Observing Nurse Interaction with Infusion Pump Technologies

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Abstract

In this paper, we describe the use of observational methods to assess the interaction between nurses and medication administration technologies. The observations were conducted to examine the use of point-of-care bar code technology and pre- and post-implementation of intravenous (IV) pumps with medication delivery software to prevent programming errors (known as Safe Medication Administration through Technologies and Human Factors or SMArT^{HF} or Smart IV pumps). A total of 62 observations were conducted for the bar code technology, 52 observations were conducted pre-implementation of the Smart IV pumps, and 63 observations post-implementation of the Smart IV pumps. We describe the procedures used to collect data, and we present preliminary observation data analysis on the physical environment and the sequence of steps used in the medication administration process under three technological conditions (bar code technology, IV pump technology (before implementation of Smart IV pump), and Smart IV pump technology (after implementation of Smart IV pump).

Introduction

Human factors engineers use various methods for describing and evaluating interactions between people and their work environment. These interactions can be analyzed at many different levels.[1] From a structural point of view, the following levels can be distinguished:

(1) political and societal organization of work;

(2) industrial relations, market, and business conditions;

(3) cooperation in groups and human relations;

(4) individual work;

(5) subtasks and workplaces;

(6) specific operations with tools and technologies; and

(7) interactions between physiological systems and environment.[1–3]

These different structural levels reveal different roles and actions of people:

(1) work-oriented political actions;

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(2) interaction within an organization and between organizations;

(3) group work;

(4) motive-related activity;

(5) goal-oriented action; and

(6) elementary operations and movements.[1]

Various methods are used to collect information on the interactions between people and their work environment at these different levels.[1, 4] In this paper, we describe an observational method used to evaluate goal-oriented actions and elementary operations of end users of medication administration technologies. The observed actions and operations represent subtasks and specific operations performed by nurses when using two types of technologies: bar code technology and intravenous (IV) pump.

According to Stanton and Young,[5] observation is a very useful human factors method that provides direct information on the interaction between people and their work environment or tools. The observational method tends to have strong face validity. However, human factors experts have also highlighted several concerns regarding observations: intrusiveness; amount of effort required in collecting and analyzing data; objectivity of the data collection and analysis; lack of information on cognitive processes; and the limited comprehensiveness of the observational method.[5, 6] It is generally agreed that the quality of the observation data depends heavily on the method of collecting, recording, and analyzing the data.[5]

Drury[6] describes eight human factors observational methods:

(1) raw event/time records;

(2) time studies;

(3) process charts;

(4) flow process charts;

(5) Gantt charts;

(6) multiple activity charts;

(7) link charts; and

(8) occurrence sampling.

Raw event/time records can be useful to analyze the time history of single events, such as in the investigation of accidents or critical incidents. Time studies provide statistical information on the duration of tasks. According to Drury,[6] "A process chart is nothing more than a plant (or office, etc.) layout with the materials movement for one or more processes marked on it." A flow chart is a process chart in which information on the physical environment has been removed. Gantt charts describe the time relationships among activities and place those activities on a timeline. A multiple activity chart is a variant of a Gantt chart where the activities are grouped into continuous bars placed over a timeline. A

link chart is a visual representation of links existing between components or elements, for instance, elements of a physical space. Evanoff and his colleagues have used link analysis to evaluate nursing tasks, track motions and physical connections, and identify heavy traffic patterns.[7, 8] In occurrence sampling, the human factors engineer observes the operator or the system at predetermined times.

In our study, we used the methods of time study and flow process charting.

The implementation of technologies changes the work of end users in foreseen and unforeseen ways.[9–11] and has both positive and negative effects on the job characteristics that ultimately affect individual outcomes quality of working life, such as job satisfaction and stress, and perceived safety and quality of care).[12] This is the basis of the Balance Theory of Job Design, developed by Smith and Carayon,[13, 14] which conceptualizes the work system into five elements that interact to produce a stress load on an individual. The five elements are the individual; the tasks; the technology and tools; the environment; and organizational factors.[13] A change in one element of the work system can have effects on another element; therefore, when suggesting a change in one element (e.g., technology), the effects on the entire work system need to be considered.

Inadequate planning when introducing new technology designed to decrease medication errors in health care—especially inadequate attention to workload and system usability that are characteristics of the task and worker elements of the work system model—has led to technology falling short of achieving its patient safety goal.[15, 16] Technologies can change the way work is performed, and because health care work and processes are complex, negative consequences of new technologies are possible.[17] Whenever implementing a technology, one should examine the potential positive *and* negative influences of the technology on the other work system elements.[18, 19] In a study of the implementation of an electronic medical record (EMR) system in a small family medicine clinic, researchers examined the impact of the EMR technology on work patterns, employee perceptions related to the EMR technology and its potential/actual effect on work, and the EMR implementation process.[20] Employee questionnaire data showed that the introduction of the EMR technology increased dependence on computers, quantitatively increased the workload, and had a perceived negative influence on performance.[21] It is important to examine for what tasks technology can be useful to provide better, safer care.[22]

A few observational studies have identified human factors deficiencies of health care technologies. For instance, Patterson et al.[15] observed medication administration before and after the implementation of bar code medication administration (BCMA) technology. These observations uncovered a variety of negative human factors "side effects" of BCMA implementation, such as worsening coordination between nurses and physicians. Another observational study by Patterson et al.[23] examined found that several human factors barriers inhibited the implementation of computerized clinical reminders for improving adherence to guidelines for HIV care, (e.g., additional workload and additional

time necessary to document decisions when the reminder's advice was not followed).

In this paper, we describe the observation methodology used to collect information on nurse interaction with different medication administration technologies. These observations have been conducted to examine the use of point-of-care bar code technology, and have occurred pre- and post-implementation of intravenous (IV) pumps with medication delivery software to prevent programming errors (known as Safe Medication Administration through Technologies and Human Factors or SMArT^{HF} or Smart IV pumps). Based on the work system model of Smith and Carayon,[13, 14] the medication administration processes consists of a series of tasks (or steps); the environment in which the tasks are performed; the policies and regulations governing the work; technologies used to carry out the tasks; communication networks; flow of work; and, most important, the complex interactions taking place between all of those factors.

Methods

Study setting

The University of Wisconsin Hospital and Clinics (UWHC) is a 450-bed, university-based, tertiary care center. It serves a broad population of urban and rural patients in south central Wisconsin and northern Illinois, with a surrounding four-State referral base. UWHC's clinical areas of excellence include its Level One trauma center; a solid organ transplant service; interventional vascular services and Comprehensive Cancer Center; and a 45-bed children's hospital. UWHC is affiliated with the University of Wisconsin School of Pharmacy and has an accredited pharmacy residency program. Through its active pharmacy program, innovation and early adoption of technology and processes to streamline the medication use process—e.g., robotics, unit dose dispensing, and decentralized unit and ICU pharmacists—has been the norm. Recent attention on reducing errors in the medication administration process resulted in the systematic implementation of point-of-care BCMA technology over 3 years, from 2001 through 2004. This technology uses bar code scanning of the medication, patient's identification band, and nurse's identification band as a double-check system to ensure the correct medication and dose are given at the correct time to the correct patient. It also documents administration.

To improve IV medication administration and decrease IV pump programming errors, UWHC implemented Smart IV pumps organization-wide in fall 2003. These IV pumps have hospital-specific drug libraries with preprogrammed dosing limits for medications.

With the recognition that the introduction of new technology causes changes in workflow and therefore requires changes to processes already in place, as well as the understanding that new technology may introduce new errors to the system, a prospective risk analysis, or failure mode and effects analysis (FMEA), was

undertaken before the introduction of the IV pumps and 1 year after partial implementation of BCMA technology.[24] Observations of the medication administration process, as described below, were performed to provide data to the FMEA team on nursing practice and interaction with current technology, emphasizing variation from accepted procedure and problems with the technology. Observation data were used for flow charting the medication use process, identifying failure modes, and estimating the likelihood of failure mode occurrence as solution generation.

Observation instruments

The steps taken to develop the observation methodologies have been described elsewhere.[25]

Instrument for observing the use of point-of-care bar coding technology

The point-of-care bar coding technology observation tool is a modified version of the tool developed for IV pump observations (see http://cqpi2.engr.wisc.edu/smarthf/tools/point-of-care_bar_coding_technology_observation_form.pdf for a copy of the observation instrument). Across the top of the tool is an area to document the patient care unit where the observation took place; the shift the observation took place; the beginning and end times of the observation; the initials of the observers; and the date the observation took place. The remainder of the top area provides space to document the number of medications being administered based on dose form. Immediately below is where the bulk of observation data are collected. Moving from left to right, the first two columns—*technology use* and *loc'n*—are used to document (1) the sequence of actions performed by the nurse relative to the correct sequence defined by procedure; and (2) the location the nurse performed the action (hallway, the medication room, patient room, or other). The sequence in which the medication administration and documentation steps are performed is recorded and compared with the ideal technological sequence as defined by both hospital policy and software programming; the *technology use* column lists this correct sequence. The location of occurrence of each step in the process is recorded with an alphabetical abbreviation representing the location. The column titled *automation surprises* is used to document unusual actions observed by the technology that surprised the user or the observer. *Staff comments* and *patient comments* are used to record comments about the technology provided by those individuals, whether made directly to the observer or overheard when talking with another user. *Interruptions* allows documentation of activities that appeared to disrupt the normal sequence of events of the user. The observer uses the area titled *comments* to record notes about the observation and the names of the medications administered to the patient. The area to the far right of the tool is used to document the lighting, noise level, and state of the physical environment in which the observation took place. Below that is an area to record particular practices that are considered deviations that could contribute to administration errors.

Instrument for observing the use of IV pump technology (pre-implementation)

The instruments used for the pre-implementation IV pump observations consists of an observation sheet, time study board, and writing instrument. (See http://cqpi2.engr.wisc.edu/smarthf/tools/pre-implem_pump_observation_form.pdf for a copy of the observation tool.) The observation recording sheet was modified several times based on input from a series of observations and discussion in research meetings.[25] The observation recording sheet is designed to record the steps (tasks) of the medication administration process in the order in which they are performed. Information about the work environment, interruptions in the process, patient and nurse comments, nurse interaction with technology, technology failures or surprises, and alarms are also recorded. The environmental factors of light, noise, and overall physical environmental (i.e., messiness, crowdedness, organization) are noted. The number of keystrokes is also documented, along with the method used to calculate the rate of administration for a medication (i.e., dose rate calculator on the pump, hand-held calculator, manually). Observers also note if tubing is already present, if and when the error alarm sounds, and if the nurse washes his or her hands. An area for written comments is also included. The shift (i.e., first, second, and third), nursing unit, and medication name are also recorded. The entire observation, from the moment the nurse secures the IV bag to pushing the "start" button on the pump, is timed using a time-study board. To respect confidentiality, no personally identifiable information about the nurse or the patient is included on the observation sheet.

Instrument for observing the use of IV pump technology (post-implementation)

The post-implementation observation instrument consists of a two-page observation sheet; an interview form; a NASA Task Load Index (TLX) question form to measure time pressure and mental workload;[26] a note card listing the visual and audio signals; and a time study board. In a later phase of observation, a Tablet PC is used to record data.

The pre-implementation observation sheet was used as the starting point and redesigned for post-implementation observations due to significant programming differences between the Smart IV pumps and previous pumps. A pump programming process flow diagram was designed, detailing the three types of pump programming: (1) basic infusion, (2) secondary infusion, and (3) Guardrails® infusion using the preprogrammed drug library or dose-rate calculator. This classification aided in data collection to follow and record the pump programming steps and alarms/alerts detected. While conducting observations, the main focus was on the steps during programming and visual or audio signals noting an advisory, alarm, error, or prompt.

The first page of the sheet contains the flow diagram mentioned above, fields to note the date or week number when the data were collected; the unit where the data were collected; name of medication administered; the label on the pump related to the just-administered medication; other pumps attached to the patient,

number of bags attached to the patient just before observed medication administration starts; duration of the observation; and automation surprises/technology failures as well as the nurse's reaction to these automation surprises and technology failures. The labels, sequence of the pumps in relation to the programming module, and number of pumps are also recorded. Audits are included in the observation to note if a double-check was performed, if the tubing was properly loaded, and if the top fitment was placed appropriately. There is also room to record notes. The second page is used to note environmental factors such as light, noise, and others present in the patient's room.

The interview sheet, designed to ask users their perceptions of the pumps, was changed slightly after preliminary observations. Questions asking nurses to describe their current shift in terms of "busyness" were replaced with NASA TLX questions on mental and temporal workload. Nurses responded to the interview questions with relative ease.

Since there are 36 different kinds of visual or audio signals that the Smart IV pump and programming module can produce, it was almost impossible to differentiate various visual and audio signals while conducting observations. To make sense of the sound and visual signals, observers used a small "cheat" sheet to identify the signals. (See http://cqpi2.engr.wisc.edu/smarthf/tools/post-implem_pump_observation_form.pdf.)

Observation procedures

In our observation methodology, the observer is a "complete observer" who does not participate in any way in the process being observed.[27]

Observing use of point-of-care bar coding technology

Observation periods were conducted at times when medications were most likely to be passed, which we determined to be in the morning (8 a.m.) and then in the evening (10 p.m.). Observations were performed on nine inpatient units, ranging from general medicine and surgical to intensive care units. The observers reached the floor 30 minutes to 60 minutes before the medication pass was scheduled to begin. Hospital policy allows nurses to begin passing medications 1 hour before they are due to be administered to help with the workload associated with administering medications for up to four patients. The observers entered the medication room on the patient care unit. The observational period began at the point the nurse logged into the bar code technology software. At this point we explained to the nurse that we were involved in a hospital quality-improvement project studying the effect of the bar code technology on nurses and that we wanted to watch him or her complete this medication administration and record what was done. If the nurse consented, we then observed the nurse access the patient medication profile, take the medication from the patient-specific medication drawer, scan the medication, enter the patient room, and administer the medication. If any action performed by the nurse or the software occurred that appeared out of the ordinary interaction, we asked the nurse what had happened and whether he or she had an explanation for it. We also benefited from the

audible alerts the scanner made when an error had occurred. This provided a convenient time to interrupt the nurse and inquire.

Interaction with the patient was limited. Upon entering the room, the nurse would usually identify the observers as people who were watching her give the medication. If this exchange did not occur, the observers indicated that they were watching the nurse administer medications for a research project. For both the nurse and the patient, a form clearly stating the purpose of the observation was provided.

Two-person teams composed of a human factors engineer and a pharmacist conducted a total of 62 observations on 9 different units. Twenty-eight observations (45 percent) were conducted during the first shift, and 34 observations (55 percent) were conducted during the second shift. The average duration of observation was about 8 minutes, with a minimum of 2 minutes and a maximum of 29 minutes.

Observing use of IV pump technology (pre-implementation)

Observations were conducted by teams of two human factors engineers who had received basic information about Smart IV pump and the medication administration process. Each team concentrated on specific areas of the hospital to gain familiarity with the staff, processes, and cultures. Upon arrival at the unit, observers went to the pharmacy area, where the research study was explained to staff present, primarily nurses. Although explaining the study to the entire staff at one time would have been more efficient, many nurses were then-occupied with patient care duties; asking them to delay their tasks to hear the explanation of the study was clearly not a possibility. Therefore many nurses were told about the study during one-on-one conversations with observers. The study had been approved by the medical school Institutional Review Board (IRB) and a waiver of consent had been granted, eliminating the need for a signed consent. Patients were asked before the observations began if they would verbally consent to observers entering the room to conduct research.

After each observation, observers met to discuss and compare aspects of their observations. Initial observations were quite slow; some observers could only collect three observations over a 3-hour period. With increased familiarity came increased efficiency, allowing observers to nearly double their rate of observation. To improve efficiency and decrease the amount of time standing in the pharmacy area waiting for nurses to administer IVs, the physician member of the research team assisted observers by retrieving scheduled administration times from the pharmacy database. This information was passed on to the observers.

A total of 52 observations were performed. Sixty percent of the observations were conducted during the first shift, 28 percent during the second shift, and 12 percent during the third shift.

Observing use of IV pump technology (post-implementation)

Initial observations were conducted by a two-person team (one person with an industrial engineering background and one clinical person). Later, to avoid medical judgments and to observe instances only from a human factors engineering standpoint, a single industrial engineer observed. Patient names, nurse names, and any other information or data that could be used to identify the nurse or patient were never recorded. An instruction form was developed to help observers complete the observation sheet. The observation rate ranged from one observation during a 2.5-hour period to four observations over a 45-minute observation period. A total of 63 observations were performed over about 46 hours during 18 observation periods. On average, observers performed about two observations over a 1.7-hour period. Twenty-one observations were conducted during the first shift, 35 observations during the second shift, and 7 observations during the third shift.

Sample

Observations were performed on a variety of hospital units, as indicated in Table 1. Observations were conducted during all three shifts.

Table 1. Number of observations by technology and unit type

Unit	Bar coding technology	IV pump (pre-implementation)	IV pump (post-implementation)
Medical	26	24	7
Surgical	9	7	7
Critical care	18	21	39
Other	9	–	10

Results

In this paper, we report preliminary analysis of the observation data. The results focus on the physical environment and the sequence of steps (tasks) used to complete the medication administration process using three different technologies, i.e., point-of-care bar code technology, IV pump (before implementation of Smart IV pump), and Smart IV pump (after implementation of Smart IV pump). Additional data analysis is being conducted and will be reported in future publications.

Observation of nursing interaction with point-of-care bar coding technology

Table 2 shows data on the physical environment as it was observed in patients' rooms and in the medication room. For each location, the following environmental factors were observed: lighting, noise, and overall physical

environment. Lighting in the medication room was observed as full, whereas lighting in patients' rooms was either primarily full or dimmed. Patients' rooms were observed to be more often quiet than the medication room. In three observations, the medication room was observed to be loud. In 12 observations, the medication room was found to be messy and disorganized.

Table 2. Observed physical environment

	Bar coding technology		IV pump (pre-implementation)		IV pump (post-implementation)
	Patient room	Medication room	Patient room	Medication room	Patient room
Lighting					
• full	23	61	30	51	46
• dimmed	32	0	21	0	14
• none–minimal	6	0	1	0	1
Noise					
• quiet	35	16	24	6	32
• normal	26	42	28	44	17
• loud	0	3	0	2	6
General physical environment					
• neat/organized	13	9	12	19	
• normal	34	40	29	25	
• messy/disorganized	15	12	10	8	
• organized					31
• normal					7
• disorganized					12
• noncrowded					22
• somewhat crowded					13
• crowded					18

The analysis of sequence of steps for the medication administration process with the bar code technology shows a total of 18 different types of sequences. The two most frequent types of sequences are—

- scan self / obtain medication / check medication / scan medication / enter patient's room / scan patient ID band / give medication / document administration (24 observations)
- scan self / obtain medication / check medication / scan medication / enter patient's room / scan patient ID band / document administration / give medication (17 observations)

Observation of nursing interaction with IV pump technology (pre-implementation)

Table 2 shows data on the physical environment for the patients' rooms and the medication room. Lighting was full in the medication room, and either full or

dimmed in patients' rooms. Patients' rooms tended to be more quiet than the medication room. The medication room was actually observed to be loud in two instances. Patients' rooms and the medication room were observed to be messy and disorganized in 10 and 8 instances, respectively.

Only 45 out of 54 observations were used in analyzing the task sequence in the medication administration process. Other observations did not provide sufficient data on the task sequence. We identified a total of 13 different task sequences performed by nurses when administering IV medication. These task sequences are displayed in Figure 1. The two most frequently observed task sequences were (1) hang IV / turn on pump / program / push start (11 out of 45 times); and (2) hanging IV / program / push start (9 out of 45 times).

Observation of nursing interaction with IV pump technology (post-implementation)

According to Table 2, lighting was often full in patients' rooms. Patients' rooms were found to be loud in six instances. In the post-implementation observations, we split the question on the general physical environment into two separate questions: one on level of organization in the space, and one on crowdedness. This was done because room organization and "crowdedness" are frequently mutually exclusive (e.g., an organized room is not necessarily uncrowded and likewise conversely). In 12 of the observations, the space was found to be disorganized, and in 18 observations, the patient's room was found to be crowded.

A total of 46 observations were conducted while a basic infusion was set up, whereas 14 Guardrail observations were performed. One observation combined a basic infusion and the use of Guardrail. An example of the sequence of steps used for a basic infusion is shown in Figure 2.

Discussion

A major strength of the observational methodology is the ability to collect data on the task actually carried out. Leplat[28] distinguishes between five representations of task: (1) the prescribed task (e.g., task instructions, procedures); (2) the implied prescribed task (i.e., representation to the person of his or her task); (3) the task the operator sets for him- or herself; (4) the task actually carried out; and (5) the representation of the performed task. Our observational methodology produced a representation of the performed tasks when administering medications that we assume represents the tasks actually carried out by the nurses. The data on sequence of steps (tasks) demonstrate a rather large diversity for each of the three types of medication administration technologies; there does not seem to be only one way of administering medication with any of the technologies.

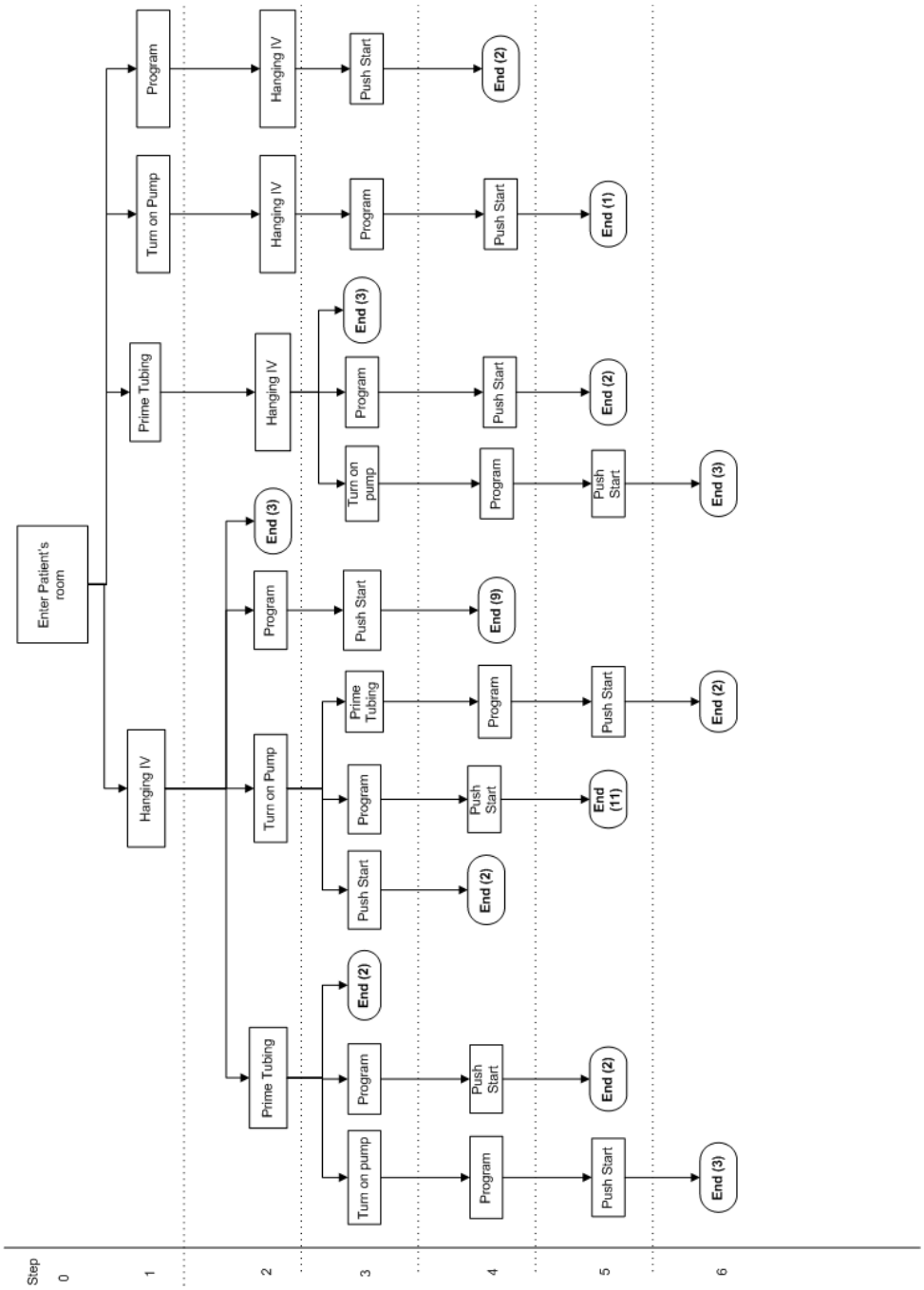
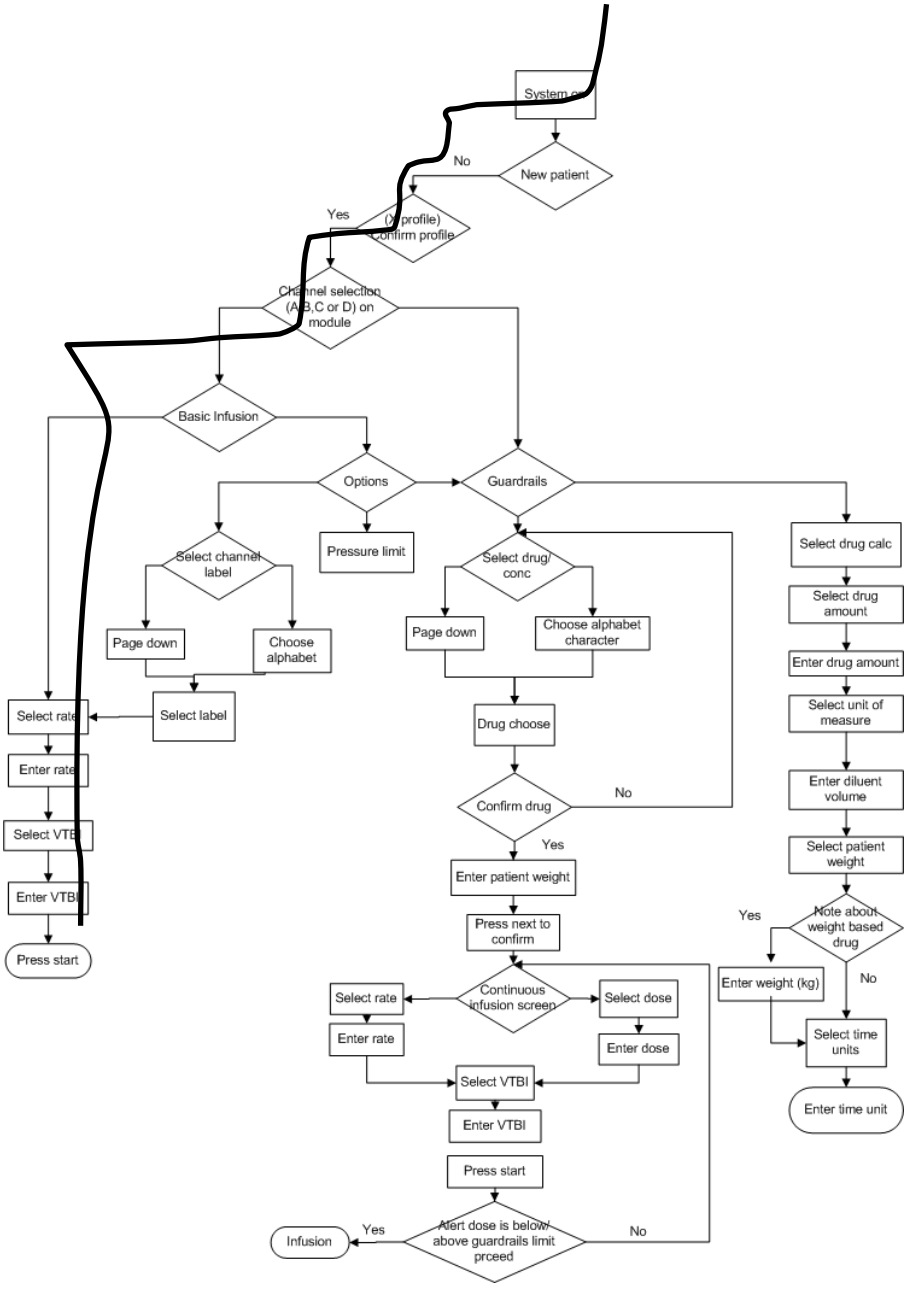


Figure 1. Sequence of tasks in IV medication administration (pre-implementation)

Note: The frequency for each sequence is given in the last box of each sequence ('End' box).

Figure 2. Example of sequence of tasks in IV medication administration for basic infusion (post-implementation)



The observational methodology provides rich, detailed information on the tasks performed by nurses when administering medication and using various technologies. The descriptive data do not provide any information on the appropriateness of the tasks or the usability and usefulness of the medication administration technologies. Additional methods and procedures can be used to obtain an evaluation of the observation data. For instance, the observation data can be presented to a group of "experts" (e.g., workers, managers) who can evaluate whether the tasks and sequence of tasks performed are appropriate.

Another evaluative method involves an FMEA of the medication administration process using the observation data as input into the assessment process.[29]

One use of the observation methodology is to provide information on what is actually being done when administering medication. In our study, the observation data of the point-of-care bar code technology was provided to an FMEA team assessing the failure modes associated with this technology. The observation data were invaluable to the FMEA team in many ways. First, it allowed for an unbiased and nonjudgmental look at the actual nursing processes in place, as opposed to outlined procedures in the nursing policy and procedure manuals. Because the observations were performed by researchers, data observed and recorded were not affected by cultural and organizational factors. Second, observers brought the experiences of dozens of nurses from different care settings to the FMEA team, a variety that would not have otherwise been possible due to nursing schedules and team size, yet was critical to team success. Next, observations were used to confirm the occurrence of failure modes on a day-to-day basis. Observers also identified variations in practice that were evaluated as potential failure modes by the team. Lastly, the human factors approach to the observations led to potential solutions for failure modes through changes in technology and the user-technology interface.

Conclusion

A key principle of human factors engineering is to assess the interaction between people and their work environment. An important distinction made by human factors engineers concerns that of "prescribed task" versus "task actually carried out." Human factors engineers are keen to evaluate the actual tasks performed by workers. In our study, we are striving to evaluate nursing interaction with various medication administration technologies. This paper has presented three observation instruments used to assess nurse interaction with point-of-care bar code technology, IV pump technology, and Smart IV pump technology. These observational tools collect information at the level of interaction between the nurse and specific technologies. It is important to realize that, even though data are collected on the environment and context of work (e.g., physical environment) and on the organization of tasks (e.g., sequence of tasks), the observation focuses on only one element of the nursing job. It does not consider the whole job of nurses, only the medication administration activity.

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