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Work-Sampling: A Statistical Approach to Evaluation of the Effect of Computers on Work Patterns in Health Care

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Introduction

An increasing number of medical informaticians in particular, and healthcare institutions in general, are in the process of implementing clinical computing systems. These systems range from small, standalone, PC-based record-keeping systems to mid-sized laboratory/pharmacy management systems, and full-scale hospital information systems. Several institutions are currently working on integrating systems of all sizes into medical centerwide academic information management systems (IAIMS) [1–4]. The need for an accurate assessment of the clinical, administrative, social, and financial effects of such systems has been recognized [5–7]. Sound, statistically valid evaluations of all types of these systems are crucial in determining the future role of computers in health care.

Miller and Sittig [8] identified five reasons for conducting an evaluation of a medical informatics research project, including: (1) to test a prototype, (2) to refine the system, (3) to assure safety, (4) to determine clinical effects, and (5) to develop new evaluation methodologies. This chapter focuses upon yet another reason for conducting a medical informatics research project evaluation: to determine its effect on the work patterns of participants in the healthcare delivery process.

Many different evaluation strategies have been employed in an attempt to determine the optimal assignment of duties and responsibilities to healthcare practitioners of differing skill and training levels. This chapter attempts to review and synthesize information concerning the pluses and minuses of these various work evaluation strategies from a broad spectrum of sources. Following a brief review of several evaluation methodologies, it focuses on the subject of Work-Sampling (WS). While the work-sampling technique has been in use since the mid-1930s [9] and there are citations in the healthcare literature of its use as far back as 1954 [10], there is still no single source that describes in detail the steps and numerous tools available to help an investigator carry out and interpret the results of a work-sampling evaluation.

Review of Work Evaluation Methodologies

There are many questions which can be asked when evaluating the effect of computers on work patterns, including: (1) how and by whom was the system used, (2) how much time was spent using the system, (3) what effect did it have on other work-related activities, (4) how long should it take to use the system, and (5) how can the work patterns, environment, and/or the computer (i.e., the input/output devices, placement and/or numbers of devices, software options and/or data entry flow, etc.) be improved so as to utilize each member of the healthcare, team's knowledge and training to its fullest extent.

Each of these questions requires specific evaluation strategies. The methodologies, described below, each seek to focus on a particular aspect of these questions. The following sections briefly describe particular study designs giving (1) an, overview of pluses and minuses and (2) a review of their findings. Of particular interest is the manner in which many of the investigators combine several evaluation methodologies to obtain a more global view of the effect of their particular computer implementation

Time-Motion Analysis

Time-motion analysis (TM) provides a direct measurement of the amount of time a specific worker spends doing a specific activity. A TM is carried out by a trained observer with a watch, who continuously observes multiple trials of selected activities and records the time spent doing each small part. Often, when looking at the time required to use a computer for a particular task, the total time spent as well as specific timing intervals, can be recorded directly by the computer with little, or no, extra human effort [11]. TM studies are particularly appropriate when one is trying to compare two different work patterns that produce the same result. Such a study might be used to compare the time spent entering a medication order into the computer via lightpen, keyboard, bar-coded chart, or a free-hand pen-based operating system with automatic optical character recognition.

For example, in a TM comparison Minda [12] found that the time required to complete a nursing assessment manually versus a menu-driven computer-based charting system, the computer was 21% faster (558 ± 237 sec vs. 706 ± 223 sec, $p < 0.05$, two-tailed t-test). She also calculated a "productivity index" that measured the number of seconds required to record an observation, and found that the computer system was more than twice as fast (3.5 ± 1.6 vs. 7.6 ± 2.2 sec/observation, $p < 0.05$). To carry out this study, Minda spent 17 days collecting data from 40 nurses on one specific task.

A clear benefit of a TM study is the accurate timing figures obtained. Disadvantages of TMs include: (1) it is labor intensive, that is, usually requiring, a one-to-one observer-to-worker ratio, (2) it is subject to both observer and worker biases (e.g., some workers are always "better" than others), (3) many trials of the same activity must be observed and measured to obtain reliable results, and (4) data-entry source code must be modified to use the computer as the timing mechanism.

Subjective Evaluations

Subjective evaluations usually take the form of questionnaires. Well-designed questionnaires can provide a personal assessment of attitudes and estimates of the time spent in completing a specific task. They may be administered orally, on paper, or even by the computer itself. Obvious advantages of using questionnaires include: (1) easy to administer, (2) easy to interpret, and (3) easy to obtain valuable cognitive information. Unfortunately, such evaluations also carry with them severe limitations, including: (1) giving imprecise measurements of work activities, (2) based on personal biases, and (3) possibly strongly influenced by recent events which may skew the results. Although subjective evaluations of the effect of a new computer system should not be used alone, when used in conjunction with one of the more quantitative methods, they provide important information to the researcher and administrator alike.

For example, Andrews and Gardner [13] combined a computer-based timing analysis with a questionnaire to evaluate the effect of using portable laptop computers for respiratory therapy charting. Their timing study found no significant differences in the amount of time required, or in the "productivity" of the therapists in the study. They did find through a questionnaire administered to six respiratory therapists involved in the pilot implementation that "*all* six therapists preferred (to chart on) ward terminals" rather than laptops. In addition, they found that work patterns varied considerably between the six therapists.

Review of Departmental Records

Departmental records, or statistics, provide a valuable source of information concerning the overall function of a particular department. Unfortunately, such retrospective epidemiologic studies or chart reviews have inherent methodological flaws [14]. In addition, unless they are extremely detailed, they tell little about what actual employees or even groups of employees do on a shift-by-shift basis. For example, if one were interested in the overall change in productivity following implementation of a new computer-based order/entry system in an out-patient pharmacy, one could check the average number of prescriptions filled in the three-month period before implementation and compare that to the average number filled in a three-month period following implementation.

In a review of departmental records conducted in the respiratory therapy department of LDS Hospital in Salt Lake City, Utah, Andrews et al. found that implementation of a computer-based charting system increased productivity (as measured by procedures billed) by 18%, while the number of therapists remained constant [15]. Following presentation of these results, they remind the reader that it is possible that all the computer actually did was "assure that all work done was billed." Their conclusion from this study was that "computer charting did not *decrease* productivity." Perhaps by using a different technique, such as TM or work-sampling, they could have made an even stronger claim for their system.

Personal Record of Activities

Each member of the staff can keep a log of activities performed and the amount of time spent on each activity [10]. Problems arise, however, during periods of intense activity resulting in periods of unaccountable behavior. In addition, if the log is done periodically, a tremendous emphasis is placed on the subject's memory; a known error source.

Description of the Work Sampling Technique

Work sampling, originally developed by Tippett in 1935 [9], consists of a series of instantaneous, randomly spaced observations of the activities being carried out by the group of workers (or possibly machines) under study [16]. WS is a fact-finding tool based on the laws of probability.[1] It can be used to measure the working time and nonworking time of a person (or machine), or to establish a time standard for a specific activity (i.e., to identify the number of minutes required to perform a certain task) [17].

Example

If, for example, one were interested in the percentage of time that the nursing staff on a particular unit spends in interacting with a new bed-side computerized charting system versus the time spent in direct patient care, a work-sampling study could be performed [18]. Such a study is based on the theory that the percentage of randomly made observations in which nurses are using the computers and/or caring for the patient compared to the total number of observation made, represents an estimate of how nurses spend their working day.

[1] That is, that a sample taken at random from a large population or group, tends to have the same distribution or percentage of occurrence, as that of the population at large.

Table 7.1. Sample work-sampling data collection.

State	Observations (%)
Nurse patient care	18 (50)
Nurse using system	11 (31)
Miscellaneous/other	7 (19)
Total	36 (100)

Table 7.1 shows a simple data collection and analysis form for an example of a WS study. If a nurse is observed using the system, a tally is placed in the OBSERVATIONS column next to "Nurse using system"; if a nurse is caring for the patient, then the mark is placed in the OBSERVATIONS column next to "Nurse patient care." When enough observations have been made (a formula and sample calculation for determining the appropriate number of observations will be presented in a following section) then the number of OBSERVATIONS are totalled—for each category (across) and then for all categories (down)—and the percentage calculated (e g., [11/36]*100 = 31%). The more observations made, the more certain one can be that the estimates represent the true percentage of time nurses spend interacting with the computer and in direct patient-care activities.

Steps in Designing a Work-Sampling Study

There are many excellent references which describe many of the steps required to design, and tools available to carry out a WS-study [17,19,20]. The following is a synthesis of those descriptions.

Step 1. *Identify research objective.* To choose the appropriate work-study technique and data-collection procedure, one must carefully identify the main hypothesis that one would hope to be able to accept or reject upon completion of the study.

Step 2. *Identify a study site and obtain approval of the manager.* Care must be taken when attempting to identify a particular unit or ward within a hospital to insure that the study site is as "normal," or representative, of the entire range of activities to be studied as possible. The departmental manger will often be able to offer sound advice on the "normal" work activities to be studied and their associated definitions [21].

Step 3. *Identify work categories and carefully define the content of each.* The work-activity categories must be selected and defined so as to leave no doubt in the mind of the observer how each activity that is observed should be categorized (see the appendix) [19]. A key point is that all activities must be able to be accounted for. Therefore, one of the most important categories in every WS study is that of *Other* or *Miscellaneous Activities*.

Step 4. *Create a data entry form.* Once the categories have been adequately described in writing, one should develop an easy-to-use data-entry or observation-recording form. The carefully worded list of categories and their associated definitions should be kept with the data collection forms at all times for easy reference.

Step 5. *Identify and train appropriate observers.* One must identify an appropriate group of WS observers. Key elements in deciding exactly who should collect the data include: (1) do they understand the job being observed, (2) can they do the observations without "getting in the way," (3) do any of the categories require that the observers know "what the subject is thinking," (4) is there someone in the area who can make the observations while also performing their regular job (i.e., a clerk or technician, or perhaps even the manager of the unit). During the training phase, attention must be given to carefully explaining the philosophy behind the description of each work category since many activities are not explicitly described. By walking around the unit and observing the myriad nursing activities for 30 minutes to an hour, one should be able to explain adequately the procedure.

Step 6. *Conduct a pilot study.* Once all the preliminary details have been worked out, one should conduct a pilot study. This study allows one to test the work categories and their definitions, and provides one with a rough estimate of the percentages of time subjects spend in each of the categories. It may be preferable to perform a short TM rather than a short WS-study at this point. A TM pilot will help to insure that all work-related activities are covered by the chosen categories as well as providing a "touchstone" against which the results of the WS-study can be compared.

Step 7. *Design the WS study.* The most important elements of the study to be determined are:

a. *The total number of observations needed* to obtain the desired accuracy. The following formula describes this relationship: $n = p(1 - p)/\sigma^2$, where n = the total number of observations, p = expected percent of time required, by the most important category of the study (from pilot), and σ = standard deviation of percentage.

   Example: Determine the number of observations needed to establish that the percentage of time nurses spend charting is 30% ± 2% (estimated from pilot study) with a 95% confidence interval (i.e., we want to be able to state with 95% confidence that nurses spend between 28 and 32% of their time charting); therefore, we set $p = 0.3$, $2\sigma = 2\%$ (or $\sigma = 0.01$), so that $n = 0.3\ (1 - 0.3)/(0.01)^2 = 2100$ observations, where n represents an estimate of the actual number of samples needed. There are also published nomograms which provide the WS-study designer with a rough estimate of the value of n [16,19,22].

b. Once the total number of observations is determined, one needs to determine *the frequency for making these observations*. A good rule-of-thumb is to limit the number of randomly made observations to less than eight per hour.
c. Another key element is *whether the observations will be made randomly or at fixed intervals.* This decision is based on whether the underlying work activities are random (lacking any prominent periodic component), such as most healthcare activities, or occur with some regularity or pattern, such as assembly-line work. If the work activities are random, then one can sample (and [23] has shown it to be preferable) at fixed intervals, otherwise the sampling intervals should be randomly selected.
d. Next, *the total length of the study needs to be established.* This decision should be based on some naturally occurring rhythm within the work pattern, for example, a five or seven-day work week, or some other cyclic pattern of activities. It is very important to make sure that equal numbers of subcycles (e.g., day vs. night and/or weekend vs. weekday) are included in the study.

   Therefore, to continue with our previous example, if we assume that we need to make 2100 observations over a seven-day period, then we need to make: 2001 observations/7 days = 300 observations/day. If we anticipate that there will be four nurses on duty at all times, then: 300 observations/day × 1 day/1440 min gives 4.8 min/observation, but since there will be four nurses on duty at all times, we can make four observations at each time point. Based on these calculations, observations could be made every 20 minutes around the clock. This would result in 288 observations/day (3 observation periods/h × 24 h/day × 4 nurses) or a grand total of 2016 observations in the entire week (which is within 5% of our original estimate (2100) of the total number of observations needed). If one wanted to be ultraconservation, then one could make observations every 15 minutes resulting in a grand total of 2688 observations (4 observations/h × 24 h/day × 4 nurses × 7 days/week).
e. Finally, *one needs to pick "normal" time* to actually perform the study. For example, one would not want to conduct a study of a cardiovascular surgical ICU during the week that many of the surgeons will be away at their annual meeting.

Step 8. *Establish independent measures of workload.* It is important to establish temporally relevant workload measures in as great a detail as possible. This will help insure that many of the underlying variables which govern the work performed will be accounted for. For example, Bradshaw et al. [21] utilized the daily patient census, a measure of patient acuity (used as an estimate of severity of illness), and the nurse staffing levels in an attempt to explain the differences in the amount of patient care provided by the nurses in the two phases of the study. In another study, Kohout et al. [24] used the total volume of prescriptions filled and the number of full-time equivalents to adjust their results.

Step 9. *Conduct the study.* Apprise all staff members being observed of the study. No matter what precautions one takes, it will only be a short time before everyone is aware of what is going on and they may be quite angry at not being informed beforehand. In addition, a carefully prepared description of the study's goals can relieve staff concerns of losing their jobs, and so on. Keep careful records of all "special events" that occur during the study period. Construct and update control charts at the end of each day [25].

Control charts are an excellent method of monitoring the quality of the data as it is being collected. Briefly, a control chart is a graph of the percentage of time spent in any single work category (although most investigators would use the key category, i.e., the one the null hypothesis is based upon) plotted for every complete shift on day (e.g., see Figure 7.1). One also plots the cumulative percentage of time spent in that particular category. As the study progresses, this cumulative line should begin to approach the final result. Control limits, for the daily percentage estimates, are then calculated using the equation under Step 7, with the terms rearranged to solve σ. Control limits are generally set at ±3 σ.

Continuing with the previous example, assume that we constructed a control chart at the end of the fifth day of the study (i.e., after 1414 total observations were made). Control limits are calculated from the equation of Step 7 and rearranged to solve σ. The numerator contains the

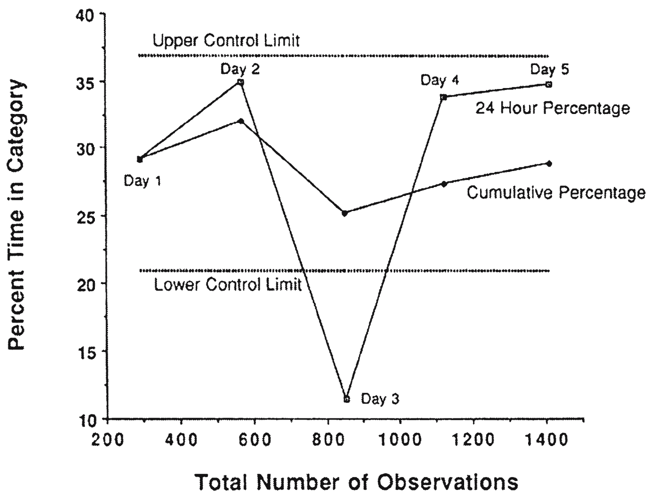

FIGURE 7.1. Control chart from example work-sampling study. Notice that the data collected on day 3 is not within control limits which indicates a potential problem with the data.

cumulative percentage of time spent in the charting category up to this point in time (28.9%). We use the average number of samples collected for each 24-hour period in the denominator (1414/5 = 282); $\sigma^2 = 0.289(1 - 0.289)/282$, or $\sigma = 2.7\%$. Therefore, we set our upper control limit to be $28.9\% + (3 \times 2.7\%) = 37\%$ (lower limit = 20.8%).

In other words, we would expect that 99% of the time each 24-hour sample should show that the nurses are spending between 20.8 and 37.0% ($28.9 \pm 8.1\%$) of their time charting. Therefore, we should carefully interview the observers who collected the data for the third day to see what, if anything, went wrong since the percentage for the third day was only 11.4%. Upon doing this we might find, for instance, that the computer terminals were down for 16 of the 24 hours under study (which accounts for the figure being 2/3 lower than it should have been). For that reason we should eliminate this particular 16-hour period from our final data analysis. It may then be necessary to continue the study for an additional 16 hours to accumulate the data required to obtain our acceptable level of accuracy. This example helps illustrate the benefits gained by constructing and maintaining current control charts as the study progresses. If we had been monitoring this example study more closely we could have quickly eliminated the bad data and increased the frequency of the observations from every 20 minutes to every 15 minutes for the remainder of the study, insuring that we would finish the study on time with enough samples to reach our predetermined confidence levels.

In addition, it is possible to use the same control-chart methodology to quantify the intraobserver reliability. To accomplish this, one would plot each observer's totals along with the overall figures and their associated confidence intervals (i.e., $\pm 3\ \sigma$). One would anticipate that, if all observers were equally adept and/or conscientious at classifying the various working activities, all the individual observer's data points would fall within three standard deviations of the final mean. If this is not the case, then one should investigate the outlier observer to ascertain the problem. If indeed there is a methodological problem that cannot be corrected, then this observer's data should not be included in the final analysis.

Step 10. *Analyze and interpret data collected.* Following completion of the study, one should carefully check the control charts and notes made during the study, and interview all observers to determine whether the data collected were truly representative of the work-related activities. Data that are unrepresentative of the normal work routine should he eliminated. Decide whether the data warrant a thorough statistical analysis or whether simple summary statistics (e.g., sum, average, and range of percentages of time spent in each category, with associated confidence intervals) would allow the research question to be answered.

If one decides that a thorough statistical analysis of the pre- versus postimplementation data is necessary, there are many different approaches one might choose, including: (1) comparison of the mean time percentages by Student's t-test [21,26], (2) comparison of mean time percentages with confidence intervals, looking for areas of overlap [27], (3) adjusting data collected both before and after computerization, using an arcsine transformation followed by analysis of variance (ANOVA) [28], and (4) compare pre- and postimplementation activity categories using a chi-square test with Cramer's V statistic to measure the strength of the hypothesized relationships [24].

Step 11. *Create final report with suggestions for realizing benefits.* It is quite possible that study will find that the first implementation of the computer system has not had the desired effect on the healthcare providers work-patterns [21,29]. In that case, however, one should not despair, but proceed with the next phase of benefits realization which may require redefinition of specific jobs, revision of software, increases and/or changes in the locations of the terminals, and so on.

Discussion

While WS studies are relatively easy to carry out and can provide important data to both medical informaticians and healthcare management alike, they are not without limitations. Following a detailed look at the results of several different WS studies, some limitations of the WS methodology will be outlined. We conclude with a brief look at the advantages of the work-sampling methodology.

Results form WS Studies

Several WS studies have been conducted in an attempt to "prove" that computer-based nurse charting reduces the amount of time nurses spend charting [6,18,21,29]. By these standards, none of these studies were successful since none was able to document a significant decrease in the amount of time nurses spent charting. On the other hand, they were successful in helping to identify particular programs that needed improvement, preferred terminal placement, and further enhancements to the system to reduce the amount of data that had to be recorded on paper.

By combining the results from other evaluation methodologies (i.e., quality and completeness charting reviews, nursing satisfaction and complaints questionnaire, etc.) with the WS data, managers and developers were able to quantify the effects of the system on the nurses' other work-related activities. Therefore, they were able to determine that the improvements in the documentation of the nurses' patient-care activities more than made up for the slight increase in the time spent charting. In addition, through use of the online charting system, one hospital was able to change the manner in which patients were billed for nursing care [31].

To be more specific, before implementatioin of time on-line charting system, all patients were charged a standard fee for nursing care (included in the room rate), regardless of their need for nursing care. Following implementation, each patient was billed for nursing care based on the actual number of minutes of nursing care they received (derived from the patient-care activities that were charted). This change to variable billing received broad acceptance throughout the hospital and was looked on very favorably by third-party payors, including Medicare. Finally, the nursing department was especially happy with the new system since they became a revenue center rather than a cost center within the hospital. By linking costs to revenue, the nursing department was able to generate productivity measurements which allowed them to look objectively at their organization and to become more efficient and cost-effective without compromising the quality of patient care.

Limitations of Work-Sampling

1. WS is not an economical solution to monitor the job-related activities of one worker or for studying a group of workers spread out over a wide area, because the observer is either idling or walking the majority of the time, rather than observing.
2. WS is not a direct measure of an individual's strengths and weaknesses; it only allows one to draw conclusions about the average behavior of the group. In addition, the percentages of time spent in each work category are only estimates of the true answers and must be treated as such.
3. WS does not provide the researcher with any measure of the quality of the work performed; only of the time spent doing it.
4. If more than one observer is involved, interobserver differences in attention to fundamental details of the WS method may invalidate the study's results. Specifically, one should be careful to insure (1) that each observer makes instantaneous observations at the prearranged times, (2) that the work categories are sufficiently well described to insure that incorrect classifications are not made, (3) that the control charts for each of the observers are relatively consistent, and (4) that enough samples are collected to reach the desired accuracy in the final estimates.
5. Although it is not likely, due to the large number of observations made, workers may be able to change their work-patterns upon sight of the observer. This so-called "Hawthorne effect"[2] has been well-documented.
6. The statistical theory behind the study may be difficult for workers and/or management to comprehend.

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[2] Named after experiments conducted at the Hawthorne Works of the Western Electric Company from 1927–1932 in which workers productivity increased in response to both positive and negative changes in working conditions. The investigators concluded that the increased attention brought on by the experimental setup motivated the workers to improve their performance regardless of working conditions [17,30].

7. A WS study requires trained observers to make inferences concerning cognitive processes (i.e., what was the worker actually thinking about). Such observers are expensive to train.

Advantages of Work Sampling

1. WS is generally far less expensive to perform than the-motion analyses and provides a quantitative estimate of the amount of time spent in each category rather than a subjective estimate such as the one obtained from a questionnaire.
2. One observer can perform WS studies of different workers and/or different tasks as opposed to a one-to-one (observer/worker) ratio in TM analyses.
3. Observations can be made over an extended time period which decreases time effects of cyclic (i.e., day-to-day, week-to-week, or even seasonal) variations.
4. The chance of obtaining skewed results due to the Hawthorne Effect is reduced in a WS study since no single worker is under direct, continuous observation for extended time periods, and the total number of observations taken makes it extremely difficult for an entire group of workers to manipulate the outcome.
5. The study can be interrupted at any time with a minimal affect on the results.
6. A WS study is not as tedious to perform on the part of the observer as a conventional time-motion analysis [32], because the observer is constantly moving around and looking at different workers. In addition, since the observations are spread out, it is quite possible that the observer can do at least a portion of his or her job.

Conclusions

This chapter has briefly reviewed several work-evaluation techniques and attempted to describe in detail the concepts behind work sampling, a technique based on sampling theory. As described throughout this chapter, work sampling studies are not without problems. Even the most thorough study can be severely compromised by the seemingly endless random occurrences that are the rule rather than the exception in health care. One should not be dissuaded for these reasons, because the potential information gained is critical in determining the future role of computers in health care.

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Appendix

Definitions of categories used in a work-sampling study designed to measure the impact of computer-based nurse charting on nursing activities (modified from Bradshaw et al., 1989):

Patient care: anything done to the patient by the nurse, e.g. giving medications, turning the patient, starting intravenous medications, i.e., inserting catheter and adjusting drip rate (distinguished from the preparation of the fluid mixture which would be obtaining supplies), fixing bandages, and bathing the patient. Also includes watching the hemodynamic monitors at the central nursing station.

Charting: any activities involving the charting of nursing actions, whether on paper or by computer. Also includes correcting and looking for errors in the chart, as well as looking for the chart itself, and calling-out computer reports.

Oral communication: talking to the patient, or with someone about a patient or other work-related subjects. Talking with physicians, other nurses, technicians, patient's family, laboratories, blood bank, clerks, etc.

Obtaining supplies: going to get anything for a patient within or outside of the unit. Includes obtaining intravenous fluids or medications, preparing medications, getting pillows, bandages, equipment needed for a procedure, or any other supplies needed for patient care.

Planning nursing care: filling out the nursing care plan at a computer terminal (distinguished from time spent performing computer-based chart or data review).

Reporting: time spent giving report at the end of the shift to the next nurse coming on duty. Note: at this time there are approximately twice as many nurses working as there are during the shift; therefore, twice as many observations must be made.

Transferring patients: filling out forms for the transfer of a patient perhaps to the step-down unit or other units within the hospital (distinguished from the actual transport of the patient, for example to surgery or x-ray, which would be considered patient care).

Data review: reviewing data at a computer terminal, e.g., reviewing laboratory test results (distinguished from time spent performing computer-based charting or making nursing-care plans).

Medication scheduling: checking the computer-generated drug schedule against that of the Kardex file.

Non-nursing activities—other: activities unrelated to patient care, such as making personal telephone calls, socializing, taking breaks, etc.