A MODEL FOR STUDY OF NURSING ACTIVITY PATTERNS

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Measurement of time required to perform various tasks on a nursing unit presents some interesting problems. These include:

1. Simple measures of daily work load, such as number of units produced or processed, are unavailable. However, counts of different types of patients may provide basic data needed to estimate work load,
2. Total work load varies from day to day since the patient mix varies even when the census may show little variation. Furthermore, many nursing tasks are such that they can neither be postponed nor performed ahead of schedule,
3. For a given work load, total time spent in a given activity, by a set of workers of a given skill level, may be influenced by the number of workers available to share the work load,
4. Different skill levels are involved and there may be some overlap of functions and tasks.

Since problems of this type are not unique to nursing units, analytical methods, suggested in this paper, are not restricted to such units.

Our goal in this research was to relate amount of time spent in different nursing activities to a selected set of variables based on staff compositions and patient mixes. Through such relationships we expected to gain insight into: (1) reaction of workers to changing work load conditions, and (2) staff composition needed to meet varying work loads.

Dependent and Independent Variables

The dependent variables in this investigation involved the aggregate times spent by nurses, on a particular nursing unit, while engaged in each of four different major activities. Specifically,

$T_1(N)$ = total time spent by nurses, on a given unit, in physical activities between 7 AM and 3 PM,
$T_2(N)$ = total time spent by nurses, on a given unit, in clerical activities between 7 AM and 3 PM,
$T_3(N)$ = total time spent by nurses, on a given unit, in oral communication between 7 AM and 3 PM,
$T_4(N)$ = total time spent by nurses, on a given unit, in standby activities between 7 AM and 3 PM.

Since these activities were considered to be mutually exclusive and all inclusive, it follows that $\sum_{i=1}^{4} T_i(N) = 480 \cdot N$, minutes per day, where N = number of nurses.

Similar definitions were used for nurses' aides with

$T_i(A)$ = total time spent by aides, on a given unit, in the i(th) activity between 7 AM and 3 PM; i=1, 2, 3, 4,

and $\sum_{i=1}^{4} T_i(A) = 480 \cdot A$ minutes per day, where A = number of aides.

Physical activities included all activities inside a patient's room, preparations for treatments and procedures, cleaning, restocking supplies, transporting patients and walking. Standby time included lunch period, coffee breaks, and other periods of inactivity. The remaining activities are self-explanatory.

The independent variables measured daily changes in staff composition (N and A, as previously defined) and patient mix. Description of patient mix in terms of care-level requirements led to use of:

P(M) = number of minimal-care patients,
P(I) = number of intermediate-care patients,
P(H) = number of high-care patients,

and in terms of hospital day to use of:

P(1st) = number of 1st-day patients,
P(2-4) = number of (2-4)th-day patients,
P(5+) = number of (5+)-day patients.

Since the subdivisions of patients were considered to be mutually exclusive and all inclusive, it follows that:

$$\text{Daily census} = P(T) = P(M) + P(I) + P(H) = P(1st) + P(2\text{-}4) + P(5+).$$

Daily classification of patients by care level was based on their physical independence as exhibited by their ability to help themselves in bathing, eating, walking and getting up. Classification by hospital day needs no explanation except that (5+) refers to patients present for five or more days.

Mathematical Model

In building a mathematical model to relate time spent in various activities to staff composition and patient mix, one must consider that both nonlinear responses and interactions may occur. The proposed model allowed for nonlinearity by including squared terms and for interactions by including some cross-product terms. For nurses, the model consisted of four equations of the form:

$$T_i(N) = \beta_{0i} + \beta_{1i}N + \beta_{2i}N^2 + \beta_{3i}A + \beta_{4i}A^2 + \beta_{5i}N \cdot A + \beta_{6i}P(T) + \beta_{7i}P^2(T) + \beta_{8i}P(M) + \beta_{9i}P(H)$$

$$+ \beta_{10,i}P(1st) + \beta_{11,i}P(5+) + \beta_{12,i}N \cdot P(T) + \beta_{13,i}A \cdot P(T) + \varepsilon_i; \quad i = 1, 2, 3, 4,$$

where the ε_i's are random errors and β_{0i}, β_{1i}, . . . , $\beta_{13,i}$ (i = 1, 2, 3, 4) are the parameters of the model, considered constant over days, for a particular nursing unit. Similar functions were hypothesized to relate the $T_i(A)$'s to the independent variables.

The nature of the model forces a relation among some of the parameters. Since $\sum_{i=1}^{4} T_i(N) = 480 \cdot N$ minutes per day, it follows that $\sum_{i=1}^{4} \beta_{hi} = 0$ for $h \neq 1$ and $\sum_{i=1}^{4} \beta_{1i} = 480$ minutes. Similar relations hold for parameters associated with activities of aides.

It should be noted that terms P(I) and P(2-4) have been excluded from the model to avoid linear dependence among the independent variables. With the model in its present form β_{8i} measures the difference in contribution to time spent in the i(th) activity between a minimal-care and an intermediate-care patient and β_{9i} is the difference in time between a high-care and an intermediate-care patient. Similarly $\beta_{10,i}$ and $\beta_{11,i}$ measure differences in time needed for 1st-day patients relative to (2-4)th-day patients and (5+)-day patients relative to (2-4)th-day patients, respectively.

Estimation of Parameters

Data were collected from a number of nursing units in two voluntary general hospitals. For each nursing unit, 70 days of data yielded 70 sets of values, on independent and dependent variables, for estimating parameters. Work sampling techniques were used to estimate values for the dependent variables so that the left hand sides in our model contain a sampling error component.

The parameters were estimated by applying the method of least squares to each equation in the model. By assuming, for a given i, the ε_i's over days were independently and normally distributed with zero mean and common variance, multiple regression techniques were applied and tests of significance performed. A term was retained in the set of equations, making up the model, if one or more of its coefficients was significant at the p = 10% probability level. If this condition was not met, the coefficients were set equal to zero and new coefficients were determined for the remaining terms for all equations.

Since the method of least squares was used to produce estimates of parameters it follows that these estimates, like the parameters they estimate, have the property that:

$$\sum_{i=1}^{4} \hat{\beta}_{hi} = 0 \text{ for } h \neq 1 \text{ and } \sum_{i=1}^{4} \hat{\beta}_{1i} = 480 \text{ minutes.}$$

Furthermore, if we choose to combine two activities, such as "oral communication" and "standby", then the coefficients in the equation for combined activities are simply the sum of the coefficients of corresponding terms in the separate equations.

Discussion of Results

Results shown in equations (1-4) in Table 1 apply to nurses on a nursing unit with all medical patients. Some interesting observations can be made from a study of these equations.

Equations (1-4) describe mathematically the interchange of time among the four major activities as the independent variables change values from day-to-day. For example, suppose the census on this medical unit increased by one intermediate or minimal-care patient and number of nurses remained the same. Predicted changes (see coefficients of P(T)) would be an increase of two minutes in physical activities and five minutes in clerical work. The increases would be offset by a five minute decrease in oral communication and a two minute decrease in standby time. Had the additional patient been a high-care case, both the coefficients of P(T) and P(H) would be involved and changes in activity times would be 15, 6, -13, and -8 minutes, respectively.

Equations (1-4) reflect the simple fact that time cannot be increased for one activity without an equivalent decrease in one or more of the other activities if the number of nurses remains constant. If the coefficient for P(T) in equation (1) had turned out to be zero, it would mean that time needed for an increase of minimal or intermediate-care patients could be absorbed within activity 1 and no time need be borrowed from other activities. Absorption within an activity could be accomplished in several ways. One way would be to interchange time among minor activities within a major activity. Another would be to decrease time spent with some or all patients by either deleting certain optional care measures or working at a faster pace. Both absorption and borrowing may occur and positive coefficients of terms like P(T) and P(H) in equations (1) and (2) represents amounts of time that must be borrowed from other categories because they can't be absorbed.

Table 1

EQUATIONS FOR ESTIMATING ACTIVITY TIMES

	R^2	$s_{y \cdot x}$ (minutes)	Equation No.
MEDICAL UNIT			
$\hat{T}_1(N) = -102 + 158\,N + 2\,P(T) + 13\,P(H)$	.36	66	(1)
$\hat{T}_2(N) = 6 + 72\,N + 5\,P(T) + 1\,P(H)$	.18	57	(2)
$\hat{T}_3(N) = 109 + 154\,N - 5\,P(T) - 8\,P(H)$	.29	84	(3)
$\hat{T}_4(N) = -13 + 96\,N - 2\,P(T) - 6\,P(H)$	.30	51	(4)
$\hat{T}_1(A) = -590 + 482\,A - 34\,A^2 + 24\,P(T) + 28\,P(H) + 7\,P(1st) - 12\,P(5+)$	.67	125	(5)
$\hat{T}_2(A) = 6 + 19\,A - 2\,A^2 - 1\,P(T) + 2\,P(H) - 1\,P(1st) - 1\,P(5+)$	.04	27	(6)
$\hat{T}_3(A) = 888 - 423\,A + 73\,A^2 - 14\,P(T) - 9\,P(H) + 20\,P(1st) + 16\,P(5+)$	.58	112	(7)
$\hat{T}_4(A) = -304 + 402\,A - 37\,A^2 - 9\,P(T) - 21\,P(H) - 26\,P(1st) - 3\,P(5+)$	.41	103	(8)
MEDICAL & SURGICAL UNIT			
$\hat{T}_1(N) = -417 + 244\,N - 24\,A + 20\,P(T) - 0.17\,P^2(T)$	.64	94	(9)
$\hat{T}_2(N) = 1206 + 71\,N - 4\,A - 72\,P(T) + 1.23\,P^2(T)$	.27	66	(10)
$\hat{T}_3(N) = -869 + 102\,N + 19\,A + 66\,P(T) - 1.28\,P^2(T)$	.32	100	(11)
$\hat{T}_4(N) = 80 + 63\,N + 9\,A - 14\,P(T) + 0.22\,P^2(T)$	.39	39	(12)
$\hat{T}_1(A) = -429 + 337\,N - 81\,N^2 + 347\,A + 14\,P(T) - 19\,P(H)$	.92	122	(13)
$\hat{T}_2(A) = 36 - 40\,N + 9\,N^2 + 12\,A - 1\,P(T) + 0\,P(H)$	.16	32	(14)
$\hat{T}_3(A) = 472 - 314\,N + 65\,N^2 + 69\,A - 11\,P(T) + 20\,P(H)$	.36	107	(15)
$\hat{T}_4(A) = -79 + 17\,N + 7\,N^2 + 52\,A - 2\,P(T) - 1\,P(H)$	.38	78	(16)

With number of patients held constant, equations (1-4) also indicate how an additional nurse tended to distribute her time among the four activities. The coefficients of N indicate that 158 minutes go into physical activities, 72 minutes into clerical work, 154 minutes into oral communication, and 96 minutes for standby.

Equations (5-8) include an A^2 term which would suggest decreasing returns from additional aides. A change from three to four aides increased physical activities by 244 minutes while a change from four to five aides increased time in this activity only 176 minutes. Also of interest was the magnitude of demands for time placed on aides by an increase in high-care patients.

Equations (9-12) include the term $P^2(T)$. In this case the fitted model revealed that time needed for physical activities, for increased census, was secured from clerical time when the census was low but for larger censuses it was secured from oral communication.

Two points are brought out in equations (13-16) for aides. One is the effect of additional nurses on time aides spent in physical and oral communication activities. An additional nurse, on this unit, increased time nurses spent in physical activities by an average 244 minutes (equation 9) while aides' time in the same activity decreased by either 68 minutes or 230 minutes depending on whether the change was from two to three or three to four nurses. The other point involves the coefficients of P(H). An increase in number of high-care patients meant a decrease in physical activity time for aides. The inference is that nurses were largely responsible for bedside care of high-care patients.

It should be noted in analyses of the type used, that values for coefficients will, in part, be dependent on overall work load for nurses and aides during data collection. Other factors affecting these coefficients would be the extent to which nurses do aide's work, aides do what nurses might do with fewer aides present and the extent to which nurses and aides consciously keep activities such as standby and oral communication at a minimum when the work load is relatively light.

Minimal and Maximal Staffing

Examination of equations (1-16) indicates that additional time needed for physical and clerical activities resulting from changes in patient counts was usually secured from oral communication and/or standby time. Recognizing that the latter categories include necessary communication, lunch, and other personal time, it is reasonable to set prescribed minimum times on a per nurse (aide) basis for the combined categories of oral communication and standby. Sufficient nurses and aides should be on duty, each day, to keep time spent in communication and standby activities above the prescribed minimums. Minimal staffing occurs when the minimum limits are reached.

Some difficulty may be encountered in determining minimum limits but, for illustration, suppose we set limits at 135 minutes per nurse and 80 minutes per aide for a medical unit. From equations (3-4) and (7-8) one can write down the following inequalities:

For nurses: $$96 + 250\,N - 7\,P(T) - 14\,P(H) \geq 135\,N, \tag{17}$$

For aides: $$584 - 21\,A + 36\,A^2 - 23\,P(T) - 30\,P(H) - 6\,P(1st) + 13\,P(5+) \geq 80\,A\,. \tag{18}$$

Thus, if $P(T) = 24$, $P(H) = 8$, $P(1st) = 2$, $P(5+) = 10$, $N = 2$, $A = 4$, the inequalities are satisfied. If $P(H) = 12$, instead of 8 neither inequality is satisfied. Rather than adding both a nurse and an aide, the addition of a nurse who spends half her time working as an aide would satisfy both inequalities.

We might also consider the problem of finding the staff size, for a particular nursing unit, which would rarely have to be augmented to care for extra heavy work loads. Such a staff size might be considered maximal. Over time, the number of patients in special categories (high-care, 1st-day, etc.) will usually be between some minimum and maximum percentage of the total number. For example, for the medical unit, the following inequalities are likely to hold:

$$P(H) \leq 0.60\,P(T),\quad P(1st) \leq 0.30\,P(T),$$

$$P(5+) \geq 0.40\,P(T).$$

If these values are substituted into inequalities (17) and (18), the results will be:

For nurses: $$115\,N \geq 15.4\,P(T) - 96 \tag{19}$$

For aides: $$36\,A^2 - 101\,A \geq 37.6\,P(T) - 584 \tag{20}$$

Thus, if census on this unit rarely exceeds $P(T) = 25$ patients, then for $N = 2.6$ and $A = 4.9$, inequalities (19) and (20) and also (17) and (18) will be satisfied, except on rare occasions.