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A SIMULATION-ILP BASED TOOL FOR SCHEDULING ER STAFF

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ABSTRACT

Healthcare facilities, especially hospitals, are under financial pressure to control cost. One element that affects cost significantly is staff. We have developed a tool that integrates a simulation model and an integer linear program (ILP). The simulation model establishes the staffing requirements for each period, and the ILP produces an optimal calendar schedule for the staff, i.e. how many staff members to start at each shift. The two models were fully integrated, under a Visual Basic interface that allowed a non expert user of the heuristic to interact with it on a repetitive planning basis.

1 INTRODUCTION

Personnel or staff scheduling problems have been studied for many years due to its importance on the overall performance of a system in terms of quality of service to the customer and cost to the organization. Different approaches have been taken, including mathematical models as well as computational ones. Some of these models have been embedded in scheduling systems. A scheduling system has two goals: 1) determine the minimum number of personnel to satisfy a set of service level requirement, and 2) build a schedule that specifies when a person should start his/her shift so that all periods in a day are covered, the staffing level requirement of each period are met, and labor laws mandates are preserved.

With shrinking reimbursement rates from the federal government (Medicare and Medicaid) and Managed Care Companies, hospitals must provide a higher level of care at a lower cost in order to survive (Ismail and Miville, 1999). Due to the Balanced Budget Act of 1997, the federal government has cut Medicare and Medicaid spending by $70.1 billion; thus, producing negative margins (Lewin Report, 1999, AHA statistics).

Over 60% of the cost of operating a hospital is in staffing (Hancock and Chan 1988). Hospitals need to use scientific management tools, and better scheduling systems, to reduce their staffing levels without affecting quality of services. Patients become dissatisfied with the service levels, especially in the Emergency Room, when they have to wait for a long period of time to receive much needed care. The latter situation occurs when staff is reduced arbitrarily.

For the last few years, administrators and managers in healthcare have turned to scientific methods to reduce cost and improve their practices. However, managers in healthcare, especially in ER, are clinicians not analysts; thus, they need tools that are easy to use and flexible for their environment. We have developed a tool that is simple to use, and which embeds a simulation and mathematical programming under a VBA application. With it, the ER administration obtains the optimal number of nurses required per shift to satisfy a predefined patients' length of stay (LOS) in the ER, based on demand and service times.

Section 2 of this paper reviews literature pertinent to the staff scheduling problem. Section 3 provides a description of the framework under which the tool was developed. Section 4, 5, and 6 provide a description of the simulation model, the ILP model, and the integration respectively. Section 7 summarizes the findings and lessons learned out of this effort, and it suggests some extensions to this work.

2 PREVIOUS WORK

This section provides a review of the literature organized in two parts: 1) focuses on mathematical models and 2) focuses on discrete event simulation for staff scheduling.

2.1 Operations Research Based Scheduling Tools

For decades, researchers have used several approaches to the staff scheduling problem including the use of statistics, work measurement, queuing models, and integer programming. Isken and Hancock (1998) discussed Tour Scheduling models as they apply to scheduling in hospital ancillary units where demand is variable by day of the week and time of the day; specifically, the authors introduced Tactical Staffing Analysis. This model was written in AMPL language and solved using the CPLEX Optimization package. The output of the solution is a text file that lists all the scheduling tours. However, as they point out mathematical models seldom provide complete answers to real problems, but they provide partial solutions, and a greater understanding of the problem.

Khan (1991) presented a solution that was a network model to minimize the flow of resources through the network. The resource is the nursing staff that needs to be assigned to different departments in the hospital. Khan used the minimal flow algorithm to solve the problem. He proved that using the minimal flow algorithm would yield the same results as the simplex method. This study can provide some insights into the staff scheduling problem of ER systems, but it does not provide a complete methodology for staffing a complex system such as an ER system.

Hancock and Chan (1988) addressed the problem of staff scheduling where the workload varies from day to day and the administrators need to schedule staff weeks in advance. The variability in demand is addressed by one of the following strategies:

- Staffing at average demand levels with no consideration to work force capability.
- Staffing at constant level, overtime permitted, and considerations to work force capability.
- Staffing at constant level, no overtime permitted, and considerations to work force capability.
- Staffing at different level each day, no overtime, and considerations to work force capability.
- Staffing at different level each day, limit on overtime and demand, work force capability considered.
- Staffing at different level each day, limit on overtime, workforce capability considered, and work task may span over two days.

For each of these strategies, the authors calculated the labor cost and the productivity for the department being staffed.

Tine and Ramayana (1982) provided a review of the manpower scheduling algorithms from a common framework. This scheduling approach is based on the idea that the scheduling problem is composed of five stages or subproblems. These five stages are the determination of temporal manpower requirements, total manpower requirement, recreation blocks, recreation/work schedules, and shift schedules. For each of these stages, they suggested different algorithms. They also compared and discussed the algorithms and solutions for each stage. The authors presented a review of the available algorithms to analyze each of the five stages of the scheduling problem.

Baker (1976) surveyed the basic mathematical models for workforce scheduling. He discussed shift scheduling and day-off scheduling in general, as well as the methods to solve such problems using mathematical programming. He presented a model for allocating overlapping shifts with demand fluctuations (the Klein City Problem). He also presented the service level policy for staff requirement in shifts scheduling. For the day-off scheduling, he discussed the problem where an employee workweek does not match the service facility operating week. For this situation, he presented a model that provides equal assignments by rotating individuals among day-off patterns.

2.2 Scheduling Using Simulation

Computer simulation can be used to model and analyze real-world problems that cannot be successfully approached by other types of analytical techniques (Fitzpatrick et. al, 1993). In the last two decades, the use of simulation as a planning and decision making tool has been spreading rapidly in the healthcare arena. Many simulation projects have been done for hospitals around the world, primarily in Emergency Departments.

Pitt (1997) reports on a project that uses simulation as a resource planning tool. The project is the PRISM project (Planning Resources using Interactive Simulation Modeling). PRISM is a general framework that supports the analysis of a range of models and variables to test different scenarios in the resource and strategic planning in hospitals.

A simulation model of a new one-stop pre-procedural work-up and assessment area of the University of North Carolina Hospitals was developed by Glick (1996) to evaluate different scenarios (staffing levels versus patient volume). For each scenario, the simulation predicted the utilization for nurses, anesthesiologists, and other pertinent staff throughout the day. The simulation also produced patient waiting time, patient time in the system and the total number of patients processed throughout the day. Using these results, a schedule for the different required staff was formulated based on the simulation results.

Evans, Gor, and Unger (1996) used simulation as well to investigate various schedules of nurses, ER technicians, and doctors to reduce the average patient time in the system. The authors created a simulation model of a particular Emergency Room using ARENA simulation package software to evaluate different personnel schedules. Five different schedules were evaluated, and a decision was made based on the average time in the system.

Other researchers have used simulation in this same manner; For instance, McGuire (1994) used simulation to reduce Length of Stay (LOS) in an emergency department. One of the alternatives that was evaluated is the introduction of additional staff to the emergency room.

Hammond and Mahesh (1995) used simulation to test manning heuristics for bank tellers to meet the desired level of services in banks. In this study, the researchers used a manning model based on queuing theory to calculate the required number of employees to meet the level of service requirements. The second part of this study is the utilization of simulation to test new management policies. The manning model provided a methodology to calculate the required number of employees while the simulation model tested for the corresponding service level.

Garcia *et al.* (1995) studied the flow of patients at Mercy Hospital in an effort to reduce the waiting times of patients. As a result of this study, a Fast Track lane was added to the Emergency Room; thus, reducing the total time in the system by 25% for patients with low priority without affecting the times of patients with higher priority. This study was performed using simulation where the authors conducted the simulation of this system with and without the Fast Track to test the effect of implementing this Fast Track on the system.

Fitzpatrick. Baker, and Dave (1993) used simulation modeling to improve scheduling of the operating room of an 800 bed medical center in the southeastern United States. In this study, three different block schedules were compared based on throughput, average waiting time, the distribution of waiting time, queue characteristics, facility utilization, and cost effectiveness. The simulation model was built using GPSS.

3 THE FRAMEWORK

Simulation models can provide a statistically accurate and insightful means to analyze and predict the performance of a system such as a hospital's emergency department, which is a complex system formed by a large number of units with strong interrelationships. On the other hand, Integer Linear Programming is an optimization technique that is concerned with finding the best possible answer to a problem. In the case of an emergency department, the schedule must meet certain conditions, such as those imposed by regulations and/or to protect staff and patients, including maximum shift length, or maximum overtime hours.

In order to make the simulation and the linear programming model useful to ED management, these two techniques have been integrated under a VBA for ARENA application (Figure 1). The simulation model determines the staff requirements during each of the predetermined periods in a day, given current conditions of demand and service times. The results, namely the number of the RN's in each of those periods, are then fed automatically to the ILP model to generate a shift-based 24-hour schedule.

Through *User-Defined Conditions*, the analyst provides the current system's conditions such as the patients arrival pattern, the service patterns of different servers in the ER system, and the target performance level of the LOS. There are two different alternatives to get the data into the simulation model. The first option is to have the user input the data manually into the simulation model. The second option is to have the user create text files that contain the data for each category. For this effort, the second option was chosen for

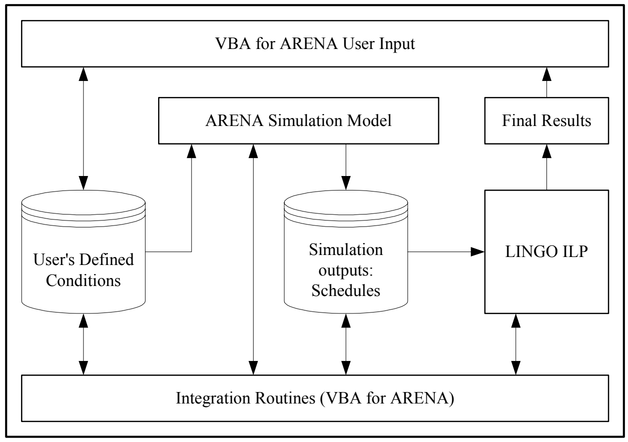

Figure 1: System Integration

no other reason than to reduce the amount of programming needed for this prototype. The user simply creates text files with a predefined format and names.

The *ARENA Simulation Model* mimics the temporal behavior of the ER, and it calculates the minimum number of staff required for each of the nine periods identified.

A set of *VBA Integration Routines* is embedded in the simulation model to support data acquisition from the user, as well as the data exchange from the user to the simulation model, from the simulation model to the ILP model, and back to the user.

A *LINGO Integer Linear Program* is used to determine the actual allocation of personnel to meet the requirements of each and every time period.

4 THE ER MODEL

Patients arrive to the Emergency Department by two different methods: 1) Fire rescue or an ambulance, or 2) by their own mean of transportation. Patients arriving by Fire Rescue or an ambulance are given highest priority and go to a bed immediately. All other patients are triaged and assigned an acuity level. There are four different acuity levels used at the model hospital; Level I, II, III and IV. When a patient arrives at the emergency room, the patient has to be first triaged and assigned an acuity level. If the acuity level is not emergent, the patient has to be registered and then would wait until a bed becomes available. Once a bed becomes available, the patient is escorted to a bed by a registered nurse (RN). The RN performs the initial patient evaluation, starts treatment, and document findings on the patient chart. After this evaluation, the patient is seen by a physician who will recommends the treatment and will order all the necessary tests, such as an X-ray, blood test, EKG, etc, and documents finding on the patient's chart. The RN, acting on the physician's orders, starts performing tests and treatments. At this time, the RN stays in charge of monitoring the patient's treatment and condition. The RN at this time could be assisting other patients as well.

Once the patient is stable and treatments are complete, the physician decides on the patient's disposition. The RN prepares and arrange for patient's disposition documenting all actions on patient's chart.

The arrival pattern presented seven different distributions (Table 1). The service times of the RN and the MD were divided into two main stages since they do not service a patient from start to finish and then move on to the next patient. For the RN, Phase 1 is from the time patient occupies a bed in the treatment area until the physician sees the patient, and phase 2 is made of the rest of the time until all treatments are completed. For the MD, Phase 1 is the time of the patient initial evaluation by the MD, when tests and treatments are ordered and documented, and Phase 2 is the time from the completion of tests until the patient is stabilized and a decision on disposition of patient is to be made. In this manner, the server (RN and MD) is seized to perform the task and then released once this task is completed. Each service time for the RN's and the MD's consisted of multiple distributions as given in Tables 2 and 3.

To build a model for the system being studied, it is necessary to know the properties of the patients being treated. All patients that came in to the emergency department were logged in with all their properties including their method of arrival, disposition, and the auxiliary procedure received (Table 4).

Times for other ancillary activities are in given in Table 5.

Table 1: Distributions for Inter Arrival Times

Period	Period	Distribution
1	12:00 AM – 3:00 AM	Exponential (0.73)
2	3:00 AM - 7:00 AM	Exponential (1.06)
3	7:00 AM - 8:00 AM	Exponential (0.54)
4	8:00 AM - 9:00 AM	Exponential (0.39)
5	9:00 AM - 10:00 AM	Exponential (0.30)
6	10:00 AM –1:00 PM	Exponential (0.26)
7	1:00 PM – 12:00 AM	Exponential (0.36)

Table 2: RN Service Times

	RN Phase I Service Time		RN Phase II Service Time	
Acuity Levels	Distribution	%	Distribution	%
I	Uniform (19,22)	0.33	Uniform (21,22)	0.33
	Uniform (31,33)	0.50	Uniform (27,30)	0.50
	Uniform (37,39)	0.17	Uniform (34,43)	0.17
II	Uniform (20,22)	0.5	Uniform (16,22)	0.33
	Uniform (30,38)	0.5	Uniform (24,25)	0.33
			Uniform (29,33)	0.34
III	Uniform (20,26)	0.4	Uniform (7,17)	0.6
	Uniform (27,31)	0.4	Uniform (24,35)	0.4
	Uniform (39,41)	0.2		
IV	Uniform (13,15)	0.33	Uniform (8,9)	0.33
	Uniform (19,24)	0.50	Uniform (13,16)	0.50
	Uniform (29,31)	0.17	Uniform (18,20)	0.17

Table 3: MD Service Times

	MD Phase I Service Time		MD Phase II Service Time	
Acuity Levels	Distribution	%	Distribution	%
I	Uniform (9,11)	0.34	Uniform (7,8)	0.67
	Uniform (15,17)	0.33	Uniform (11,13)	0.33
	Uniform (19,20)	0.33		
II	Uniform (3,6)	0.60	Uniform (4,8)	0.40
	Uniform (11,14)	0.40	Uniform (11,15)	0.60
III	Uniform (4,6)	0.80	Uniform (4,6)	0.50
	Uniform (10,12)	0.20	Uniform (10,11)	0.33
			Uniform (11,17)	0.17
IV	Uniform (3,6)	0.33	Uniform (2,6)	0.50
	Uniform (7,8)	0.67	Uniform (8,11)	0.50

Table 4: Patient Behavior Percentages

	Action	Percentage
Arrival	Arrival by fire rescue or ambulance	24
	Arrival by own transportation	76
Departure	Patients admitted	46
	Patients discharged	45
	Patients leave against medical advice (AMA)	3.3
	Patients leave without being seen (LWBS)	5.7
Procedures	Patients have lab procedures	69
	Patients that have radiology procedures	55
	Patients that have EKG procedures	42

Table 5: Auxiliary Service Times

Activity	Distribution
Registration Service Time	Normal (11.1,4.2)
Triage Time	2 + Weibull (7.37, 1.69)
Lab Service Time	10 + Gamma (23.3, 2.56)
Radiology Service Time	9.5 + Weibull (18.2, 1.34)
EKG Service Time	Triangular (15,21,30)

Once the model was verified and validated, the conditions for the experiments were established. Initially, the simulation model was run for 10 replications, and the LOS for each replication was recorded. These values were used to calculate the sample size required to achieve a reliability level of ± 3.61 when building a 95% confidence interval. From these, it was established that the number of replications required is 38.

5 ILP MODEL

An optimization ILP model is used to find the optimal number of staff (RN's) needed to work each shift. To build the ILP model, the first step was to identify the shifts that are used by the hospital. In this case, the shifts used are 12 hours in length, with start and end times as in Table 6. Based on these shifts, a period could have nurses from different shifts; for example, period 1 (12:00AM-3:00 AM) has nurses from shift 3 (3:00 PM - 3:00 AM) and nurses from shift 4 (7:00 PM - 7:00 AM). Table 7 shows each period with its corresponding shifts coverage.

The ILP objective function seeks to minimize the labor cost for RN's. For this model the cost of one RN per shift is given in Table 6. A minimum of one RN is required at all times. Then the ILP model is

$$\text{Minimize} \quad z = \sum_{i=1}^{n} c_i X_i$$

Subject to

$$\sum_{i=1}^{n} X_i \geq a_j \qquad \forall\ j = 1, 2, \ldots, m$$

$$X_i \geq 1 \text{ and integer} \qquad \forall\ i = 1, 2, \ldots, n$$

Where

X_i = Number of nurses working shift i

c_i = Salary cost for a nurse during shift i

a_j = Number of RN's required per period as determined in the simulation model

i = Index for shifts

j = Index for periods

n = Maximum number of shifts

m = Maximum number of periods

The ILP model with actual data (Table 6 and Table7) is as follows:

$$\text{Min} \quad Z = 300\,X_1 + 345\,X_2 + 375\,X_3 + 375\,X_4 + 400\,X_5$$

Subject to:

$$X_3 + X_4 \geq a_1 \text{ (Period 1)}$$
$$X_4 + X_5 \geq a_2 \text{ (Period 2)}$$
$$X_1 + X_5 \geq a_3 \text{ (Period 3)}$$
$$X_1 + X_5 \geq a_4 \text{ (Period 4)}$$
$$X_1 + X_5 \geq a_5 \text{ (Period 5)}$$
$$X_1 + X_2 + X_5 \geq a_6 \text{ (Period 6)}$$
$$X_1 + X_2 + X_3 \geq a_7 \text{ (Period 7)}$$
$$X_1 + X_2 + X_3 + X_4 \geq a_8 \text{ (Period 8)}$$
$$X_2 + X_3 + X_4 \geq a_9 \text{ (Period 9)}$$

Table 6: Shifts Data

Shift #	Start Time	End Time	Labor Cost
1	7:00 AM	7:00 PM	$300.00
2	11:00 AM	11:00 PM	$345.00
3	3:00 PM	3:00 AM	$375.00
4	7:00 PM	7:00 AM	$375.00
5	3:00 AM	3:00 PM	$400.00

Table 7: Period and Corresponding Shifts

Time Period	Time Period Covered Shifts					Minimum Number of Nurses Needed
	1	2	3	4	5	
12:00 AM – 3:00 AM			X	X		a_1
3:00 AM – 7:00 AM				X	X	a_2
7:00 AM – 8:00 AM	X				X	a_3
8:00 AM – 9:00 AM	X				X	a_4
9:00 AM – 10:00 AM	X				X	a_5
10:00 AM – 1:00 PM	X	X			X	a_6
1:00 PM - 6:00 PM	X	X	X			a_7
6:00 PM – 8:00 PM	X	X	X	X		a_8
8:00 PM – 12:00 AM		X	X	X		a_9

In the above ILP model, there are three equations that are similar, (Period 3, 4, and 5) differing only in the right hand side (RHS) constant (a_j). The constraint with the $\max\{a_3, a_4, a_5\}$ will render the other two constraints redundant. These equations are left in the ILP model because the values of a_3, a_4, and a_5 may change due to changes in the input parameters of the simulation model. Any change to the input parameters of the simulation model will result in changes to the results of the simulation model, which in turn will affect the values a_j. Since this model is meant to be reusable, these similar constraints have been left in to allow the model to choose its own redundant constraints, depending on current conditions. It is also worth noting that labor costs change over time. Therefore, the values of c_j (salary cost for a nurse during a shift) are read from a text file, allowing flexibility in the constraint equations as well as in the objective function of the ILP model. Every time the ILP model is run, the labor cost text file is read by the ILP model assigning values to each c_j. The LINGO Model is given in Figure 2.

6 VBA INTEGRATION

The tool is the integration of several commercial of the self (COTS) software. As shown in Figure 1, the two main

```
SETS: Nurses_Periods/ RN1 RN2 RN3 RN4 RN5 RN6
RN7 RN8 RN9/ : Demand;
    Nurses_Shifts/ SH1 SH2 SH3 SH4 SH5/ : Re-
quirement;
    Cost_shifts/C1 C2 C3 C4 C5/ : Cost;
End Sets
DATA:
Demand = @File( 'Finalschedules.txt' );
Cost = @File( 'ShiftCost.txt' );
@TEXT('shifts.TXT') = Requirement;
ENDDATA

[OBJECTIVE] MIN = Cost(C1)*Requirement(SH1) +
Cost(C2)*Requirement(SH2) +
Cost(C3)*Requirement(SH3) +
Cost(C4)*Requirement(SH4) +
Cost(C5)*Requirement(SH5);

@GIN(Requirement(SH1));
@GIN(Requirement(SH2));
@GIN(Requirement(SH3));
@GIN(Requirement(SH4));
@GIN(Requirement(SH5));
Requirement(SH3) + Requirement(SH4) >= De-
mand(RN1);
Requirement(SH4) + Requirement(SH5) >= De-
mand(RN2);
Requirement(SH1) + Requirement(SH5) >= De-
mand(RN3);
Requirement(SH1) + Requirement(SH5) >= De-
mand(RN4);
Requirement(SH1) + Requirement(SH5) >= De-
mand(RN5);
Requirement(SH1) + Requirement(SH2) + Require-
ment(SH5) >= Demand(RN6);
Requirement(SH1) + Requirement(SH2) + Require-
ment(SH3) >= Demand(RN7);
Requirement(SH1) + Requirement(SH2) + Require-
ment(SH3) + Requirement(SH4) >= Demand(RN8);
Requirement(SH2) + Requirement(SH3) + Require-
ment(SH4) >= Demand(RN9);
END

! Terse output mode
SET TERSEO 1
! Open a file
DIVERT Shifts.TXT
! Send solution to the file
SOLUTION
! Close solution file
RVRT
! Quit LINGO
QUIT
```

Figure 2: The LINGO ILP Model

components of the tool are: a simulation model and an integer linear program. The tools used to develop these two components are ARENA and LINGO. These tools have a master-slave relationship, with ARENA retaining the master role because of its VBA capability. Figure shows the macro steps of the heuristic that enable the communication between the user and ARENA and ARENA and LINGO. The user never interacts directly with LINGO, only with ARENA through a simple and friendly interface.

Figure 3 shows the steps in the VBA integration. It required the programming of several ARENA model events:

- RunBegin
- RunEndReplication
- RunEnd.

The code for gathering data and implementing Reyes' (1998) goal driven simulation heuristic is very extensive, but since the interesting part was the embedding of the ILP model, Figure 4 provides the subset of the VBA code that triggers and controls LINGO.

```
1   Get the goal (LOS) from user
2   Load files (schedules)
        Change = 0
3   Run Simulation
4   At end of Simulation run,
    For i = 1 to n (Number of periods per day)
        Calculate 95% CI on LOS for n periods
        If Goal < MAX(los_i) then RN_i = RN_i + 1
        Change = 1
    Next i
5   If Change_i = 1 , then
        Stop Simulation
        Update physical model (SCHEDULES)
        Go to step 3
    Else
        Export RN_i from SCHEDULES to file
    End If
6   Trigger Lingo ILP model
    Load Files (cost, RN_i)
    Get solution, transfer to a file
8   Pause simulation execution, retain control
9   Trigger Lingo ILP model
    Load Files (cost, RN_i)
    Solve ILP model,
    transfer results to an ASCII file
10  Read ILP results file
11  Display final Results.
```

Figure 3: Steps in the Integration Process

At the conclusion of the simulation run, the number of nurses is exported from the SCHEDULES element to a text file. A VBA routine (*LingoControl*) triggers LINGO to run the pre-formulated LINGO ILP model. The LINGO model is programmed to read the text file containing the number of nurses required per time period. VBA for ARENA runs the ILP model, via the DDE facility of Sendkeys. The results are then exported to a text file that is in turn read by VBA for ARENA to exhibit the final results through a user form.

```
Sub LingoControl()
    Dim LingoConnector, thefile, Start
    DIm PauseTime
    Dim TotalCost, TotalHours As Integer
'
' Triggering Lingo
'
    thefile = "staffing.lg4"
    LingoConnector=Shell("lingo.EXE",1)
    AppActivate LingoConnector
    SendKeys "%Fo", True ' ALT+F and O
SendKeys thefile, True ' sending file name to
be opened
SendKeys  "{tab  2}{enter}",  True  'click  on
                   OPEN in dialog box"
SendKeys "%LS", True            ' running the
                   model
'
'pausing to allow solver to finish
'
      PauseTime = 3    ' Set duration.
      Start = Timer    ' Set start time.
      Do While Timer < Start + PauseTime
        DoEvents    '
      Loop
'Resume control from Lingo
      SendKeys "C", true
      SendKeys "%FX", True  'Close Lingo

Open "Shifts.txt" For Input As #15
      I = 0
      While Not EOF(15)
         Input #15, My
         I = I + 1
      Wend
      Close #15
ObsNum = I
ReDim m(ObsNum) As Integer

Open  "Shifts.txt"  For  Input  As  #15   '  Open
file.
Do While Not EOF(15)
   For I = 1 To ObsNum
       Input #15, z
       m(I) = z
   Next I
Loop
Close #15

   RNSH1 = m(1)  : RNSH3 = m(3)  : RNSH2 = m(2)
   RNSH4 = m(4)  : RNSH5 = m(5)

TotalCost = 300 * RNSH1 + 345 * RNSH2 + 375 *
RNSH3 + 375 * RNSH4 + 400 * RNSH5
TotalHours  =  12  *  (RNSH1  +  RNSH2  +  RNSH3  +
RNSH4 + RNSH5)

   Load ResultForm
      ResultForm.Shift1.Text = RNSH1
      ResultForm.Shift2.Text = RNSH2
      ResultForm.Shift3.Text = RNSH3
      ResultForm.Shift4.Text = RNSH4
      ResultForm.Shift5.Text = RNSH5
      ResultForm.Hours.Text = TotalHours
      ResultForm.Objective.Text = TotalCost
      ResultForm.Show
End Sub
```

Figure 4: VBA Code to Control LINGO

7 CONCLUSIONS

This work presents a tool that integrates two proven tools, simulation and integer linear programming to help ER managements to staff their departments correctly without over-spending.

The value of this tool had to be ascertained by answering one question: *Is the heuristic at least as good as the empirical method currently used* ? This implies that even if the heuristic is as good as the empirical approach there is an intrinsic value in using it, namely that the process of generating the schedule is automated; hence, the schedules are less prone to errors and can be generated faster.

Since this heuristic was established for staff scheduling in ER, the total nurse-hours per day for the empirical approach and the heuristic were calculated at different demand levels. Table 8 shows the total nurse hours for each of the two methods. For the empirical method, an ER manager was consulted to perform the staffing of nurses at the different patients levels. As can be seen in Table 8, the schedule is fixed between 40 and 80 patients, the total of nurse-hours are then increased proportionally based on the number of patients.

Table 8: Total Nurse-Hours

Trials (Number of patients)	TH	TE	Trials (Number of patients)	TH	TE
40	84	112	66	84	112
44	72	112	70	72	112
48	72	112	74	96	112
51	72	112	75	84	112
53	84	112	76	84	112
54	84	112	78	96	112
56	84	112	79	108	112
59	84	112	82	84	156
61	96	112	83	84	156
62	96	112	85	120	156
63	72	112	87	96	168
64	72	112	90	120	168
65	84	112			

A t-test was used to answer the question. The hypothesis test is set up as follows:

$$H_0: T_E < T_H$$
$$H_1: T_E \geq T_H,$$

where,

T_H = Total person-hours for Heuristic

T_E = Total person-hours for Empirical

Since the resulting confidence interval (24.67, 44.13) does not contain zero, and the two tail significance level is less than 0.005, we reject the null hypothesis. Thus, there is sufficient evidence to conclude that there is a difference between the two populations. Furthermore, because the difference T_E - T_H is positive (34.4), schedules generated using the heuristic requires less person hours than the schedules generated using the empirical method. Therefore, the heuristic is better than the empirical approach.

The mean improvement in the total person-hours is 34.40 hours per day, that is a 28% improvement. Estimating nursing hourly rate to be at $35.00, the 28% improvement, for a 15 beds emergency room, will result in an annual savings of approximately half a million dollars (34.4 hours/day*$35.00/hour * 365 days/year = $439,460). If a hospital decides to implement this heuristic, they must own ARENA and LINGO software packages, which implies an investment of approximately $25,000.00. Given the expected savings, investing in the software is profitable.

This tool will aid ER management in determining the exact number of staff required to achieve a specific goal, which is the time in the system that a patient spends in ER. With this tool, ER management would be able to determine the number of nurses by shift based on a specific time that they would like to have the patients out of the system. They would also be able to calculate based on their labor rates, the cost associated with a specific time in the system. They also can use this tool to experiment with three different important factors; labor cost, time in the system, and number of nurses.

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