EVALUATING THE USE OF FLOWSHEETS IN PEDIATRIC INTENSIVE CARE TO INFORM DESIGN

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Flowsheets are central artifacts of information collection and exchange to support the monitoring and diagnosis of patient status in the pediatric intensive care unit. This study used field observations to examine the design and use of flowsheets. Strengths of the current paper document include portability, bundling of related data, and allowing for notes and annotations. However, the static nature of the paper document requires that users manually calculate and carry over important trends and relationships. Spatial constraints of the paper document make it necessary to squeeze data into a small space with data sometimes being difficult to read. Electronic flowsheets have the potential to overcome these limitations and introduce new features, but depending on their design, may eliminate the strengths of the original system. Studying actual practices in the work environment yielded insight into the use of the document to inform the design of an electronic flowsheet system.

INTRODUCTION

Calls to improve patient safety have led both the medical and engineering communities to pay increased attention to the design of healthcare systems. Hospitals contain many tightly-coupled sociotechnical systems, which require the coordination of people, tools, and technologies that are distributed in both time and space. The computerization of order entry, medical record, and other information technology systems holds promise for reducing preventable medical errors. However, these same technologies can create new sources of error by altering work and decision making patterns (Horsky, Zhang & Patel, 2005; Ash, Berg, & Coiera, 2003). Therefore, studying the transition path from one system to another and understanding the system impact of engineering solutions is important.

Distributed cognition is concerned with the transmission of information through both internal and external representations. Individuals and groups create artifacts and tools and rearrange the physical environment to aid in performing their tasks (Hutchins, 1995). During this reconfiguration process, an increased amount of the cognitive load is shifted from individuals to the environment. In some instances an individual’s task may fundamentally change depending on the tools provided (Zhang & Norman, 1994). For example, the physical and cognitive processes involved in performing calculations differ considerably among using a pen and paper, calculator, multiplication table, slide rule, or abacus.

Two principle tenets distinguish distributed cognition from traditional information processing theories. First, the unit of analysis is a system rather than cognition of an individual’s mind. Second, the scope of elements that may contribute to cognition is expanded from only individuals to include artifacts, materials and the physical environment.

Intensive care units (ICUs) are prime examples of distributed systems. ICUs require complex and timely coordination and exhibit considerable differences in information requirements from patient to patient and from other hospital units (Munir & Kay 2005). The pediatric intensive care unit (PICU) serves critically ill newborn to adolescent patients with a wide range of medical and surgical problems.

Information in the PICU is transferred through a variety of sources including face-to-face communication and through paper and electronic artifacts. One such artifact, the flowsheet, is a multi-page, hour by hour paper record that bundles together key physiological parameters and interventions. A recent study by Brown, Borowitz, and Novicoff (2004) identified the flowsheet as the most frequently used information source in a neonatal intensive care unit. While this study examined a single ICU, flowsheets are widely used artifacts in intensive care.

As a centralized patient record, the flowsheet serves as a form of information exchange across multiple healthcare providers distributed in space and time. Although paper-based flowsheets meet many information requirements they may not be the optimal instrument for data representation due to their static nature and the need to aggregate different data elements across several time spans. Introducing an electronic flowsheet has the potential to address some of these deficiencies, however, most electronic medical systems are designed to mimic paper systems rather than take advantage of the features that a new medium affords. Depending on the design of the electronic flowsheet, information exchange could actually become impaired if data elements that were fairly easily compared on paper are hidden or scattered across several screens of information when computerized.

Studying flowsheets in of the context of their real-world use could lead to effective designs. This paper describes an analysis of flowsheet design and use in the PICU work domain at an academic medical center. The results offer design implications for moving to an electronic flowsheet.

METHODS

Over 25 hours of observations were conducted during day and night shifts, morning and evening rounds, and shift changes.
Informal (unstructured) interviews with multiple nurses, resident, fellow and attending physicians, and respiratory therapists were conducted during both day and night shift. Shadowing of nurses and a fellow physician also occurred at those times. Completely de-identified copies were made of flowsheets for some patients. Copies of blank flowsheets, code sheets, checklists, and other documents were obtained and examined.

**WORK DOMAIN ANALYSIS**

Work domain analysis (WDA) (Vicente, 1999) served as the framework for analyzing the PICU. The abstraction decomposition space (ADS) is the primary tool of WDA. The purpose of an ADS is to identify the environmental constraints that shape task performance. The methodology is frequently applied to causal systems (governed by laws and principles of nature), such as petrochemical and nuclear power supervisory control, but has also been applied to intentional systems (governed by regulations, priorities and values) such as emergency response and military command and control. Medical applications of the ADS (Hadjukiewicz, Vicente, Doyle, Milgram & Burns, 2001; Sharp & Helmicki, 1998) concentrated on the functional relationships within the human body. This research analyzed the PICU as an intentional system and focused on the activities necessary to effectively manage the unit. These activities, termed technical work, are an integral aspect of the health care domain (Nemeth, Cook, O’Connor & Klock 2004).

To understand the context of flowsheet use in the PICU, the scope of the WDA included the unit as a whole. We constructed an ADS that divided the unit into two domains, unit management and patient management. The results most relevant to flowsheet use will be presented here.

**Flowsheet structure and layout**

The layout and information included on flowsheets vary across hospitals and units, but the row-column format with axes of time and data is preserved. The structure of the observed flowsheet consists of four 8.5” by 11” double-sided pages connected to each other such that it can be spread out and flipped over, or folded and paged through to create one 8.5” by 11” booklet. Each page has related variables across the x-axis and time on the y-axis. One flowsheet bundles together key information over a 24 hour period for a particular patient. The first page of the flowsheet (see Figure 1) contains vital signs (e.g. heart rate, blood pressure, etc.), nursing assessments and PRN (“pro re nata”, a Latin phrase that translates to “as needed”) medications and interventions. Fluid input and output comprise the next two pages and can be viewed as a two-page spread. Patient teaching and education checklists are on the next page. The reverse side of the flowsheet contains ventilator information (filled in by respiratory therapists), two pages for notes, and a page for lab values. When the flowsheet is completely folded, the vital signs page is the face and the nursing checklists are on the reverse. The face page also includes a bar-code sticker with patient identification information, the date, current and past patient weight, head circumference, length and abdominal girth; however, these latter six fields are often left blank.

Both fixed and free-text time scales are utilized. The vital signs and fluid input and output pages have fixed time scales that use only the hour digits of military time and start at 00 (12:00 am) and have a row for each hour until 23 (11:00 pm). As Figure 1 illustrates, blood pressure and heart rate may be taken more frequently than once per hour, 4 columns for each measure are provided so that data can be recorded in 15 minutes intervals. Lab data, ventilator settings and the notes pages use a free-text format because they are recorded at variable intervals. The full four-digit military time is given for each entry in the free-text time field. Even though the fixed scales only provide the hour digits, not all the information in a row is necessarily recorded on the hour, rather just at some point before the next hour. This feature bundles the information gathered during an hour into a single row instead of spreading the information over multiple rows, which is necessary because of the spatial constraints of the flowsheet. An exception to this division occurs on the front page where PRNs are recorded in the fixed time rows, but the four digit time is often written next to the intervention.

![Figure 1. Sample of the front page of the flowsheet.](image)

**Flowsheet users**

Nurses and respiratory therapists, as well as resident, fellow and attending physicians provide care on the unit throughout the day and make the majority of clinical decisions. A typical shift includes seven to eight nurses, a respiratory therapist, at least one resident, a fellow, and an attending. At night, the latter two may be on call. Nurses care for one or two patients depending on their experience and the condition of the patients.

Miller and Sanderson (2005) found that nurses’ chief information concern is monitoring and detecting change in key physiological parameters, while physicians maintain a broader view of patient physiological functions and treatment strategies. Likewise, physicians, respiratory therapists and nurses interact with the flowsheet differently. The focus of this paper is describing the transfer of information among sources.

*Resident, fellow, and attending physicians.* In general, physicians use the flowsheet to identify trends, track responses to therapies, diagnose new problems, and determine patient state. To prepare for daily rounds, residents review and copy key parameters down from the flowsheet as part of their data gathering process. During rounds, an interdisciplinary team discusses each patient in depth. Residents present the patient
information they gathered, then the team discusses the plan of care and new orders are entered for the day. Nurses bring their patients’ current and previous flowsheets and will speak up with any pertinent information recorded after the resident assessed the patient. Physicians may ask for additional data from the flowsheet that is not included in the resident’s notes.

Attending physicians hand off care during evening rounds. The concentration of the second set of rounds is on gaining situational awareness of patients and evaluating their response to treatments, rather than on teaching and developing a plan of care. Much of the data the fellow or attending presents on rounds was previously gathered from the flowsheet. While discussing patients, the flowsheet is often further examined by multiple physicians.

Other health care professionals. Patient care is delivered in conjunction with numerous other health care professionals including respiratory, physical and occupational therapists; surgeons, anesthesiologists, pharmacists, nutritionists, radiologists, phlebotomists, speech pathologists, and several other specialists and technicians. All hospital patients require some combination of these services, and intensive care patients often necessitate an especially large set of care providers. Respiratory therapists interact with the flowsheet in the most direct way. They are responsible for recording the ventilator settings and changes and making notes of their actions and assessments. The other health care providers regularly need a specific data element and often consult the flowsheet to find the information.

Nurses. Nurses gather flowsheet data from a variety of distributed sources including the bedside monitor, blood gas machine, infusion pumps, medical information systems for lab results, scales, the urimeter for measuring urine output, and their own assessments of the patient. Inputs (food, liquid and medications) and vital signs are recorded at least every hour, while outputs (urine, stool, and drainage) are recorded as needed. Data from the main hospital laboratory is collected at least once per day. The frequency of data collection from the unit’s blood gas machine (used to measure patients’ serum pH, oxygenation, etc.) is highly patient dependent, but is often recorded more than 10 times a day. Nursing assessments are also performed at rates dependent on the patient, but at least one is completed per shift. Additionally, nurses make notes throughout the flowsheet for clarification and documentation as required.

When nurses discover abnormal data or are alerted to out of range values by the monitoring systems they notify a physician. Abnormal data could be single values or trends over time. Nurses also look closely at data after interventions, such as procedures or medication changes. Physicians will eventually see the flowsheet when assessing patients, however they rely on nurses to alert them to urgent changes.

Flowsheets aid in nursing hand off of care. Nursing shift changes occur twice daily at 7:00 am and pm. The incoming and outgoing nurses have an approximately 30-minute meeting to exchange information. Patient history, condition, events, interventions, and areas of concern are discussed. Nurses point out abnormal data on the flowsheet and often use it as a guide when describing the events of the day.

Several variations and conventions of nursing flowsheet use were observed. For example, each page features variable column widths, line weights, and data types. The pages with fixed time scales have bold row lines after 07:00 and 15:00, signifying shift changes, although there is also a shift change at 19:00. Data are presented in several forms on the first page (see Figure 1). Blood pressure is recorded as the systolic and diastolic (separated by a “/”) then followed by the mean arterial pressure often with a line drawn over it. This is likely for two reasons. First, if each number was presented in its own column, 12 columns would be needed to accommodate the 15 minute intervals. Second, placing the systolic physically over the diastolic follows a common convention and viewing them on a parallel plane would likely impair the readability of blood pressure. The other forms of data include check boxes, words and abbreviations, circled letters, number and letter combinations, fractions, two and four digit times, and staff signatures. Decimals also appear in different forms throughout the flowsheet. Some nurses record the decimal numeral after a decimal point while others print it as superscript, and still others use both conventions at once. Since multiple nurses fill in a flowsheet, a particular column may have a mixture of these methods.

Fluid balance is an important consideration for most patients in the PICU. This balance is tracked on the input and output pages of the flowsheet. While the cumulative input/output difference is the key measure of fluid balance, there is no location on the flowsheet for this number. Nurses often use the margin between the two pages to track the cumulative difference. Each of the two pages has columns for hourly and cumulative totals, but the difference calculation is performed and recorded at varying times depending on the patient. Often the total difference from the last flowsheet is recorded somewhere in the header of the two pages. While examining the hourly and cumulative totals over time is critical, only the current dose and changes are important for each drip medication. The current dose is documented every hour, even when no changes occur over long periods of time, resulting in a matrix of numbers containing considerable repetition with a few important data points (changes) interspersed. An advantage of this structure is the ability to scan across a row to calculate the hourly input total. Dose changes are usually marked with an up or down arrow in the cell before the change occurred and the time, medication name, direction arrow, and new dose are recorded in the titration changes column.

Additionally current medication lists are recorded at midnight and 8:00 am in the page headers (see top of Figure 2). One purpose of creating this list is to remind the nurse to check that the infusions pumps are set at the proper dose. Prescribed doses follow the medication name in these grids; however, the units are not the same units as the hourly doses listed below. Manual calculations are performed to verify the correct hourly dosage. The prescribed dose is multiplied by the patient’s weight and by any unit conversions. Next, the concentration of the drug must be obtained by dividing by volume and possibly converting units. Finally, the prescribed dose is divided by the concentration to obtain the hourly dosage. For example, if a 5kg patient is prescribed a
20mg/50ml concentration of milrinone at 1 mcg/kg/min, the pump should be set to 0.75 ml/hr. (1 mcg/kg/min * 5kg * 60min/hr * 0.001 mcg/mcg = 0.3 mg/hr \rightarrow (0.3 mg/hr)/(20mg/50ml) = 0.75 mg/hr).

**Strengths of the paper flowsheet**

**Bundles.** Expert clinicians frequently use bundles in intensive care to manage information effectively. Bundles consist of meaningful data that when grouped together aid in the completion of a task (Gordon, Ash, Lavelle, Lyman, Delcambre, Maier, Weaver & Bowers, 2001). The flowsheet is a key bundle used by clinicians when seeking patient information. The physical organization of artifacts, in this case the arrangement and grouping of data on the flowsheet, contributes to cognitive processing in the tasks for which they are designed (Hutchins 1995).

![Figure 2. Sample of current medications and fluids](image)

**Structure.** Another benefit of the current flowsheet is that it is both structured and flexible. The data are organized in a familiar manner which promotes scanning multiple variables at a time or quickly assessing trends in a particular variable across time. At the same time, the document is also quite flexible. Notes and annotations can potentially be written anywhere on the document, providing an easy way to deal with unique and unanticipated events. Margins are used for performing calculations and calibration tests. Free text entry for notes allows for quick data entry by allowing abbreviations, conventions, and symbols.

**Portability.** Finally, the document is easily carried to the location where it is needed, whether to the patient’s bedside, the clinical information system, or to the conference room during rounds.

**Weaknesses of the paper flowsheet**

**Spatial Constraints.** Small column size, limited space, and relationships among data elements all contribute to spatial constraints. For example, PRN orders and medications are allocated a ½” x ¾” box for recording the time, drug name/order, and dose for each medication given. In cases where many doses are given within an hour, the recording may consume space allocated for future hours. Such a case is demonstrated in Figure 3 where the row for 13:00 contains “13:30 1.5 mg morphine” and 14:00 holds “to OR 13:45.” Likewise, temperature location is an annotation that is generally written in the neighboring row or column. In Figure 4, the circled “R’s” indicates that the temperature was taken rectally and is first written in the column for heart rate (141) and the next instance is recorded in the temperature column above the temperature (36.7).

Additional constraints appear in cases when a patient is on more medications than can fit in the 10 provided columns. Nurses may anticipate this and split the 5/8” columns in half to accommodate more medications. In these cases the documentation is very difficult to read and write, and the probability of misinterpreting information appears likely.

Similarly, cases arise where labs or ventilator settings are checked more often then the document affords. In these cases, additional pages are used and stapled to the flowsheet. When a patient enters a severely critical state and needs immediate attention and action, nurses may be recording vital signs as often as every minute on a document called a code sheet. Code sheets are placed with flowsheets in the medical record and “see code 12 record” is often written on the flowsheet.

![Figure 3. Overflowing text](image)

**Figure 3. Overflowing text**

**Figure 4. Temperature annotation**

**Handwriting and free text.** Handwriting is frequently difficult to read, which likely affects the ability to accurately scan the document. Nurses' and respiratory therapists' notes are commonly difficult to read. Many nurses and physicians reported ignoring these notes because of the readability and inconsistency of content. Often information is recorded to serve as documentation that an event occurred or a physician conferred an order. Generally this information is not pertinent when diagnosing patients. Previously free text was listed as a benefit for providing flexibility, but it can also be a disadvantage. When annotating data or writing notes, nurses may use abbreviations unfamiliar to other health care providers. Free text adds flexibility and speed, but may sacrifice legibility and clarity.

**Static nature.** The disadvantage of the artifact’s static nature is apparent in tracking medications. Medications that are started during the day are listed at the bottom of the input page and a column in the main table, but are not added to the grids in the page header. Medication lists in the header are only current at the time they were created. To determine the current medications at any other time, one has to look across the row of the current hour to see which columns have an entry. The first row of the table contains medication names but cannot be checked alone because canceled medications may be listed. Also, dosage changes are marked in the main
IMPLICATIONS FOR MOVING TO AN ELECTRONIC FLOWSHEET

An electronic flowsheet has the potential to improve upon the current monitoring system. Legibility of notes, dosage calculations, automatically updating medication lists, aggregation of related data, and online access and storage are a few of the benefits such a system can offer. However, the implementation of an electronic system may produce negative impacts on cognitive load and workflow due to the need to have a computer to enter and access the information, limitations of screen real estate, and a potentially less flexible documentation system. The degree to which this is overcome and the ultimate benefit compared to the initial system will depend on the design of the electronic system. Thus, the following features should be considered when designing electronic flowsheets:

Access
- Multiple health care providers in distributed locations may need simultaneous access to the flowsheet.
- More than one user may want to enter data at the same time.
- Nurses may want to enter flowsheet data from multiple locations when data sources are distributed.

Functionality
Electronic flowsheets should...
- automate calculations such as fluid balance and drip rates
- support comparing data elements from multiple groups of data (e.g. vitals, labs, and ventilator). These data are easily compared with the paper document.
- support notes, annotations, calculations, calibrations or other methods of augmenting data entries and dealing with unique situations.
- support data analysis over multiple time spans. For example, fluid balance over the last 6, 24 and 48 hours.
- present data in familiar ways, such as having systolic pressure over diastolic pressure instead of side by side in a table.
- provide normal and critical ranges for data, and allow these ranges to be adjusted based on the desired patient state and age-specific norms (for example, the normal mean blood pressure of a neonate is much different from that of an adolescent).
- support prioritizing or flagging hand-written notes to draw attention to important notes and not to notes mainly serving as documentation of events.

Introducing a new technology will often significantly alter work patterns. In the PICU, nurses record data at least hourly, but in many electronic systems humans are taken out of the loop by feeding patient data directly to the online flowsheet. Cognitive processes involved in reading and writing information are a significant part of the overall task (Berg, 1996). Therefore, new electronic designs will not only have to improve the display of data compared to a paper-based flowsheet but will also have to overcome any loss of situational awareness due to eliminating the recording task.

CONCLUSIONS/FUTURE WORK

Implications for converting to an electronic system from a technical work perspective have been outlined in this paper. Conversion to an electronic flowsheet will presumably impact information exchange among providers. Replicating the paper artifact online will limit the utility of an electronic system, as will eliminating the strengths of the paper system. The next phase of this project will be to how to best support these activities through interface design and to design and test alternative electronic methods of recording, accessing, and interpreting flowsheet data.

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