} = 1$ indicates that nurse i does work on day j.

The deviational variables will be denoted $d_{a,b}$ where a indicates the goal and b indicates the constraint. Let n be the number of nurses, c be the minimum level and f be the desired level of staffing.

Goal 1, meet the minimum staffing requirement, can be written:

4.1) $$\sum_{i=1}^{n} X_{i,j} - d^{+}_{1,j} + d^{-}_{1,j} = c \qquad j = 1, 2, \ldots, 14$$

If the unit also requires a minimum number of nurses at a certain skill level, the constraints are similar. If, for example, $e < c$ RNs are needed and $m < n$ are available, the formulation is:

Goal 1A:

4.2) $$\sum_{i=1}^{m} X_{i,j} - d^{+}_{1,j+14} + d^{-}_{1,j+14} = e \qquad j = 1, 2, \ldots, 14$$

For the first goal, $d^{-}_{1,j}$ will be minimized and for goal 1A, $d^{-}_{1,j+14}$ will be minimized.

Next, each nurse must work the number of shifts to which he/she is assigned:

4.3) $$\sum_{j=1}^{14} X_{i,j} - d^{+}_{2,i} = k_i \qquad i = 1, 2, \ldots, n$$

where k_i = the number of shifts which nurse i works. Note that the negative deviational variable is omitted because nurse i must work at least k shifts. Goal 2 will be achieved by minimizing $d_{2,i}$.

Goal 3 will be attained by minimizing $d^{+}_{i,j}$ on weekends. In this schedule, weekends will be those days when j = 6, 7, 13 or 14.

Often a hospital will have a desired staffing level that is distinct from the minimum staffing level. The constraints for goal 4 are:

4.4) $$\sum_{i=1}^{n} X_{i,j} + d^{-}_{4,j} - d^{+}_{4,j} = f \qquad j = 1, 2, \ldots, 14$$

where $f > c$.

In addition, the model must not schedule nurses to work more than five days in a row. This constraint can be met by developing a formulation which assures that no nurse works more than five days in any six day period. Only twelve days are available to schedule each nurse because of the requirement that nurses must get every other weekend off. There are seven six-day periods in these twelve days. If a nurse must have $X_{i,j} = 0$ for i = 13, 14 then the days-in-a-row constraints will be as follows:

4.5) A) $$\sum_{j=1}^{6} X_{i,j} \leqslant 5 \qquad i = 1, 2, \ldots, n/2$$

B) $$\sum_{j=2}^{7} X_{i,j} \leqslant 5 \qquad i = 1, 2, \ldots, n/2$$

C) $\sum_{j=3}^{8} X_{i,j} \leq 5$ $\qquad i = 1, 2, \ldots, n/2$

$\vdots$

G) $\sum_{j=7}^{12} X_{i,j} \leq 5$ $\qquad i = 1, 2, \ldots, n/2$

For nurses n/2 + 1, ..., n, the first constraint will be:

4.6) A) $\sum_{j=8}^{13} X_{i,j} \leq 5$ $\qquad i = n/2 + 1, \ldots, n$

$\vdots$ and the last constraint:

G) $\sum_{j=14}^{5} X_{i,j} \leq 5$ $\qquad i = n/2 + 1, \ldots, n.$

These nurses must have $X_{i,j} = 0$ for j = 6, 7.

The objective function will consist of the deviational variable which were derived in the goal constraints. Priority level 1 will be:

4.7) $\text{Min } Z = d^-_{1,j} + d^-_{1,j+14}$ $\qquad$ for $\qquad j = 1, \ldots, 14$

Priority level 2 is:

4.8) $\text{Min } Z = d^+_{2,i}$ $\qquad$ for $\qquad i = 1, 2, \ldots, n$

although weights may be added for some values of i. This will occur if nurse i is close to forty hours on his/her normal shift schedule (in which case it will cost the hospital 1.5 times as much for him/her to work overtime as for another nurse) or if it costs the hospital more to pay an RN overtime than an LPN or Tech.

Priority level 3 is:

4.9) $$\text{Min } Z = d^{+}_{1,j} \qquad \text{for} \qquad j = 6, 7, 13, 14$$

Priority level 4 is:

4.10) $$\text{Min } Z = d^{-}_{4,j} + d^{+}_{4,j} \qquad \text{for} \qquad j = 1, 2, \ldots, 14.$$

The problem is to achieve 4.7-4.10 subject to 4.1-4.6.

Section 3.3: An Application to a Large Unit with Variable Shift Lengths

The first example is for a large unit with sixty-four nurses. The shifts/nurse, lengths of shifts and number of nurses/shift are elaborated upon in Table I in the appendix. This problem is a difficult one because the nurses do not work a standard eight-hour shift. The ten hour shifts could change the problem drastically because the need for nurses would have to be divided into two hour periods rather than eight hour periods. It is best to treat the nurses who work ten hours as if they had eight hour shifts because this simplifies the problem tremendously.

The twelve hour shifts present a more manageable problem. If nurses X_{22} and Y_{20} must work back-to-back then these two 12-hour nurses can be treated as three 8-hour nurses. The eight 12-hour nurses therefore are treated as twelve 8-hour nurses. Each shift will lose its "12-hour nurses" and gain four 8-hour nurses. Constraints must be added to ensure that the three new "8-hour nurses" work back-to-back. If they do not, the two 12-hour nurses that they represent will have their shifts split up.

The following changes are made to Table I:

	Day		Evening			Night		
Nurse	Shifts/ period	Shift length	N	S/P	SL	N	S/P	SL
X_{22}	6	8	Y_{18}	6	8	Z_{19}	6	8
X_{23}	6	8	Y_{19}	6	8	Z_{20}	6	8
X_{24}	6	8	Y_{20}	6	8	Z_{21}	6	8
X_{25}	6	8	Y_{21}	6	8	Z_{22}	6	8

The following constraints will provide the results that are listed above.

4.11) $2X_{22,j} - Y_{18,j} - Z_{19,j} = 0 \qquad j = 1, \ldots, 14$

$2X_{23,j} - Y_{19,j} - Z_{20,j} = 0 \qquad j = 1, \ldots, 14$

$2X_{24,j} - Y_{20,j} - Z_{21,j} = 0 \qquad j = 1, \ldots, 14$

$2X_{25,j} - Y_{21,j} - Z_{22,j} = 0 \qquad j = 1, \ldots, 14$

These will force Y = Z = 0 when X = 0

and Y = Z = 1 when X = 1.

The information in Table III, which includes the hospital's weekend off policy, can be used to write the rest of the constraints. There will be constraints for each of the three shifts at each goal level.

4.12) Minimum Shifts

$$\sum_{i=1}^{25} X_{i,j} - d^{+}_{1,j} + d^{-}_{1,j} = 9 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{21} Y_{i,j} - d^{+}_{1,j+14} + d^{-}_{1,j+14} = 9 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{22} Z_{i,j} - d^+_{1,j+28} + d^-_{1,j+28} = 9 \qquad j = 1, \ldots, 14$$

4.13) Number of Shifts

$$\sum_{j=1}^{14} X_{i,j} - d^+_{2,i} = k_i \qquad i = 1, \ldots, 25$$

$$\sum_{j=1}^{14} Y_{i,j} - d^+_{2,i+25} = k_{i+25} \qquad i = 1, \ldots, 21$$

$$\sum_{j=1}^{14} Z_{i,j} - d^+_{2,i+46} = k_{i+46} \qquad i = 1, \ldots, 22$$

4.14) Desired Level

$$\sum_{i=1}^{25} X_{i,j} - d^+_{4,j} + d^-_{4,j} = 11 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{21} Y_{i,j} - d^+_{4,j+14} + d^-_{4,j+14} = 11 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{22} Z_{i,j} - d^+_{4,j+28} + d^-_{4,j+28} = 11 \qquad j = 1, \ldots, 14$$

In addition, the days-in-a-row constraints must be included. The objective will have four priority levels. In descending order:

4.15) A) $\text{Min } Z = d^-_{1,j} \qquad j = 1, \ldots, 42$

B) $\text{Min } Z = d^+_{2,i} \qquad i = 1, \ldots, 68$

C) $\text{Min } Z = d^+_{1,j} \qquad j = 6,7,13,14,20,21,27,28,34,35,41,42$

D) $\text{Min } Z = d^+_{4,j} + d^-_{4,j} \qquad j = 1, \ldots, 42$

A solution will be found by achieving 4.15 subject to 4.11-4.14.

Unfortunately this problem has over 1500 variables and 600 constraints. The software that is available at the University of Oregon Computing Center cannot solve such a large problem easily, however a schedule could be formulated at the proper facilities.

Section 3.4: A Computer Solution to a Medium-sized Unit

The second unit is of a more manageable size. There are only 27 nurses and each works eight hour shifts. The figures can be found in Table III in the appendix. The minimum and desired levels of staffing are:

	Day	Evening	Night
Min Nurses	4	4	2 weekends 3 weekdays
Min RNs	2	2	1
Des Nurses	4 weekends 5 weekdays	4 weekends 5 weekdays	2 weekends 3 weekdays

The decision variables will be found in Table IVa,b,c. The goals will be:

4.16) Minimum Staffing:

$$\sum_{i=1}^{10} X_{i,j} - d^+_{1,j} + d^-_{1,j} = 4 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{7} X_{i,j} - d^+_{1,j+14} + d^-_{1,j+14} = 2 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{11} Y_{i,j} - d^+_{1,j+28} + d^-_{1,j+28} = 4 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{7} Y_{i,j} - d^{+}_{1,j+42} + d^{-}_{1,j+42} = 2 \qquad j = 1, \ldots, 14$$

$$\sum_{i=1}^{6} Z_{i,j} - d^{+}_{1,j+56} + d^{-}_{1,j+56} = 3 \qquad j = 1,2, \ldots, 5;\ j = 8, \ldots, 12$$

$$\sum_{i=1}^{6} Z_{i,j} - d^{+}_{1,j+56} + d^{-}_{1,j+56} = 2 \qquad j = 6, 7, 13, 14$$

$$\sum_{i=1}^{4} Z_{i,j} - d^{+}_{1,j+70} + d^{-}_{1,j+70} = 1 \qquad j = 1, \ldots, 14$$

4.17) Number of Shifts:

$$\sum_{j=1}^{14} X_{i,j} - d^{+}_{2,i} = k_{i} \qquad i = 1, \ldots, 10$$

$$\sum_{j=1}^{14} Y_{i,j} - d^{+}_{2,i+10} = k_{i+10} \qquad i = 1, \ldots, 11$$

$$\sum_{j=1}^{14} Z_{i,j} - d^{+}_{2,i+21} = k_{i+21} \qquad i = 1, \ldots, 6$$

4.18) Desired Level:

$$\sum_{i=1}^{10} X_{i,j} - d^{+}_{4,j} + d^{-}_{4,j} = 5 \qquad j = 1, \ldots, 5;\ j = 8, \ldots, 12$$

$$\sum_{i=1}^{11} Y_{i,j} - d^{+}_{4,j+10} - d^{-}_{4,j+10} = 5 \qquad j = 1, \ldots, 5;\ j = 8, \ldots, 12$$

The desired levels for weekends and for night shift can be denoted in the objective function with deviational variables from constraints that already have been used.

4.19) Priority A:

$$\text{Min } Z = d^-_{1,j} \qquad j = 1, \ldots, 84$$

Priority B:

$$\text{Min } Z = d^+_{2,i} \qquad i = 1, \ldots, 27$$

Priority C:

$$\text{Min } Z = d^+_{1,j} \qquad j = 6,7,13,14,34,35,41,42,62,63,69,70$$

Priority D:

$$\text{Min } Z = d^+_{4,j} + d^-_{4,j} \qquad j = 1, \ldots, 22$$

$$\text{Min } Z = d^+_{1,j+56} \qquad j = 1, \ldots, 14$$

In addition, the days-in-a-row constraints must be added for all nurses who work more than five shifts during the scheduling period. There is more than one solution that will achieve the maximum level of goal attainment. The computer solution therefore can be adjusted to avoid day off/day on/day off patterns. A solution will be found by achieving 4.19 subject to 4.16-4.18.

The solution was found by applying Dauer and Kreuger's Iterative Approach[7] to a 0-1 formulation of the LINMAX package at the University of Oregon Computing Center. All goals on the day shift were achieved completely except for goal #4, the desired level of staffing:

$$d^+_{4,1} = d^+_{4,4} = d^+_{4,11} = 1$$

On the evening shift, once again all goals are completely achieved except for #4:

$$d^-_{4,15} = 1$$

On the night shift, goal #2, minimize overtime, is underachieved:

$$d^{+}_{2,26} = 1 \qquad \text{or} \qquad d^{+}_{2,27} = 1.$$

On the last day of the scheduling period, one of the Techs must work an extra shift. $Z_{5,14} = 1$ when $Z_{6,14} = 0$ and $Z_{5,14} = 0$ when $Z_{6,14} = 1$. The resulting schedule is shown on the following three pages.

Medium-Sized Unit Day Shift Schedule

	Scheduling Day													
	Week 1							Week 2						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Nurse	M	T	W	H	F	SA	SU	M	U	W	H	F	SA	SU
1	1	1	1	1	0	1	1	0	1	1	1	0	0	0
2	1	0	0	0	0	0	0	1	1	0	0	1	1	1
3	1	1	0	0	1	1	1	1	0	0	0	0	0	0
4	1	0	1	1	0	0	0	0	0	0	0	1	1	1
5	1	1	0	0	0	0	0	0	0	1	1	1	0	0
6	0	0	0	0	0	0	0	0	0	1	1	1	1	1
7	0	0	1	1	1	1	1	0	0	0	0	0	0	0
8	0	0	0	1	1	1	0	1	1	1	1	0	0	0
9	1	1	1	1	1	0	1	1	1	1	1	0	0	0
10	0	1	1	1	1	0	0	1	1	0	1	1	1	1

Medium-Sized Unit Evening Shift Schedule

	Scheduling Day													
	Week 1							Week 2						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Nurse	M	U	W	H	F	SA	SU	M	U	W	H	F	SA	SU
1	1	1	1	0	0	1	1	0	1	1	1	1	0	0
2	0	1	1	1	0	0	0	1	1	1	0	1	1	1
3	1	1	0	1	1	0	0	1	1	1	0	0	0	0
4	1	1	1	0	0	0	0	1	1	0	0	0	0	0
5	1	1	1	1	1	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	1	1	1	1	1
7	0	0	0	0	0	1	1	1	0	0	1	1	0	0
8	1	0	0	0	0	0	0	0	0	0	1	1	1	1
9	0	0	0	1	1	1	1	1	0	0	0	0	0	0
10	0	0	1	1	1	0	0	0	0	0	0	0	1	1
11	0	0	0	0	0	1	1	0	1	1	1	0	0	0

Medium-Sized Night Shift Schedule

	Scheduling Day													
	Week 1							Week 2						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Nurse	M	U	W	H	F	SA	SU	M	U	W	H	F	SA	SU
1	1	1	1	1	1	0	0	1	1	1	0	0	0	0
2	0	0	0	0	1	1	1	0	0	0	1	1	0	0
3	0	0	0	0	0	0	0	0	1	1	0	1	1	1
4	1	1	1	1	1	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	1	1	1	0	0	1	1	1	0/1
6	1	1	1	1	0	0	0	1	1	1	1	0	0	1/0

CHAPTER 4

CONCLUSIONS

This model drew largely upon Arthur and Ravindran's Nurse Scheduling Model,[8] but many of their assumptions were relaxed: nurses were allowed to work any number of shifts per week and the case of the 12-hour shift was added. In addition, the model was extended to the normal two-week scheduling period and constraints were added that precluded the possibility of a nurse working more than five consecutive days. Finally, it was thought best to handle the day-off/day-on/day-off pattern manually in order to simplify the mathematical aspects of the problem.

These solutions will give Sacred Heart Hospital a base schedule that can be adjusted manually as needs and goals change. For example, a nurse who works five shifts may prefer them consecutively rather than in three consecutive shifts followed later in the period by two shifts. Both types of patterns will be found in the final solution and these can be modified easily as shown in the solution to the day shift for nurses six and seven.

Further extensions could be made to this model. If the hospital can quantify a rate of substitutability between LPNs and RNs or if the hospital has a different weekend-off policy, the model could be modified. Finally, the possibility of ten-hour shifts could be included, but it is unlikely that the benefits would be worth the complexities that would be introduced.

The value of mathematical programming for nurse scheduling is in the reduction of time and improvement in scheduling that it achieves. The schedule for night shift was simple enough to perform manually, but to solve the day and evening shift schedules by hand would be a bit like solving a Rubik's cube without knowing a pattern; the task can be performed, but it's a long and tedious one. The hospital administrator who schedules the medium-sized unit has examined the goal programming solution and plans to implement it, after making slight modifications. It is hoped that similar models will find wider use in hospitals in the near future.

APPENDIX

TABLE I. Large Unit

	Day		Evening			Night		
Nurse	Shifts/ period	Shift length	N	S/P	SL	N	S/P	SL
X_1	8	10 hrs	Y_1	6	10	Z_1	8	10
X_2	7	10	Y_2	6	10	Z_2	8	10
X_3	7	10	Y_3	6	10	Z_3	8	10
X_4	7	10	Y_4	8	10	Z_4	8	10
X_5	10	8	Y_5	10	8	Z_5	7	10
X_6	10	8	Y_6	9	8	Z_6	6	10
X_7	10	8	Y_7	8	8	Z_7	4	10
X_8	10	8	Y_8	5	8	Z_8	8	8
X_9	9	8	Y_9	6	8	Z_9	5	8
X_{10}	8	8	Y_{10}	8	8	Z_{10}	8	8
X_{11}	8	8	Y_{11}	9	9	Z_{11}	10	8
X_{12}	8	8	Y_{12}	8	8	Z_{12}	8	8
X_{13}	8	8	Y_{13}	9	8	Z_{13}	7	8
X_{14}	7	8	Y_{14}	8	8	Z_{14}	8	8
X_{15}	7	8	Y_{15}	7	8	Z_{15}	8	8
X_{16}	7	8	Y_{16}	6	8	Z_{16}	10	8
X_{17}	7	8	Y_{17}	9	8	Z_{17}	8	8
X_{18}	5	8	Y_{18}	6	12	Z_{18}	8	8
X_{19}	5	8	Y_{19}	6	12	Z_{19}	6	12
X_{20}	5	8	Y_{20}	6	12	Z_{20}	6	12
X_{21}	1	8	Y_{21}	6	12			
X_{22}	6	12						
X_{23}	6	12						

TABLE II. Day Shift of the Large Unit

	(1) M	(2) U	(3) W	(4) H	(5) F	(6) SA	(7) SU	(8) M	(9) U	(10) W	(11) H	(12) F	(13) SA	(14) SU
RN_1	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$	$X_{1,4}$	$X_{1,5}$	$X_{1,6}$	$X_{1,7}$	$X_{1,8}$	$X_{1,9}$	$X_{1,10}$	$X_{1,11}$	$X_{1,12}$	0	0
RN_2	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$	$X_{2,4}$	$X_{2,5}$	$X_{2,6}$	0	0	$X_{2,9}$	$X_{2,10}$	$X_{2,11}$	$X_{2,12}$	$X_{2,13}$	$X_{2,14}$
RN_3	$X_{3,1}$	$X_{3,2}$	$X_{3,3}$	$X_{3,4}$	$X_{3,5}$	$X_{3,6}$	$X_{3,7}$	$X_{3,8}$	$X_{3,9}$	$X_{3,10}$	$X_{3,11}$	$X_{3,13}$	0	0
RN_4	$X_{4,1}$	$X_{4,2}$	$X_{4,3}$	$X_{4,4}$	$X_{4,5}$	$X_{4,6}$	0	0	$X_{4,9}$	$X_{4,10}$	$X_{4,11}$	$X_{4,12}$	$X_{4,13}$	$X_{4,14}$
RN_5	$X_{5,1}$	$X_{5,2}$	$X_{5,3}$	$X_{5,4}$	$X_{5,5}$	$X_{5,6}$	$X_{5,7}$	$X_{5,8}$	$X_{5,9}$	$X_{5,10}$	$X_{5,11}$	$X_{5,12}$	0	0
RN_6	$X_{6,1}$	$X_{6,2}$	$X_{6,3}$	$X_{6,4}$	$X_{6,5}$	$X_{6,6}$	0	0	$X_{6,9}$	$X_{6,10}$	$X_{6,11}$	$X_{6,12}$	$X_{6,13}$	$X_{6,13}$
RN_7	$X_{7,1}$	$X_{7,2}$	$X_{7,3}$	$X_{7,4}$	$X_{7,5}$	$X_{7,6}$	$X_{7,7}$	$X_{7,8}$	$X_{7,9}$	$X_{7,10}$	$X_{7,11}$	$X_{7,12}$	0	0
RN_8	$X_{8,1}$	$X_{8,2}$	$X_{8,3}$	$X_{8,4}$	$X_{8,5}$	$X_{8,6}$	0	0	$X_{8,9}$	$X_{8,10}$	$X_{8,11}$	$X_{8,12}$	$X_{8,13}$	$X_{8,14}$
RN_9	$X_{9,1}$	$X_{9,2}$	$X_{9,3}$	$X_{9,4}$	$X_{9,5}$	$X_{9,6}$	$X_{9,8}$	$X_{9,9}$	$X_{9,9}$	$X_{9,10}$	$X_{9,11}$	$X_{9,12}$	0	0
RN_{10}	$X_{10,1}$	$X_{10,2}$	$X_{10,3}$	$X_{10,4}$	$X_{10,5}$	$X_{10,6}$	0	0	$X_{10,9}$	$X_{10,10}$	$X_{10,11}$	$X_{10,12}$	$X_{10,13}$	$X_{10,14}$
RN_{11}	$X_{11,1}$	$X_{11,2}$	$X_{11,3}$	$X_{11,4}$	$X_{11,5}$	$X_{11,6}$	$X_{11,7}$	$X_{11,8}$	$X_{11,9}$	$X_{11,10}$	$X_{11,11}$	$X_{11,12}$	0	0
RN_{12}	$X_{12,1}$	$X_{12,2}$	$X_{12,3}$	$X_{12,4}$	$X_{12,5}$	$X_{12,6}$	0	0	$X_{12,9}$	$X_{12,10}$	$X_{12,11}$	$X_{12,12}$	$X_{12,13}$	$X_{12,14}$
RN_{13}	$X_{13,1}$	$X_{13,2}$	$X_{13,3}$	$X_{13,4}$	$X_{13,5}$	$X_{13,6}$	$X_{13,7}$	$X_{13,8}$	$X_{13,9}$	$X_{13,10}$	$X_{13,11}$	$X_{13,12}$	0	0
RN_{14}	$X_{14,1}$	$X_{14,2}$	$X_{14,3}$	$X_{14,4}$	$X_{14,5}$	$X_{14,6}$	0	0	$X_{14,9}$	$X_{14,10}$	$X_{14,11}$	$X_{14,12}$	$X_{14,13}$	$X_{14,14}$
RN_{15}	$X_{15,1}$	$X_{15,2}$	$X_{15,3}$	$X_{15,4}$	$X_{15,5}$	$X_{15,6}$	$X_{15,7}$	$X_{15,8}$	$X_{15,9}$	$X_{15,10}$	$X_{15,11}$	$X_{15,12}$	0	0
RN_{16}	$X_{16,1}$	$X_{16,2}$	$X_{16,3}$	$X_{16,4}$	$X_{16,5}$	$X_{16,6}$	0	0	$X_{16,9}$	$X_{16,10}$	$X_{16,11}$	$X_{16,12}$	$X_{16,13}$	$X_{16,14}$
RN_{17}	$X_{17,1}$	$X_{17,2}$	$X_{17,3}$	$X_{17,4}$	$X_{17,5}$	$X_{17,6}$	$X_{17,7}$	$X_{17,8}$	$X_{17,9}$	$X_{17,10}$	$X_{17,11}$	$X_{17,13}$	0	0
RN_{18}	$X_{18,1}$	$X_{18,2}$	$X_{18,3}$	$X_{18,4}$	$X_{18,5}$	$X_{18,6}$	0	0	$X_{18,9}$	$X_{18,10}$	$X_{18,11}$	$X_{18,12}$	$X_{18,13}$	$X_{18,14}$
RN_{19}	$X_{19,1}$	$X_{19,2}$	$X_{19,3}$	$X_{19,4}$	$X_{19,5}$	$X_{19,6}$	$X_{19,7}$	$X_{19,8}$	$X_{19,9}$	$X_{19,10}$	$X_{19,11}$	$X_{19,12}$	0	0
RN_{20}	$X_{20,1}$	$X_{20,2}$	$X_{20,3}$	$X_{20,4}$	$X_{20,5}$	$X_{20,6}$	0	0	$X_{20,9}$	$X_{20,10}$	$X_{20,11}$	$X_{20,12}$	$X_{20,13}$	$X_{20,14}$
RN_{21}	$X_{21,2}$	$X_{21,2}$	$X_{21,3}$	$X_{21,4}$	$X_{21,5}$	$X_{21,6}$	$X_{21,7}$	$X_{21,8}$	$X_{21,9}$	$X_{21,10}$	$X_{21,11}$	$X_{21,12}$	0	0
RN_{22}	$X_{22,1}$	$X_{22,2}$	$X_{22,3}$	$X_{22,4}$	$X_{22,5}$	$X_{22,6}$	0	0	$X_{22,9}$	$X_{22,10}$	$X_{22,11}$	$X_{22,12}$	$X_{11,13}$	$X_{22,14}$
RN_{23}	$X_{23,1}$	$X_{23,2}$	$X_{23,3}$	$X_{23,4}$	$X_{23,5}$	$X_{23,6}$	$X_{23,7}$	$X_{23,8}$	$X_{23,9}$	$X_{23,10}$	$X_{23,11}$	$X_{23,12}$	0	0
RN_{24}	$X_{24,1}$	$X_{24,2}$	$X_{24,3}$	$X_{24,4}$	$X_{24,5}$	$X_{24,6}$	0	0	$X_{24,9}$	$X_{24,10}$	$X_{24,11}$	$X_{24,12}$	$X_{24,13}$	$X_{24,14}$
RN_{25}	$X_{25,1}$	$X_{25,2}$	$X_{25,3}$	$X_{25,4}$	$X_{25,5}$	$X_{25,6}$	$X_{25,7}$	$X_{25,8}$	$X_{25,9}$	$X_{25,10}$	$X_{25,11}$	$X_{14,12}$	0	0

TABLE III. Large Unit

Day			Evening			Night		
Nurse	Type	# Shifts	Nurse	Type	# Shifts	Nurse	Type	# Shifts
X_1	RN	9	Y_1	RN	9	Z_1	RN	8
X_2	RN	6	Y_2	RN	9	Z_2	RN	5
X_3	RN	6	Y_3	RN	7	Z_3	RN	5
X_4	RN	6	Y_4	RN	5	Z_4	RN	5
X_5	RN	5	Y_5	RN	5	Z_5	Tech	6
X_6	RN	5	Y_6	RN	5	Z_6	Tech	8
X_7	RN	5	Y_7	RN	5			
X_8	LPN	7	Y_8	Tech	5			
X_9	Tech	10	Y_9	Tech	5			
X_{10}	Tech	10	Y_{10}	Tech	5			
			Y_{11}	Tech	5			

TABLE IVa: Medium-sized Unit Day Shift Schedule

Nurse	(1) N	(2) U	(3) W	(4) H	(5) F	(6) SA	(7) SU	(8) M	(9) U	(10) W	(11) H	(12) F	(13) SA	(14) SU
1	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$	$X_{1,4}$	$X_{1,5}$	$X_{1,6}$	$X_{1,7}$	$X_{1,8}$	$X_{1,9}$	$X_{1,10}$	$X_{1,11}$	$X_{1,12}$	0	0
2	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$	$X_{2,4}$	$X_{2,5}$	0	0	$X_{2,8}$	$X_{2,9}$	$X_{2,10}$	$X_{2,11}$	$X_{2,12}$	$X_{2,13}$	$X_{2,14}$
3	$X_{3,1}$	$X_{3,2}$	$X_{3,3}$	$X_{3,4}$	$X_{3,5}$	$X_{3,6}$	$X_{3,7}$	$X_{3,8}$	$X_{3,9}$	$X_{3,10}$	$X_{3,11}$	$X_{3,12}$	0	0
4	$X_{4,1}$	$X_{4,2}$	$X_{4,3}$	$X_{4,4}$	$X_{4,5}$	0	0	$X_{4,8}$	$X_{4,9}$	$X_{4,10}$	$X_{4,11}$	$X_{4,12}$	$X_{4,13}$	$X_{4,14}$
5	$X_{5,1}$	$X_{5,2}$	$X_{5,3}$	$X_{5,4}$	$X_{5,5}$	$X_{5,6}$	$X_{5,7}$	X_{58}	X_{59}	$X_{5,10}$	$X_{5,11}$	$X_{5,12}$	0	0
6	$X_{6,1}$	$X_{6,2}$	$X_{6,3}$	$X_{6,4}$	$X_{6,5}$	0	0	$X_{6,8}$	$X_{6,9}$	$X_{6,10}$	$X_{6,11}$	$X_{6,12}$	$X_{6,13}$	$X_{6,14}$
7	$X_{7,1}$	$X_{7,2}$	$X_{7,3}$	$X_{7,4}$	$X_{7,5}$	$X_{7,6}$	$X_{7,7}$	$X_{7,8}$	$X_{7,9}$	$X_{7,10}$	$X_{7,11}$	$X_{7,12}$	0	0
8	$X_{8,1}$	$X_{8,2}$	$X_{8,3}$	$X_{8,4}$	$X_{8,5}$	0	0	$X_{8,8}$	$X_{8,9}$	$X_{8,10}$	$X_{8,11}$	$X_{8,12}$	$X_{8,13}$	$X_{8,14}$
9	$X_{9,1}$	$X_{9,2}$	$X_{9,3}$	$X_{9,4}$	$X_{9,5}$	$X_{9,6}$	$X_{9,7}$	$X_{9,8}$	$X_{9,9}$	$X_{9,10}$	$X_{9,11}$	$X_{9,12}$	0	0
10	$X_{10,1}$	$X_{10,2}$	$X_{10,3}$	$X_{10,4}$	$X_{10,5}$	0	0	$X_{10,8}$	$X_{10,9}$	$X_{10,10}$	$X_{10,11}$	$X_{10,12}$	$X_{10,13}$	$X_{10,14}$

TABLE IVb: Medium-sized Unit Evening Shift Schedule

Nurse	(1) M	(2) U	(3) W	(4) H	(5) F	(6) SA	(7) SU	(8) M	(9) U	(10) W	(11) H	(12) F	(13) SA	(14) SU
1	$Y_{1,1}$	$Y_{1,2}$	$Y_{1,3}$	$Y_{1,4}$	$Y_{1,5}$	$Y_{1,6}$	$Y_{1,7}$	$Y_{1,8}$	$Y_{1,9}$	$Y_{1,10}$	$Y_{1,11}$	$Y_{1,12}$	0	0
2	$Y_{2,1}$	$Y_{2,2}$	$Y_{2,3}$	$Y_{2,4}$	$Y_{2,5}$	0	0	$Y_{2,8}$	$Y_{2,9}$	$Y_{2,10}$	$Y_{2,11}$	$Y_{2,12}$	$Y_{2,13}$	$Y_{2,14}$
3	$Y_{3,1}$	$Y_{3,2}$	$Y_{3,3}$	$Y_{3,4}$	$Y_{3,5}$	$Y_{3,6}$	$Y_{3,7}$	$Y_{3,8}$	$Y_{3,9}$	$Y_{3,10}$	$Y_{3,11}$	$Y_{3,12}$	0	0
4	$Y_{4,1}$	$Y_{4,2}$	$Y_{4,3}$	$Y_{4,4}$	$Y_{4,5}$	0	0	$Y_{4,8}$	$Y_{4,9}$	Y4,10	$Y_{4,11}$	$Y_{4,12}$	$Y_{4,13}$	$Y_{4,14}$
5	$Y_{5,1}$	$Y_{5,2}$	$Y_{5,3}$	$Y_{5,4}$	$Y_{5,5}$	$Y_{5,6}$	$Y_{5,7}$	$Y_{5,8}$	$Y_{5,9}$	$Y_{5,10}$	$Y_{5,11}$	$Y_{5,12}$	0	0
6	$Y_{6,1}$	$Y_{6,2}$	$Y_{6,3}$	$Y_{6,4}$	$Y_{6,5}$	0	0	$Y_{6,8}$	$Y_{6,9}$	$Y_{6,10}$	$Y_{6,11}$	$Y_{6,12}$	$Y_{6,13}$	$Y_{6,14}$
7	$Y_{7,1}$	$Y_{7,2}$	$Y_{7,3}$	$Y_{7,4}$	$Y_{7,5}$	$Y_{7,6}$	$Y_{7,7}$	$Y_{7,8}$	$Y_{7,9}$	$Y_{7,10}$	$Y_{7,11}$	$Y_{7,12}$	0	0
8	$Y_{8,1}$	$Y_{8,2}$	$Y_{8,3}$	$Y_{8,4}$	$Y_{8,5}$	0	0	$Y_{8,8}$	$Y_{8,9}$	$Y_{8,10}$	$Y_{8,11}$	$Y_{8,12}$	$Y_{8,13}$	$Y_{8,14}$
9	$Y_{9,1}$	$Y_{9,2}$	$Y_{9,3}$	$Y_{9,4}$	$Y_{9,5}$	$Y_{9,6}$	$Y_{9,7}$	$Y_{9,8}$	$Y_{9,9}$	$Y_{9,10}$	$Y_{9,11}$	$Y_{8,12}$	0	0
10	$Y_{10,1}$	$Y_{10,2}$	$Y_{10,3}$	$Y_{10,4}$	$Y_{10,5}$	0	0	$Y_{10,8}$	$Y_{10,9}$	$Y_{10,10}$	$Y_{10,11}$	$Y_{10,12}$	$Y_{10,13}$	$Y_{10,14}$
11	$Y_{11,1}$	$Y_{11,2}$	$Y_{11,3}$	$Y_{11,4}$	$Y_{11,5}$	$Y_{11,6}$	$Y_{11,7}$	$Y_{11,8}$	$Y_{11,9}$	$Y_{11,10}$	$Y_{11,11}$	$Y_{11,12}$	0	0

TABLE IVc: Medium-sized Unit Night Shift Schedule

Nurse	(1) M	(2) U	(3) W	(4) H	(5) F	(6) SA	(7) SU	(8) M	(9) U	(10) W	(11) H	(12) F	(13) SA	(14) SU
1	$Z_{1,1}$	$Z_{1,2}$	$Z_{1,3}$	$Z_{1,4}$	$Z_{1,5}$	$Z_{1,6}$	$Z_{1,7}$	$Z_{1,8}$	$Z_{1,9}$	$Z_{1,10}$	$Z_{1,11}$	$Z_{1,12}$	0	0
2	$Z_{2,1}$	$Z_{2,2}$	$Z_{2,3}$	$Z_{2,4}$	$Z_{2,5}$	0	0	$Z_{2,8}$	$Z_{2,9}$	$Z_{2,10}$	$Z_{2,11}$	$Z_{2,12}$	$Z_{2,13}$	$Z_{2,14}$
3	$Z_{3,1}$	$Z_{3,2}$	$Z_{3,3}$	$Z_{3,4}$	$Z_{3,5}$	$Z_{3,6}$	$Z_{3,7}$	$Z_{3,8}$	$Z_{3,9}$	$Z_{3,10}$	$Z_{3,11}$	$Z_{3,12}$	0	0
4	$Z_{4,1}$	$Z_{4,2}$	$Z_{4,3}$	$Z_{4,4}$	$Z_{4,5}$	0	0	$Z_{4,8}$	$Z_{4,9}$	$Z_{4,10}$	$Z_{4,11}$	$Z_{4,12}$	$Z_{4,13}$	$Z_{4,14}$
5	$Z_{5,1}$	$Z_{5,2}$	$Z_{5,3}$	$Z_{5,4}$	$Z_{5,5}$	$Z_{5,6}$	$Z_{5,7}$	$Z_{5,8}$	$Z_{5,9}$	$Z_{5,10}$	$Z_{5,11}$	$Z_{5,12}$	0	0
6	$Z_{6,1}$	$Z_{6,2}$	$Z_{6,3}$	$Z_{6,4}$	$Z_{6,5}$	0	0	$Z_{6,8}$	Z6,9	$Z_{6,10}$	$Z_{6,11}$	$Z_{6,12}$	$Z_{6,13}$	$Z_{6,14}$

FOOTNOTES

[1]Milton Friedman, Essays in Positive Economics, (Chicago: University of Chicago Press, 1953), p. 8.

[2]Martin Shubuk, "Approaches to the Study of Decision-Making Relevant to the Firm," in The Making of Decisions: A Reader in Administrative Behavior, edited by William J. Gore and J. W. Dyson, (New York: Free Press of Glencoe, 1964), pp. 31-50.

[3]U.S. Department of Health and Human Services, Public Health Service, National Center for Health Statistics, Health United States and Prevention Profile, 1983, (Hyattsville, Maryland: U.S. Department of Health and Human Services, 1983), p. 177.

[4]Ibid.

[5]Ibid., p. 198.

[6]Abigail Trafford and Clemens P. Work, "Scoring Hospital Costs: The Brewing Revolt," U.S. News and World Report, 95 (Aug. 22, 1983), p. 41.

[7]Jerald P. Dauer and Robert J. Krueger, "An Iterative Approach to Goal Programming," Operational Research Quarterly, 28 (1977), 671-681.

[8]Jeffrey L. Arthur and A. Ravindran, "A Multiple Objective Nurse Scheduling Model," AIIE Transactions, 13 (March, 1981), 55-60.

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