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Exploring the workload balance effects of including continuity-based factors in nurse-patient assignments

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Abstract. *Workload balance in nurse-patient assignments is important for ensuring quality in patient care. Unbalanced workloads can lead to high levels of nursing stress, medical errors, lower-quality outcomes, and higher costs. Studies have proposed assignment strategies based on patient acuity, location, and characteristics of specialized units. These methods do not address the part of workload associated with continuity in care coordination, and the potential benefits associated with continuity-based assignments. We present the results of a pilot simulation study comparing an acuity-oriented method to a continuity-based approach, using acuity as a measure of workload. Our results suggest that a purely continuity-based approach can result in skewed workloads when measured by patient acuity. In future work, we plan to consider hybrid methods, which may be able to provide the benefits of both continuity and acuity based methods.*

Keywords: nurse-patient assignment, balanced workload, acuity-based assignment, continuity-based assignment

1 Introduction

Nurse-patient assignment is an important routine task for patient care delivery and hospital operation. These assignments determine how the patient care workload is distributed among the available nurses to provide care in a work shift [5]. Unbalanced nurse-patient assignments may occur. In such scenarios, patients requiring more difficult and time-consuming care may be assigned to one nurse in a shift, compared to the workloads assigned to other nurses in the shift. These imbalances can lead to increased nursing working pressures, missed care, or medical errors, which can result in lower-quality health outcomes for patients and increased health care costs [2]. Balanced-workload nurse-patient assignments can help to avoid these negative outcomes.

Many hospital units use manual methods to assign nurses to patients. These strategies can vary based on a unit's working norms [1]. For example, a unit might allow nurses select their own patients, or make assignments via a round-robin method, or a charge nurse might set up assignments based on the walking distance between patient rooms, or from a patient room to the nursing station or storage locations [11]. Interesting interdisciplinary work has emerged from collaborations between nursing and engineering researchers, where scholars have proposed mathematical solutions to solve the nurse-patient assignment problem. These approaches consider patient acuity as a metric, and assign nurses to patients using optimization and heuristic methods [5] [9].

Clearly, there is value in balancing workloads using measures such as acuity and walking distance. However, continuity in patient care is also important. Information sharing for care coordination is critical for care delivery [10], but the time and effort related to this are not represented in measures of acuity [12] [13]. For example, grouping a set of patients as a care group, and transferring the group as a set to another nurse at shift change time can reduce communication barriers. Similarly, assigning nurses to patients that they have cared for in previous shifts can result in a reduced learning curve in meeting a patient's needs. Such continuity-based approaches methods can reduce transmission costs in care coordination [14].

While acuity-only approaches can miss opportunities afforded by methods that promote continuity, we suspect that a pure-continuity assignment approach would come with a high cost in terms of acuity balance. In this research-in-progress, we seek to demonstrate this cost with a simulation experiment, showing the potential extent of workload imbalance using a pure-continuity approach for nurse-patient assignment. In next steps in this research effort, we plan to explore hybrid methods that can deliver a combination of the workload-balancing benefits of acuity-only methods, as well as the information transmission benefits of continuity-based approaches.

2 Related work

Work in nurse-patient assignments has considered both general-setting inpatient care as well as specialty settings. For general inpatient settings, patient acuity and walking distance are two major factors considered in the literature. Acuity-based decision-making approaches consider factors such length of stay, diagnosis, and nurse specialty [9], while distance-based approaches consider measured distances between important locations or recorded time spent walking [11]. Other research considers acuity in specialty settings. In a neonatal intensive care unit, a nurse can be assigned to only a small number of babies, and cannot be assigned to patients in more than one zone [6] [7]. Research has also applied optimization for scheduling nursing assignments in an outpatient chemotherapy setting, aimed at more balanced workloads across the available nursing resources and scheduling windows [5]. These strategies are designed to work within the constraints and norms of specialty settings, and cannot be applied in general inpatient settings.

While there are studies that report on the benefits of reducing transmission costs [14], to our knowledge, there are few systematic studies that consider the impact of continuity-based assignment on workload balance. Our work aims to begin to address this gap in the literature, with the goal of developing hybrid approaches that can take advantage of the benefits of both acuity-based and continuity-based approaches.

3 Overview

Studies have demonstrated the value of acuity as a metric for generating balance in workload assignments. However, not all of a nurse's time is spent on acuity-driven activities. One example of this is care coordination. Studies have demonstrated that current Electronic Health Record (EHR) implementations do not provide sufficient support for care coordination [12], even though such information transfers are critically important, especially for managing fragile patients, or those with chronic conditions [8]. Absent automated support for information transfers, nurses must initiate in-person communication for knowledge transfers. This generates logistical challenges, for example, in finding the person to or from whom a nurse must transfer information. Studies suggest that continuity-based assignments could help overcome care coordination challenges [10] [14].

Acuity-based and continuity-based assignment methods differ significantly in their bases for decision-making. Acuity metrics are typically based on a quantification of the count and difficulty of the interventions that a patient requires. In contrast, continuity-based assignment methods seek to improve communication and information transfer by removing logistical challenges or reducing required learning curve at knowledge-transfer time [11]. These methods do not consider acuity in assignment.

While there is value in the goals of continuity-based assignment, a purely continuity-based approach would likely result insignificant workload imbalances, when the workload is measured by acuity balance across assignments. We seek to demonstrate these effects in this research-in-process paper. We plan to develop hybrid approaches that incorporate both acuity and continuity as our work continues.

4 Method and Pilot Study

We seek to compare the variation of workload balance for acuity-based and continuity-based approaches using variation from average acuity for a shift as a metric of imbalance. In a simulation study, we compare four assignment approaches: an acuity-based approach, a continuity-based approach, and assignment methods using random and round-robin approaches. We first define a simple metric for acuity based on nursing workload. We then describe the assignment methods for comparison. Since random allocation and round-robin are generally well-understood, to save space, we describe only the acuity-based and continuity-based approaches, and provide a running example to show how each method assigns nurses to patients. We then present a brief pilot study showing the workload balance impacts of each of these methods.

4.1 Nursing Workload and Patient Acuity

Acuity-based workload assignments typically characterize nursing workload in terms of patient care requirements for workload balancing purposes [5][7][9], i.e., patients with more acute conditions will, on average, require more work in terms of patient care. A nursing shift consists of a number of different care activities, each representing a different portion of a nurse's workload. A study of 767 nurses in 36 hospitals identified five categories of care activities and the associated portion of an average nursing shift accounted for by each category: documentation (35.3%), care coordination (20.6%), patient care activities (19.3%), medication administration (17.2%), and patient assessment (7.2%) [3].

We model patient acuity as a function of these percentage allocations for direct patient care. Our model assumes that the time required for direct care would be similarly allocated, in relative terms, to the average time allocations over the course of a shift. Of the five categories, only three account for variation in acuity across a set of patients: patient care activities, medication administration, and patient assessment activities. Documentation varies roughly directly with overall care activities. Intuitively, this makes sense: each care activity must be documented, so the more care a patient requires, the more documentation that patient will require. Care coordination involves the logistics of communication among healthcare providers at care transfer points, where the specifics of a patient's needs must be clearly conveyed from one caregiver to another [10]. This generally does not vary with acuity; rather, it varies more with the number and scope of obstacles and logistical challenges associated with arranging face-to-face communication in a busy inpatient setting. The time associated with care coordination is therefore associated with continuity, which is the focus of our study.

We model acuity as a weighted function t, shown in Expression (1), of expected effort across three aspects of nursing workload for a patient: medication (denoted d), care assessment (denoted r) and care activities (denoted a). The weights for d, r, and a are based on the percentages of expected effort [3] normalized to sum to 1.0, i.e., overall acuity for a patient will fall in the range [0,1]. The input values for d, r, and a can come from a variety of possible sources, including manual estimation and acuity assessments provided by an EHR. In this work, we assume a simple estimation of patient acuity for each of the three dimensions on a 1-5 Likert scale (where 1 refers to low acuity for a dimension, and 5 refers to high acuity) at the beginning of each shift. Division by 5 ensures that patient overall acuity scores fall in the range [0,1].

$$\mathrm{t} = (0.39\mathrm{d} + 0.44\mathrm{r} + 0.17\mathrm{a})/5 \quad (1)$$

4.2 Method

As a part of the larger research project, we generated a set of simulated shift sequences. While this work is not yet complete, we used a portion of one of our shift sequences in our study here. The overall data set contains 1,700 simulated patients, where each patient stays for between four and twelve shifts distributed normally around a mean of 7. A patient's acuity score varies on a per-dimension and per-shift basis; acuity for a dimension (d, r, and a) for a patient-shift is drawn from a normal distribution over the integers in the range [1,5] with a mean of 3, and the overall acuity for a patient in a shift is calculated based on Expression (1). The shift schedule has two 12-hour shifts per day. Nurses are assigned to either the day or night shift, and typically work four days a week.

We describe the acuity-based and continuity-based methods that form the focus of our research here, and illustrate each approach using a sample shift from our simulated shift sequences. We model a nursing shift as follows. A set of nurses is scheduled to work in shift c. Each nurse h_j is assigned to a working package w, where a working package consists of a set of patients. Each patient p_i is represented in shift c with a tuple (p_i, e, t_{p_i},) that represents the patient's status in shift c, where p_i is the patient ID, e represents the count of shifts the patient has been in the unit as of shift c (e.g., a new admission would have a value of e=1), and t_{p_i}holds the patient's acuity in shift c. We summarize our notation in Table 1.

Table 1. Notation

Parameter	Description
t_{p_i}	acuity for p_i
p_i	patient with ID i
e	patient shift in stay
d	medication time
r	care activity time
a	assessment time
c	current working shift
h_j	nurse with ID j
w	working package

The continuity-based approach requires references to the set of working packages in the previous working shift, so we selected a sample shift c from mid-shift-sequence. In shift c, we have 4 nurses and 23 patients; the nurse patient ratio is 1:5.8, which is representative of real-world nurse-patient ratios [4]. The four nurses in shift c are h_1, h_3, h_4, and h_5. The patients in shift c are (p_{108}, 3, 0.844), (p_{110}, 2, 0.766), (p_{15}, 3, 0.746), (p_{48}, 3, 0.742), (p_{14}, 5, 0.732), (p_{25}, 2, 0.722), (p_{53}, 3, 0.698), (p_{26}, 3, 0.688), (p_{38}, 3, 0.68), (p_{115}, 2, 0.678), (p_{63}, 3, 0.62), (p_{59}, 3, 0.60), (p_{89}, 3, 0.59), (p_{74}, 3, 0.58), (p_{36}, 3, 0.532), (p_{75}, 3, 0.512), (p_{65}, 3, 0.492), (p_{51}, 2, 0.458), (p_{34}, 3, 0.444), (p_{90}, 1, 0.442), (p_{77}, 3, 0.39), (p_{96}, 1, 0.312), and (p_{91}, 3, 0.278).

4.3 Acuity-based assignment

The acuity-based approach attempts to balance workload across nurses in a shift by minimizing the deviation from average acuity in nursing workload. We allocate one w per available nurse. We sort patients by descending acuity t_{p_i}, and assign the top acuity patients will be assigned to a working package w. We calculate the total acuity for each w. We sort the working packages by ascending acuity, and the remaining unassigned patients by descending acuity. We assign the highest-acuity patient to the lowest-acuity working package in the round, and continue the sort-assign process until all patients have been assigned to working packages. Once all patients have been assigned to working packages, we assign each working package to a nurse.

We illustrate the acuity-based assignment approach using the sample shift as an example. Since these assignments are based on the patient acuities, we omit e the patient information tuple. There are 23 patients and four nurses, so there will be 6 sort-assign rounds. In the round 1, we used the arrangement as below: w_1:[(p_{108}, 0.844)], w_2:[(p_{110}, 0.766)], w_3:[(p_{15}, 0.746)], w_4:[(p_{48}, 0.742)]. In round 2, the arrangements were: w_4:[(p_{48}, 0.742), (p_{14}, 0.732)], w_3:[(p_{15}, 0.746), (p_{25}, 0.722)], w_2:[(p_{110}, 0.766), (p_{53}, 0.698)], and w_1:[(p_{108}, 0.844), (p_{26}, 0.688)]. In round 3, the acuity totals are 1.464, 1.468, 1.474, and 1.532 for working package w_2, w_3, w_4, and w_1, respectively, before assignment. Round 3 assignments were: w_2:[(p_{110}, 0.766), (p_{53}, 0.698), (p_{38}, 0.68)]; w_3:[(p_{15}, 0.746), (p_{25}, 0.722), (p_{115}, 0.678)]; w_4:[(p_{48}, 0.742), (p_{14}, 0.732), (p_{63}, 0.62)]; and w_1:[(p_{108}, 0.844), (p_{26}, 0.688), (p_{59}, 0.60)].

In the final round, the total acuities of each working packages are 3.15, 3.43, 3.45, and 3.52 for w_1, w_2, w_3, and w_4, respectively, and the final assignments are: w_1:[(p_{108}, 0.844), (p_{26}, 0.688), (p_{59}, 0.60), (p_{74}, 0.58), (p_{90}, 0.442)], w_2:[(p_{110}, 0.766), (p_{53}, 0.698), (p_{38}, 0.68), (p_{36}, 0.532), (p_{51}, 0.458), (p_{96}, 0.312)], w_3:[(p_{15}, 0.746), (p_{25}, 0.722), (p_{115}, 0.678), (p_{75}, 0.512), (p_{65}, 0.492), (p_{91}, 0.278)], and w_4:[(p_{48}, 0.742), (p_{14}, 0.732), (p_{63}, 0.62), (p_{89}, 0.59), (p_{34}, 0.444), (p_{77}, 0.39)]. We assigned w_3 to h_1, w_2 to h_3, w_1 to h_4, and w_4 to h_5.

4.4 Continuity-based assignment

In the continuity-based assignment approach, we attempt to reduce the time and effort associated with care coordination and improve continuity of care by transferring working packages intact from one shift to the next. If the set of patients and the number of nurses do not change between shifts, then the assignment strategy is a simple matter of assigning a nurse to each working package. However, we need to account for scenarios where the number of nurses changes from shift to shift, as well as patient admissions and releases. Thus, we introduce the concept of average nurse-patient ratio (denotes as *n-p* ratio) to balance patients across working packages in a shift. Intuitively, the *n-p* ratio describes the desired number of patients per working package when the patient count across working packages is balanced. In all scenarios described below, the patient allocation to a working package or selection for transfer to a different working package is based on a random selection; i.e., the continuity-based method does not consider acuity in decision-making.

If the nurse count in c is the same as the nurse count in shift c-1, but the number of patients in any working package w is bigger than the average *n-p* ratio, we will assign patients to other working packages that do not reach the average *n-p* ratio. If the nurse count in c is greater than the nurse count in c-1, we create new working packages for each additional nurse. Based on the *n-p* ratio in the current shift, we transfer patients from the previous shift's working packages (which exceed the *n-p* ratio) to the new working packages. If the nurse count in c is less than the nurse count in c-1, we need to assign patients to a smaller number of working packages, so we designate one or more working packages for disassembly. Patients in these working packages are transferred to existing working packages based on the *n-p* ratio. In all cases, newly-admitted patients are assigned to working packages based on the *n-p* ratio.

We illustrate the continuity-based approach using the sample shift and the data for the prior shift (c-1) in our simulated shift sequence. This method does not consider acuity in decision-making; therefore, the patient acuity t_{p_i} is not shown in the patient information. In shift c-1, there were five working packages: w_1:[(p_{74}, 2), (p_{75}, 2), (p_{65}, 2), (p_{91}, 2)], w_2:[(p_{15}, 2), (p_{14}, 4), (p_{25}, 1), (p_{63}, 2), (p_{59}, 2)], w_3:[(p_{48}, 2), (p_{53}, 2), (p_{36}, 2), (p_{51}, 1)], w_4:[(p_{110}, 1), (p_{38}, 2), (p_{89}, 2), (p_{34}, 2)], and w_5:[(p_{108}, 2), (p_{26}, 2), (p_{115}, 1), (p_{77}, 2)]. The input for working packages in c is the same working package with incremented patient shift numbers: w_1:[(p_{74}, 3), (p_{75}, 3), (p_{65}, 3), (p_{91}, 3)], w_2:[(p_{15}, 3), (p_{14}, 5), (p_{25}, 2), (p_{63}, 3), (p_{59}, 3)], w_3:[(p_{48}, 3), (p_{53}, 3), (p_{36}, 3), (p_{51}, 2)], w_4:[(p_{110}, 2), (p_{38}, 3), (p_{89}, 3), (p_{34}, 3)], and w_5:[(p_{108}, 3), (p_{26}, 3), (p_{115}, 2), (p_{77}, 3)]. In addition, there are two new admissions in c: (p_{90}, 1) and (p_{96}, 1). The *n-p* ratio in this shift is 1:5.8.

There were five nurses in c-1, but only four in c; therefore, we delete one working package w_1:[(p_{74}, 3), (p_{75}, 3), (p_{65}, 3), (p_{91}, 3)] in c. These patients, as well as the newly admitted patients, are transferred to the intact working packages from c-1 based on n-p ratio. After all transfers and assignments, the working package assignments for c are as follows: w_2:[(p_{15}, 3), (p_{14}, 5), (p_{25}, 2), (p_{63}, 3), (p_{59}, 3), (p_{91}, 3)], w_3:[(p_{48}, 3), (p_{53}, 3), (p_{36}, 3), (p_{51}, 2), (p_{90}, 1), (p_{96}, 1)], w_4:[(p_{110}, 2), (p_{38}, 3), (p_{89}, 3), (p_{34}, 3), (p_{65}, 3), (p_{75}, 3)], and w_5:[(p_{108}, 3), (p_{26}, 3), (p_{115}, 2), (p_{74}, 3), (p_{77}, 3)]. The total acuities of each working packages are: w_2: 3.698, w_3: 3.184, w_4: 3.484, and w_5: 3.18. We assigned w_2 to h_1, w_3 to h_3, w_4 to h_4, and w_5 to h_5.

The final patients' acuities for random assignments are: h_1: 2.594, h_3: 3.796, h_4: 3.552, and h_5: 3.604. And the final patients' acuities for round robin algorithm are: h_1: 3.56, h_3: 3.764, h_4: 3.47, and h_5: 2.752.

The average patients' sum of acuity per nurse is 3.387. We used the standard deviation (denoted as SD) of workload acuity as a metric to the variation of workload acuity across different assignment methods, where SD shows how far each method deviates from the average workload acuity in the shift. In our example shift, SD for the acuity-based method is 0.138, the SD for the random method is 0.466, the SD for the round robin method is 0.382, and the SD for the continuity-based method is 0.218.

5 Pilot study and discussion

A single shift experimental test is not sufficient to explore the differences among the four approaches, so we performed a pilot study using a 26-shift sequence from one of our simulated shift sequences, and ran each method for each approach. Table 2 shows the average SD across the sequence of shifts for each method studied.

Table 2. Pilot Test Results

	Acuity	Random	Round robin	Same Working Package
Std. Deviation	0.125	0.379	0.308	0.323

As we suspected, we found that the acuity-based method provided the best overall balance of workload acuity, the continuity-based approach delivered workload acuity imbalances in the same range as that provided by Random and Round Robin methods. In future work, we intend to explore the potential for hybrid methods incorporating both continuity and acuity in nursing assignments, with the goal of capturing a balance of the benefits of each assignment technique.

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