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COMPUTER SIMULATION AS A METHOD FOR SELECTING NURSE STAFFING LEVELS IN HOSPITALS

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ABSTRACT

Efficient utilization of staff resources is perhaps the most critical issue facing nursing department administrators today, and has been a matter of concern to nursing service administrators since at least the early 1940's. This study used computer simulation to examine the effect on wage costs and staffing adequacy of varying nurse staffing levels. Three Psychiatric care units in a large VA hospital served as models for the simulation study. The staffing patterns tested were 40%, 50%, 60%, and 80% of maximum workload. Due to a quirk in rounding, the 40% and 50% staffing levels were exactly the same for these nursing units. The 80% staffing level produced direct wage costs 8% higher than the 50% level and 6.7% higher than the 60% level. It also produced 11.6% overstaffing as compared with 1.7% for the 60% staffing level and .2% for the 50% level. The 50% staffing level produced .9% understaffing as compared with .4% for the 60% level and .3% for the 80% level. It was concluded that both the 50% and 60% staffing levels performance was acceptable. Graphical representation of the data demonstrated that the optimal staffing level fell at approximately the 55% staffing level.

1. INTRODUCTION

Due to a variety of factors in the hospital environment, efficient allocation of nursing staff resources is perhaps the most critical issue facing nursing department administrators today. Nursing's attention to problems in hospital nurse staffing is, however, not new. Imbalances between available nursing hours and patient care needs in hospitals have been a concern to nursing administrators since at least the 1940s (Giovanetti, 1978). It is therefore surprising that there are no computerized decision support tools to assist nursing department managers to identify optimal staffing levels for their Master Staffing Plans. This study examined the effects of staffing level changes on wage costs and the incidence of overstaffing and understaffing through use of a computer simulation based decision support model. The purpose of this study was to select the optimal nurse staffing level in three units of the Ann Arbor, Michigan Veterans Administration Hospital. This hospital used Skill Center Staffing as its Master Staffing Pattern. (In Skill Center staffing, nurses work only in wards similar to the one in which they usually work. For example, pediatric nurses work in all the pediatric floors, but do not work in adult or intensive care type units). Optimal nurse staffing was defined as the level of staffing that jointly minimized wage costs, overstaffing, and understaffing. The independent variable was staffing level.

Joint minimization of the three dependent variables--wage costs, overstaffing, and understaffing--is necessary if staffing levels are to be optimized because these three factors are not independent of each other. The relationship between overstaffing and excess wage costs is fairly obvious. Overstaffing means that condition in which the hospital is paying for nurses to be idle because there is not enough patient care or other work for them to do. The relationship between understaffing and wage costs is less clear. Generally, understaffing will tend to produce lower wage costs because the paid nursing hours are insufficient to complete the workload. Therefore, understaffing could be used to control wage costs; but this choice is made at the expense of care quality. Paradoxically, chronic understaffing may increase wage costs if the shortages are consistently alleviated through use of expensive overtime or external agency nurses. Thus, while chronic overstaffing always tends to increase wage costs, chronic understaffing may either increase or decrease wage costs. The relationship between understaffing and overstaffing is not generally well understood in nursing.

Due to the many random variables that exist in the typical hospital nursing unit staffing situation, a perfect match between nursing hours and patient care hours is not generally possible. Previous research (McHugh, 1988) clearly demonstrated that Master Staffing Plans which eliminate overstaffing do so at the cost of massive increases in understaffing. Conversely, Master Staffing Plans that eliminate understaffing produce very large overstaffing costs.

If perfect balance were possible, exactly the number of required nursing hours would be provided each day. In this ideal situation, neither overstaffing nor understaffing would occur. All wage cost dollars invested would be used to produce an appropriate match between care needs and nursing hours available. Finally, wage costs would be minimized by a staffing system that used only "regular" hourly wages so as to avoid overtime rates and the high hourly costs of using nurses from "PRN" nursing pool agencies. In this context the concept, "minimizing wage costs" is a matter of eliminating overstaffing and paying for required nursing care hours at the lowest hourly rate. Unfortunately, this ideal situation does not often exist.

Obviously, overstaffing can be entirely eliminated if one is willing to tolerate very severe understaffing as the steady state condition. Understaffing can be entirely eliminated if the cost of idle nursing time (engendered by severe overstaffing) is no object. In actual practice, neither of these scenarios is realistic. Ideally, staffing programs should be designed to provide exactly enough nurses to handle the required workload. However, because of the variable nature of workload and nursing hours actually available (given absences), it is not now possible to avoid all instances of overstaffing and understaffing. In practice, administrators attempt to jointly minimize understaffing and overstaffing by providing the best possible match between nursing hours and patient requirements given their budget constraints.

To the extent that overstaffing and understaffing are jointly minimized, wage costs will reflect appropriate expenditure of direct wage cost dollars. In this study, wage costs have been reported for the information of the reader, but the performance of each staffing level was primarily judged by its joint incidence of overstaffing and understaffing.

Simulation models have been used sparingly in nursing administration research. However, they have long been used in other human service organizations that have complex, variable workload demands combined with variable worker availability. Computer simulation was used to assist New York Police and Fire Departments to select effective systems for deploying their personnel resources (Carter, Ingall, & Walker, 1975; Kolesar & Walker, 1975). In hospital administration, researchers have employed simulation for applications such as admissions scheduling (Hancock, Martin, & Storer, 1978; Hamilton, Hancock, &

Hawley, 1975). Computer simulation was used to evaluate the effects of different staffing levels in the Medical ICU and stepdown unit at University Hospitals of Cleveland (Duraiswamy, Welton, & Reisman, 1981). However, more staffing decision support systems designed for total hospital use were not found in the literature.

2. METHOD

Design. A matched sample experimental research design was employed. Using a computer simulation to create the purity of a laboratory experiment, this study controlled potentially confounding variables through perfect matching of all relevant extraneous variables and through isolation of all other known and unknown variables in the research environment. Simulation (rather than linear programming) was used because more than one random variable must be used in modeling a hospital unit. Such variables as daily workload, nursing absences (by shift), availability of extra nurses from a variety of sources and by shift must all be accounted for, and these variables are known to vary randomly. These extraneous variables were perfectly matched across the levels of the independent variable (staffing level) so that the unique effect of each staffing level on the dependent variables could be observed.

Sample. The Veterans Administration Hospital located in Ann Arbor, Michigan contributed data from its nursing units as a study site. The Ann Arbor VA Hospital is a 409 bed federal hospital. The hospitals' nursing units are organized around "Skill Centers", or units that have similar patient populations and demand similar nursing skills. The three skill centers are: ICU, Medical/Surgical, and Psychiatry. This report focuses on the results for the three units in the Psychiatric skill center.

The unit of observation in this study was one simulated year of model performance for each tested staffing level. The following staffing levels were tested: 40% of the maximum expected workload, 50% of maximum expected workload, 60%, and 80%. Model performance was tested for ten years for each staffing level. Thus the total sample size was 4 levels X 3 units X 10 years of model performance = 120.

The 50% staffing level (mean workload staffing) is the most common level in use today. Ten percent above (60% staffing) and below (40% staffing) the 50% level were selected for testing. In addition, the 80% staffing level was examined because it was in common use prior to the 1960s with a very old staffing pattern (that did not require nurse to work in units outside their home unit) and is again being tried in a few hospitals because it may reduce nursing turnover.

Apparatus. The Henrikson implementation of the General Purpose Simulation System (GPSS/H) was the simulation language used. Data were analyzed through the Michigan Interactive Data Analysis System (MIDAS) program. Both GPSS/H and MIDAS were accessed through the Michigan Terminal System (MTS) on the Amdahl mainframe computer at the University of Michigan.

Procedure. Information about the nursing department structure and workload and staffing conditions were obtained from the Chief Nurse's office. Those data were used to design the simulation program. Once written, the program was subjected to extensive testing and program validation procedures by both desk checking results at multiple points within the running programs, and by using the GPSS/H debugging facility. Once the program was verified it was programmed to run for ten years for each of the staffing levels tested. In the following section, some critical aspects of simulation model development are discussed.

There are many variables in the interface between nursing availability and patient care needs. These include daily workload fluctuations, staff absences, availability of part time staff to work extra hours, the willingness of staff to work overtime, the ability to reduce excess staffing (through floating or offering unpaid time off), and availability of per diem agency staff. Workload variation followed a Poisson Distribution pattern. The other extraneous random variables were assumed to exhibit a flat distribution and were assigned a simple probability function in the program.

Workload distribution has been defined as a stochastic variable with a Poisson distribution. The point values for the distribution were specific to the intensity of the distribution. The probability function for a Poisson variable **X** follows the rule:

$$\frac{e^{-m}\, m^{-x}}{X!}$$

where **m** is the intensity of the process and **e** is a mathematical constant. A computer program was written in Basic to generate the probabilities of point values in each workload distribution.

In the VA hospital model, actual patient classification raw data were obtained for the months of July, August, and September, 1985. (The data were in the form of daily reports of numbers of patients in each classification for each unit.) The VA uses a patient classification system designed for and validated in the VA hospital system. A program was written in the Basic Language to derive each unit's average daily workload from these data. The Basic program was used to input one day's data, multiply the number of patients in each class by the VA formula for workload hours for that class, sum the hours across classes, and store the result each day in a counter, and finally print out the mean daily workload.

The average number of unscheduled absences was used to calculate the probability that simulated nurses would fail to report for duty. Operationally, this was accomplished by randomly selecting a number of nurses each shift who were absent. For example, there might be a 20% probability of one absence, a 3% probability of two absences, and a .5% probability that three nurses would fail to report to work. The actual probabilities varied according to size of the unit--a unit with 20 scheduled nurses was much more likely to have three absences on a shift than a unit with 10 scheduled nurses.

In the VA hospital, records of absences by unit were available. These obtained data were used to calculate absence probabilities for the VA hospital model for each unit. It must be noted that VA absence rates were technically high because the VA hospital grants many more paid days off per year than other hospitals. The VA hospital awarded six weeks paid vacation time plus the additional 10 holiday/personal days. Therefore, the percentage of absences was high [(2080 hours per year / 8 hours per day] - 40 days paid leave = 220 scheduled work days, 8 / 220 = .036).

The VA hospital was unable to estimate the probability of obtaining voluntary overtime work. A simple calculation of the number of overtime hours paid may give no information on the number of requests to work overtime that were refused. As with absence rates, overtime availability was a flat probability function. These probabilities were arbitrarily defined for all units and all hospitals as follows: there was a 40% chance of failing to obtain nurses willing to work overtime, a 40% chance of finding one nurse willing to work overtime, a 15% chance of obtaining two nurses, and a 5% chance of obtaining three nurses.

As with overtime availability, the VA hospital was unable to provide any information on intermittent and off duty part time staff availability rates. These two sources were treated as a single source for the purposes of the simulation because they were both paid for their time at a regular rate. The probabilities for obtaining staff from these sources was a linear combination of the probabilities for each.

VA hospital policies restrict the extent to which part time nurses may work extra hours. Therefore, an arbitrary probability of 60% was assigned to the likelihood of obtaining extra hours from part time staff. This was divided as follows: 0 nurses obtained = 40%, 1 nurse obtained = 50%, 2 nurses obtained = 7%, and 3 nurses obtained = 3%.

In the event of excess staffing, nurse administrators have few options if forced short term layoffs --that is, nurses forced to take an unpaid day off--are not used. (The VA hospital did not use forced short term layoffs because of the expectation that such an administrative action would lead to increased morale problems and higher turnover rates). The three options in the event of excess staffing were:

1. Pay the excess nurses to stay and work the shift even though there is little or no work for them to do;
2. Permit the excess nurses to take one of their paid vacation or personal days;
3. Permit the nurses to take an unpaid day off.

Options 2 and 3 had the same effect on hourly wage costs since vacation hours were not part of direct wage costs. If the nurse took a vacation day, s/he was paid for that particular day, but also reduced her/his paid non-work time by one day. Therefore, the probability of getting a nurse to go home when nursing hours exceeded workload consisted of the joint probability of options 2 and 3. Again, the VA hospital did not keep any data on the incidence of nurses going home when workload was low (or more common, being called prior to the start of the shift and asked if they would rather not come to work). However, most of the head nurses claimed that they usually found at least one nurse who was happy to take an unpaid day off or unscheduled paid leave day when staffing was excessive. Arbitrarily, this method of reducing excess staffing was assigned a 90% probability of success. This probability was divided into 70% probability of one nurse taking the day off, and 20% probability of two nurses taking the day off.

3. RESULTS

Wage Costs. There were significant wage cost differences among three of the four staffing levels ($F[3,36]=1616$, $p<.0001$). (See Table 1). The 40% and 50% staffing levels produced the same number of nurses scheduled per year. (This unusual situation was a function of the size of the units' regular staff and rounding, and did not occur in further studies of other Skill Centers. Essentially, a reduction of only 10% in this Skill Center meant a reduction of less than one nurse per shift). Therefore, the 40% and 50% staffing levels produced the same direct wage costs, and of course, the same amounts of overstaffing and understaffing. Thus, they will be jointly reported as the 50% staffing level. (Due to rounding, there was a small difference between the dollar costs of these two staffing levels). The 60% staffing level produced yearly direct wage costs 1.4% higher ($9,400) than the

Table 1: Direct Wage Cost Differences Among Staffing Levels in the Psychiatric Care Skill Center

Staffing Level	Direct Costs	Bi-Level Difference	Dollar Difference	Percent Difference
40/50 Pct.	$663,780	50% vs 60%	$ 9,400	1.4%
60 Pct.	$673,180	60% vs 80%	$48,320	6.7%
80 Pct.	$721,500	50% vs 80%	$57,720	8.0%

50% staffing level. The 80% staffing level produced wage costs 6.7% higher than the 60% staffing level (a yearly increase of $48,320) and 8% higher than the 50% staffing level (a cost increase of $57,720 for the 80% over the 50% staffing level). Although the differences are statistically significant, the dollar amounts of those differences are considerably smaller than expected. In a hospital with a direct wage budget of $4.5 million dollars annually, there was less than $10,000 difference among the three tested staffing levels (see Table 1).

Staffing Adequacy. There were significant differences among the staffing levels for both overstaffing ($F[3,36]=11,733$, $p<.0001$) and understaffing ($F[3,36]=33$, $p<.0001$). As the values of the F-test show, the size of the differences among the staffing levels for overstaffing was larger than the size differences for understaffing. This finding was a function of the extremely large amount of overstaffing produced by the 80% staffing level (see Table 2). Interestingly, the 80% staffing level provided no statistically significant advantage over the 60% staffing level

Table 2: Staffing Adequacy Differences Among Staffing Levels in the Psychiatric Care Skill Center

Staffing Level	Excess Nurses		Nurses Short	
	Number	%	Number	%
Forty/Fifty Percent	18	.2%	76	.9%
Sixty Percent	163	1.7%	36	.4%
Eighty Percent	1225	11.6%	30	.3%

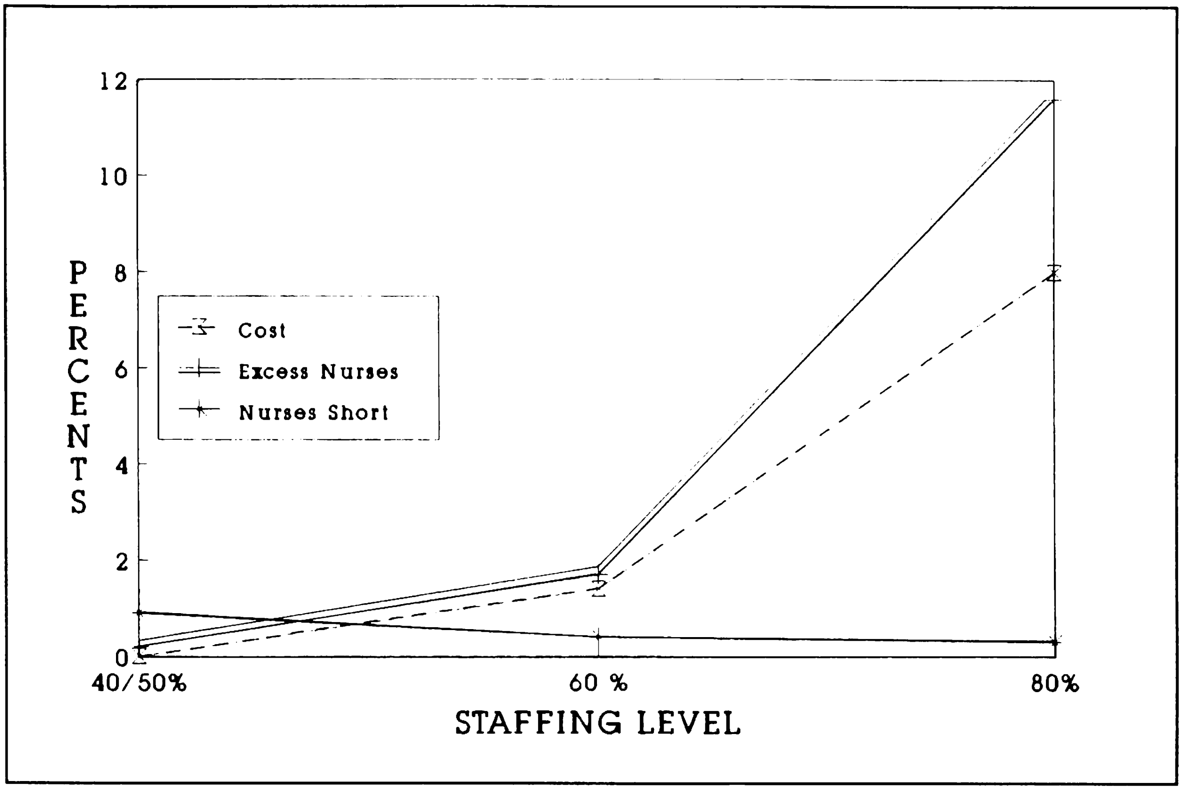

Figure 1 Costs and Staffing Adequacy by Staffing Level

for reduction in the incidence of understaffing. Therefore, the 80% staffing level is rejected. The choice between the 50%, and 60% staffing levels was not as easily determined. The 60% staffing level cost only slightly more than the 50% level and some of this cost was expended on a slightly higher rate of overstaffing (the Sheffee multiple comparisons found no significant bivariate differences between the 50% and 60% staffing levels for direct wage costs). However, the 60% staffing level produced a somewhat smaller incidence of understaffing. The joint minimization of overstaffing and understaffing requires balance between these two phenomena. Neither the 50% nor the 60% staffing levels provide that balance. Therefore, it would appear that the most efficient staffing level falls somewhere between the 50% and 60% staffing levels.

Optimizing Staffing Levels. As can be seen in Figure 1, the 40/50% staffing level constituted the lowest cost solution. This level also produced almost no overstaffing (.2%). However, it permitted a comparatively high level of understaffing. On average, the Psychiatric Skill Center was understaffed once a week with the 40 / 50% staffing level. In contrast, the 80% staffing level produced understaffing only once every 44 days. The 80% staffing level produced significantly higher wage costs ($p<.0001$) than the other three staffing levels. It also produced overstaffing at least once each day (and often there was more than one idle nurse on an overstaffed day). Because of the poor match between care needs and available nursing hours, the 80% staffing level is unacceptable. Although the 40/50% and 60% staffing levels were not ideal, they were acceptable.

The choice between the 50% and 60% staffing levels was not simple. The difference in wage costs between these two staffing patterns was only 1.4% per year. The 50% staffing pattern produced less overstaffing (.2% versus 1.7%), but a higher incidence of understaffing (.9% versus .4%). The optimal staffing level falls somewhere between the 50% and 60% staffing level at about the 55% level (see Figure 1).

4. CONCLUSIONS

Nursing departments wishing to choose an optimal staffing level will want to consider a variety of factors in their environment. These data provide evidence that staffing in the range of 50% to 60% of expected maximum workload (for average to slightly over the average workload in the unit) will be optimal. Actually, some of the wage cost and staffing adequacy differences are so small that many hospital managers might find them inconsequential in a multi-million dollar budget. Due to the increase in indirect wage costs for the 60% staffing level (such as health insurance and other benefits), nursing management might opt for the 50% staffing level.

Nursing Service Administrators will want to make their choice on the basis of factors such as the hospital's financial situation, the risks to patient of understaffing conditions, and whether excess nurses who cannot afford to take unpaid days off can be usefully assigned to tasks such as writing or updating procedure manuals. It may be critical for some units to always be well staffed while the condition of patients in other units might not be compromised by a slightly higher incidence of understaffing. For example, units like the neonatal intensive care unit might have to incur relatively high rates of overstaffing because the effects of understaffing are potentially lethal to that unit's patients.

In the future, the decision might well need to be influenced by other factors such as the unit's ability to recruit and retrain staff, the staff's willingness to work overtime to cover understaffed conditions, and the degree of illness of patients in the various units. Other considerations might include the nursing staff's resistance to working overtime, and a nurse turnover problem that can be partially attributed to the staff's dissatisfaction with working in understaffed conditions. In these cases, the 60% staffing level might actually prove more economical due to a reduction in hidden costs related to improved staff morale.

Today, nurse managers have little more than their own intuition to guide their selection of a master staffing plan. Managers in industry have long made use of forecasting, linear programming, computer simulation and other decision support tools. Nursing has not had access to automated decision support tools for a variety of reasons, the most important of which has been inaccessibility of computer resources to nurse managers. During the last ten years, the price of microcomputers has decreased while their processing power has increased exponentially. For these reasons, extremely powerful computer resources are now within the reach of every nurse manager.

Greater sophistication about computers has made nurse managers more willing to invest in tools to help them improve their staffing decisions. However, the computer based management decision support tools for nursing now available are generally focused on assisting the nurse manager to fine tune an existing staffing pattern. They provide little or no information about the performance of the master staffing plan itself, and are not of use for making comparisons among several master staffing plans or for testing the long term effects of specific changes in the master staffing plan. This study used computer simulation to address just one of the research questions generated by the lack of such information: What is the optimal staffing level for the VA hospital Psychiatric Nursing Skill Center?

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REFERENCES

Duraiswamy, N., Welton, R., and Reisman, A. (1981). Using computer simulation to predict ICU staffing needs. The Journal of Nursing Administration, 11(2):39-44.

Carter, G., Ingall, E., & Walker, W. (1975). A simulation model of the New York City fire department: its use in deployment analysis. In The Rand Paper Series (P-51101). California: The Rand Corp.

Giovanetti, P. (1978). Patient Classification Systems in Nursing: A Description and Analysis (DHEW Pub. No.(HRA) 78-22. Springfield, Va.: National Technical Information Service.

Hamilton, R., Hancock, W., and Hawley, K. (1975). The Admissions Scheduling and Control System: The Admissions Simulator. Report Number 75-1, Bureau of Hospital Administration, School of Public Health II. Ann Arbor, Michigan: The University of Michigan.

Hancock, W., Martin, J., and Storer, R. (1978). Simulation-based occupancy recommendations for Adult Medical/Surgical Units using admissions scheduling systems. Inquiry, 15:25-32.

Kolesar, P., & Walker, W. (March, 1975). A simulation model for police patrol operations. In Rand Reports (R-1625/1-HUD). New York: Rand Institute:222.

McHugh, M. (1988). Comparison of four nurse staffing patterns using computer simulation. Nursing and Computers: Proceedings of the Third International Symposium on Nursing Use of Computers and Information Science. St. Louis: C.V. Mosby Company.

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