A Social Network Analysis-based Approach to Evaluate Workflow and Quality in a Pediatric Intensive Care Unit

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Abstract

Pediatric Intensive Care Units (PICUs) provide care for children at imminent risk of death. Coordination of physicians and nurses is critical to ensure the provision of quality care. In addition, clinicians’ workflow, especially for nurses, is complex and fragmented, and therefore, it should be carefully assessed. In this research, we propose a Social Network Analysis-based approach combined with Quality Improvement (QI) principles to provide a framework to assess workflow and identify current factors that could affect clinical efficiency and nurse satisfaction. The tools provided were valuable to assess and visualize complexity and fragmentation of nursing workflow. According to the analysis conducted nurses spend on average 21% of their time in patient monitoring, 24% in collaboration, 27% in documentation, 10% in transit, 7% in medication, and 11% in miscellaneous activities. Network graphs were developed to provide visualization of workflow inefficiencies and to better understand relationships and connections between tasks. These results were utilized in the development of QI tools to investigate root causes of clinical inefficiencies and nursing dissatisfaction in more detail.

Keywords
Social Network Analysis, Quality Improvement, Workflow Assessment, Pediatric Intensive Care Unit, Clinical Efficiency

1. Introduction

Efforts to provide a more patient and family-centered healthcare experience have led major changes in healthcare delivery including remodeling of hospital units to provide private patient rooms and installation of electronic health records (EHR) and other health information technology (HIT). Implementation of these new standards inevitably results in changes to nursing workflow. Furthermore, the limitations of some of these contemporary patient care units, including limited visibility of patient rooms, longer travel times to supplies and greater distances between nursing staff members make effective workflow paramount to providing high-quality patient care, ensuring patient safety and maintaining nurse job satisfaction in a high-fidelity environment like a pediatric intensive care unit (PICU). In fact, key organizational factors such as information technology systems and unit structure have been found to play significant roles in nursing satisfaction and efficiency [1], and patient outcomes [2].
The Health Information Technology for Economic and Clinical Health Act (HITECH Act), which became law as a part of the American Recovery and Reinvestment Act (ARRA) helped to accelerate the pace of adoption of electronic health records. Both HIT and EHR play a major role in nursing workflow. Perceptions of the effect of EHR implementation on patient care and nurse workflow are varied. Some studies show perceptions of improved speed and increased documentation completeness without having a negative impact on time at the bedside [3,4]. Others have shown that nurses perceive EHRs as being a detriment to patient care [5]. Mador and Shaw [6] summarized results from studies that examined the effect of implementation of an EHR on actual time spent documenting. The summary revealed inconsistent results with 25% of studies finding decreased time spent versus 33% with increased time spent and 42% with no change. Furthermore, evidence has been recorded that indicates clinician dissatisfaction with EHR may attenuate over time [7]. Additional research is necessary to further elucidate the implications of EHRs in the context of nursing workflow.

The dynamic environment of intensive care requires nurses to change tasks many times in the performance of patient care activities. For example, one study reported that nurses changed task an average of 125 times per hour or changing activities more than once every 30 seconds [8]. Workflow inefficiencies created by unnecessary task changes could be addressed with best practice guidelines. This complex and fragmented environment must be understood in order to identify potential areas of improvement not only with respect to efficiency, but also satisfaction.

Many workflow assessment strategies have been employed previously in healthcare including observational studies and clinician questionnaires [1,7,9,10,11]. However, because SNA focuses more specifically on interactions and connections, a SNA-based workflow examination may provide a more inclusive model of nursing patient care patterns. Nursing workflow models established by SNA-based assessment will be utilized in the development of quality improvement initiatives. To our knowledge, application of SNA methodology to assess nursing workflow and establish potential QI strategies in a pediatric critical care setting is a novel approach.

The purpose of this study was to assess workflow of PICU nurses in order to pinpoint areas that could potentially be improved to increase efficiency and satisfaction. The approach uses SNA and QI tools to provide a better understanding of the workflow issues in the PICU. The visualization provided by the SNA-based approach will aid in the identification of areas for improvement and serve as a stimulus to move forward in implementing necessary PICU patient care strategies and policy changes.

2. Problem Description and Methodology

The Penn State Milton S. Hershey Medical Center (PSMHMC) is 491-bed Magnet-designated hospital in South Central Pennsylvania [12]. PSMHMC includes the Penn State Hershey Children’s Hospital (PSHCH) which is the only children’s hospital in the region. PSHCH serves an area with more than one million children [13] and is responsible for caring for more than 125,000 patients each year [14]. Recently, it was ranked as one of the nation’s best children’s hospitals for five specialties: cancer, urology, orthopedics, neurology, and neurosurgery [15]. In addition, the PSHCH PICU has consistently scored as one of the highest ranking PICU’s in terms of survival rates [16].

The PICU at PSHCH moved to a new facility in 2013 composed of 18 private rooms equipped to accommodate 24/7 family presence. The PICU staff of almost 40 nurses had to adapt to the new state-of-the-art facility. Although, the updated design has positively impacted various clinical activities, it also has incorporated new challenges in terms of workflow. Workflow assessment is necessary to identify strengths as well as problem areas in order to maximize benefits of the new facility.

In this study, a framework is proposed based SNA and QI approaches to assess complexity and fragmentation of the workflow in the PICU. The aim is to identify areas of improvement that will increase PICU efficiency and improve nurse satisfaction. Figure 1 provides a summary of the proposed methodology; details are discussed in the subsequent sub-sections.
2.1 Focus Group, Brainstorming and Survey Design
The initial phase of the proposed methodology was to conduct an observational study in which key organizational factors affecting workflow were analyzed. Non-structured interviews were conducted with a pediatric intensivist, a nurse manager, and a PICU clinical nurse specialist. The interview questions were grounded in known workflow issues in PICU settings. Based on the observational study, review of literature and the feedback received from the non-structured interviews, an open-ended questionnaire was developed. This approach of including a literature review and expert groups to design and produce the initial items of a questionnaire are a common practice [17]. The questionnaire was distributed among six key stakeholders in the PICU including attending physicians and nursing leadership. The main objective of the questionnaire was to broadly identify the most relevant workflow issues impacting clinician efficiency and satisfaction. The results obtained from the surveys were used as the baseline to apply Root Cause Analysis (RCA) tools and understand major workflow inefficiencies and their root causes.

2.2 Social Network Analysis
SNA was used in parallel to the survey as complementary approach of assessing disruptions in PICU workflow and identifying the tasks that affect efficiency and increase likelihood of errors. SNA has recently gained greater acceptance in healthcare settings. Most of the SNA applications that have been explored in healthcare fields aim to provide a better understanding of collaboration networks and their interesting patterns [18,19,20]. In this project, we use a different approach: we utilize SNA to visualize workflow based on the interconnectedness among the various nursing tasks conducted in a PICU. To the best knowledge of the authors, few studies have incorporated SNA to assess workflow in healthcare [10].

2.2.1 Data Collection
The data used to develop the SNA was collected from a time-motion study. The tasks conducted as well as their sequence were recorded and then transferred to a database structure. The study included direct observation of six two-hour blocks in which four nurses were shadowed. This pilot study considered only day shifts. However, due to the known differences between day and night shifts, future work will involve collecting more two-hour block samples, including data collection from night shifts.

2.2.2 Data Analysis
The data collected was entered into a symmetrical matrix structure based on the tasks. The cells represent the frequency in which two tasks are consecutively encountered in the workflow. Tasks network graphs were created using NodeXL, a SNA software based on Microsoft Excel. The Harel-Koren Fast Multiscale Algorithm [21] was used to generate the graphs. The main elements in a SNA graph are nodes and edges. For this study, we propose that tasks are represented by nodes and the interconnectedness between two sequential tasks is represented by an
edge connecting those two tasks. Additionally, the time spent on the tasks and the frequencies in which the tasks occur sequentially are represented by the size of the node and width of the edge respectively. In order to make the graphs easy to visualize, the nodes are colored according to the category in which they are grouped. As the tasks conducted by physicians and nurses are typically different, two separate graphs are needed to visualize the workflow of these two types of clinician personnel.

2.3 Quality Improvement and Verification
QI approaches including, survey, brainstorming and RCA were utilized as systematic methods to identify various causes of the workflow inefficiencies and dissatisfaction in the PICU. Through these tools, a better understanding of the workflow issues was gained. Hidden inefficiencies were detected and opportunities to improve were identified. Fishbone diagrams were developed to provide a structured way to visualize key areas of inefficiencies and their major root causes. These diagrams were developed and verified with key PICU personnel. In some cases, additional causes of inefficiencies were incorporated into the diagrams.

3. Results and Discussion
In this section we present the results and discuss the main findings.

3.1 Initial Visit and Survey Development
During a visit to the former PICU facility, we identified areas in need of improvement which were divided into three main categories: Daily Operation, Layout, and Information Technology system interaction. The visit served as the starting point to identify those issues that could be mitigated by moving to the new facility and those that would remain unchanged, such as those related to HIT systems interaction. The identification of potential non-value added tasks were made through field observation and informal survey with the PICU staff including attending physicians, residents and nurses. The main daily tasks undertaken by nurses were identified and grouped into seven main categories; 1) Patient monitoring, 2) Collaboration, 3) Medication, 4) Documentation, 5) Transit, 6) Supervision, and 7) Miscellaneous. Additionally, sub-categories were created and are shown in Table 1. All the tasks and activities identified were then verified with key clinical leaders in the PICU.

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3.2 Social Network Analysis to Assess Workflow Fragmentation

A time-motion study was conducted based on the tasks previously identified. The results from this study indicated that nurses spend on average 21% of their time in Patient Monitoring, 24% in Collaboration, 7% in Medication, 27% in Documentation, 10% in Transit, and 11% in Miscellaneous activities. The results obtained are similar to results that have been reported in the literature. According to Douglas et al. [8] approximately 23% of PICU nurses’ day is spent on Patient Monitoring, 28% in Coordination, and 22% in Documentation and Order management.

Other interesting observations were made during the time-motion study. On average, the duration for each one of the task categories mentioned was 59, 61, 104, 163, and 135 seconds respectively. Using the detailed tasks identified, it can be said that nurses perform on average 0.8 different tasks per minute; in other words, in a 5 minute-time frame, nurses perform 4 different activities. These numbers reflect the complexity and fragmentation in critical care nursing workflow. In Figure 2, a Box Plot is presented to illustrate the variability of the percentages of time spent on each one of the task categories. As usual, in a Box Plot graph, the left limit of each box represent the 25th percentile, the line dividing the two colors represent the 50th percentile, the right limit of the each box represents the 75th percentile, the “whiskers” give extra information about the spread of the data. In addition the symbol “+” represents the mean of the sample. Valuable information can be inferred from the box plot. For instance, it can be said that the percentage of time spent on Miscellaneous activities is highly variable if compared against the other categories. It indicates that the data collected is more spread, and therefore, accuracy on its prediction is more difficult. Although Documentation also presents a wide “whiskers” range, the 25th – 75th percentile range is very tight. Additionally, task categories such as Patient Monitoring present more homogeneous data and a tight 25th – 75th percentile range.

![Figure 2. Box Plot for Task Categories](image)

Complexity and fragmentation in the workflow can also be visualized through a task-sequence chart. In Figure 3 a task-sequence chart is provided to show fragmentation in workflow. The data graphed represent a 100-minutes window for a sample obtained during a morning shift. These types of graphs are valuable to broadly understand the distribution of time spent on each task, to visualize what task require less and more time, and to investigate what tasks are interrupted more frequently.

![Figure 3. Task-Sequence Chart](image)

In order to explore in more detail the complexity of the workflow and interconnectedness among the several tasks, network graphs were developed. In these types of graphs, nodes represent the entity under analysis (i.e., tasks or categories) and the edges represent whether two tasks or task categories have been found sequentially in the workflow. The size of the circle is proportional to the time spent on the corresponding task and the width of the
edges is proportional to the frequency or intensity in which two tasks are sequentially arranged. In Figure 4, a general network graph is shown to illustrate how category tasks are interrelated. As previously found, it can be said that among the categories identified, Documentation is the group of tasks that is more time consuming, followed by Collaboration and Patient Monitoring. By visualizing the edges of the network graph, it can be said, for instance, that Documentation and Collaboration sequences are much more frequent than Miscellaneous and Medication sequences. Various analyses can be made from the graph provided such as determining the probabilities that a nurse will perform a task given that another task was just conducted. Equilibrium can be calculated using Markov Chains from the transition probabilities from one stage (task) to another.

![Network Graph for Task Categories](image)

A more detailed network graph is presented in Figure 5. This graph provides an expanded visualization that could serve to explore inefficiencies in a more detailed manner. The interconnectedness and sequence of any two tasks for the various categories can be visualized. One of the inferences that can be made from the graph is the high centrality of the use of HIT systems. This task is connected to almost every other task. It indicates that HIT systems play a major role not only for indirect care activities, but also as a driver for coordination and communication. A high frequency can be appreciated for the sequences Electronic – Nurse-Nurse Communication and Electronic – General Care. In addition, the density of the graph is 0.366 which indicates that 36.6% of the total possible connections among every task are present in the network. Although this number can appear low, considering the relatively large size of the network, this number is impactful. It indicates that the workflow is relatively highly fragmented and complexly interconnected.

![Network Graph for Detailed Tasks](image)
One of the main advantages of SNA is that the levels of abstraction or details can be adjusted as required to investigate specific workflow patterns. For instance, let us assume that *Coordination* is required to be explored into more detail maintaining the groups for the other task categories. This new abstracted network graph is shown in Figure 6. Details such as how coordination occurs, what specific communication interactions appear in the workflow, and how different clinical staff supports other task categories can be visualized from this type of graph.

**Figure 6. Network Graph for Coordination Tasks**

### 3.3 Quality Improvement to Identify Causes of Workflow Inefficiencies

Results from the survey and SNA were used to identify and evaluate the major causes for the key workflow issues. Although the objective of the procedure was not conducting an exhaustive search for causes of inefficiencies, the authors were able to identify the most pressing factors that affect nursing workflow. The issues identified were categorized into various groups. The four most important are shown in a fishbone diagram in Figure 2.

**Figure 7. General Fishbone Diagram**
Four major categories were encountered as main issues for clinicians’ efficiency and satisfaction: communication, HIT, layout, and procedures. The root causes identified to cause communication issues were: a) multiple hands-offs, which produce inefficiencies in coordination, b) underutilization of electronic devices, those devices include portable telephones, digital communication screens, software alerts, among others, c) lack of HIT alerts, this issue has reduced the ability to timely communicate between different clinician specialties, and d) training, especially related to the awareness of the various capabilities and interconnectedness among electronic devices that could be used to support communication. The main root causes for layout issues are: a) distances / unit size, a main characteristic of the new facility are its long hallways and extended area, which has lead to increased transit distances and time, b) visibility, the new family-centered design has reduced visibility, which decreases direct patient visibility and creates coordination issues when seeking assistance from other clinical staff, c) room labeling is not intuitive, d) monitoring layout, monitors are not properly laid out to overcome lack of visibility of the new unit structure, and e) access to equipment and meds, location of equipment is not generally convenient, processes of medication retrieval are cumbersome.

Each of the root causes identified was explored in detail to identify causes of inefficiencies. Four new fishbone diagrams were created. Figure 3 depicts an illustration for the main cause “PROCEDURES”.

As already mentioned, the root causes identified for the PROCEDURES were a) family-centered design, b) coordination, c) stocking, and d) personnel. The major causes identified for a) were: a.1) lack of standardization for procedures conducted during the night shifts in which families are usually sleeping in the rooms, a.2) issues caused by inappropriate behaviors of the families, and a.3) lack of procedures to set families’ expectation with respect to this new family-centered facility. The major causes identified for b) were: b.1) coordination during admission and discharge processes, clinical staff is not notified of patient arrival/departure, b.2) bed management, including assignment needs improvement, b.3) underutilization of available electronic devices to improve communication, and b.4) lack of standardization for some procedures during rounds. The major causes identified for c) were: c.1) procedures to review medicine stock needs improvement, although stock is electronically controlled, stocking is not automatically conducted, c.2) storage room can be improved by designing it based on frequency of use, and c.3) more appropriate labeling of medical supplies would be helpful. The major causes identified for d) were: d.1) too many people involved on patient placement, it can affect coordination, d.2) lack of facilitator in charge of informing families of family presence procedures and policies, and d.3) lack of personnel in charge of special procedures.

These fishbone diagrams were developed based on the knowledge gained from SNA and surveys. The graphs generated were valuable to identify various areas of inefficiencies. Some of the root causes mentioned above such as underutilization of communication devices, lack of unit visibility, and distances can be inferred from the high frequency between the sequences Other Transit – Nurse-Nurse Communication. In this case, nurses that seek advice
from other nurses usually walk around the hallways until they find the right person. From the network graph, times can be also be visualized and causes of inefficiencies can be inferred. For instance, the time spent on the task Medication Storage (categorized into Transit) is considerable. From this observation, the authors were able to identify lack of stocking procedures, and medication storage design as areas for improvement.

One of the considerations that have to be accounted for when conducting an in situ time-motion study is that the presence of the observer could affect the normal behavior of the subjects under analysis - which is known as the “Hawthorne Effect” [22]. This could be overcome by using other less invasive data collection methods such as non-invasive video recording.

4. Conclusions and Future Work

The proposed methodology was found to be suitable to assess complexity and fragmentation in nurses’ workflow. Moreover the complementary approach taken, utilizing QI principles and SNA tools, provided a structured framework to identify major causes of workflow inefficiencies. The tools used aimed to develop a broader and better understanding of the workflow issues affecting clinical efficiency and nurses’ satisfaction. A main advantage of the approach taken is that they provide tools to visualize interconnectedness between tasks, time spent on tasks, frequency in which two tasks are sequentially encountered and structured frameworks to visualize main category issues and their root causes.

According to the results obtained from the time motion study, nurses spend on average 21% of their time in Patient Monitoring, 24% in Collaboration, 7% in Medication, 27% in Documentation, 10% in Transit, and 11% in Miscellaneous activities. These results are similar to those that have been reported in the literature [8]. Based on the surveys conducted and the network graphs developed, it was found that HIT systems play an essential role in almost every task that nurses conduct on a daily basis. From the analysis, areas of improvement were identified and solutions were proposed to the key PICU stakeholders. Future work will include a categorization of those solutions according to their ease of implementation and potential impact on workflow efficiency. A decision matrix and solution priorities will be proposed based on the same measures. These results will help decision makers better allocate resources and efforts to improve clinical efficiency and nursing satisfaction.

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