Modeling of ICU Nursing Workload to Inform Better Staffing Decisions

by
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B.S. Electrical and Computer Engineering, Cornell University, 2008

Submitted to the MIT Sloan School of Management and the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration and
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In conjunction with the Leaders for Global Operations Program at the
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Abstract

Beth Israel Deaconess Medical Center (BIDMC) has partnered with the Gordon and Betty Moore Foundation's to eliminate preventable harm in the Intensive Care Unit (ICU). Many medical publications suggest nursing workload as a major contributor to patient safety. However, BIDMC was not using any tool to measure nursing workload, and as a result, nurse staffing decisions were made solely based on the ad hoc judgment of senior nurses. The objective of this thesis is to create a prospective nursing workload measurement and ultimately use it to improve staffing decisions in ICUs.

To create a nursing workload measurement, a wildly-adopted patient-based scoring system, the Therapeutic Intervention Score System (TISS), was modified to BIDMC's ICUs. With consultation from clinicians and nurses, changes were made to the TISS to reflect BIDMC's workflow, and a new nursing workload scoring system called the Nursing Intensity Score (NIS) was created. The NIS for each patient per shift was calculated over a two-year period to gain further insights to improve staffing decisions.

After looking at the current state, there was no correlation between nursing staffing and overall patient workload in the unit. In addition, nurses with 1 patient (1:1 nurses) had significantly less workload than nurses with two patients (1:2 nurses) even though they were expected to be the same. Finally, there was one overworked nurse (150% of median nursing workload) in every three shifts in the ICU.

A prospective approach to analyze patient workload was developed by dividing patients based on clinical conditions and categorizing the results on two axis: the nominal workload level and the variability around the nominal value of workload. This analysis suggests that, a majority of patients are predictable, including a few patients with high but predictable load. On the other hand, some patients are highly unpredictable. A nursing backup system was proposed to balance workload between 1:1 and 1:2 nurses. To test the proposal, a simulation was developed to model the ICU with the goal of minimizing the number of overworked nurses. The best backup system was a buddy pairing system based on predictive model of patient conditions, with the resource nurse as the ultimate backup.

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I would like to thank members on my BIDMC research team, Adam Traina and Agnes Hu, for onboarding me in the beginning, contributing insightful solutions in the middle, and supporting my recommendations in the end.

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1 Introduction

With the enacting of the Affordable Care Act, hospitals throughout United States have been focusing on delivering better outcomes without increasing in cost. The Beth Israel Deaconess Medical Center (BIDMC) has been a leader in healthcare quality, and ever since establishing the Silverman Institute for Health Care Quality and Safety in 2007, its leadership position has been strengthened [1]. Patients facing life-threatening illness or injury are admitted to the Intensive Care Unit (ICU). With funding from Gordon and Betty Moore Foundation, a multi-year, multidisciplinary project was established to focus on improving patient safety in ICUs throughout the hospital [2]. A team of two MIT Leaders for Global Operations (LGO) students and an MIT operations research graduate student was brought in to work on the development of systematic safety approaches. This thesis will be dedicated to measuring nursing workload and improving staffing decisions in the ICU at BIDMC. The motivation for this effort is the understanding that nursing overload is likely to be a major driver of risk and avoidable harms in the ICU.

1.1 Project Background

BIDMC was funded by with the Gordon and Betty Moore Foundation work on the development of systematic risk management to eliminate preventable harm in the ICU [2]. As part of the partnership, the Risky States project is a collaboration with MIT to develop predictive models and identify environmental states (drivers) that elevate the risk in the ICUs. The Risky States model uses classification and clustering methods to identify those drivers. The single most important driver contributing to the riskiness of the ICUs is nursing workload [3] [4].

As one of the leading hospitals in the Boston area, BIDMC has 7 adult ICUs with 77 patient beds in all areas of specialties, including medical, surgical, neuroscience, coronary, cardiovascular, and trauma [5]. This thesis is focused on Medical ICU 6 (MICU 6) for in-depth study and pilot. The insights and methodologies emerged from this work are applicable to other ICUs as well.

Because BIDMC is a teaching hospital, the clinical care team consists of an ICU intensivist leading a team of interns, residents, and fellows [6]. There are over 30 nurses working regularly in the MICU 6 where 5 nurses are staffed per shift. Nurses work 12-hour shifts starting from 7AM to 7PM for 3 days a week. Nursing schedule is usually determined several weeks in advance, but because of constant changes in the ICU, nurse staffing is finalized at the bed meeting 3 hours before the start of each shift. In bed meetings, senior nurse managers discuss relevant patient information, such as patient count, patient acuity, and expected patient movements (admissions and discharges), and nurse staffing information to get an accurate assessment of nursing needs throughout the hospital. This ultimately leads to refinements on how many nurses are allocated to each ICU unit, and how nurses are assigned to patients within a given unit. However, BIDMC currently lacks a formalized tool to assess patient load, so often times, staffing decisions are based on ad hoc experience and intuition of senior nurses. Once the nursing team for the shift is set, the charged nurse, also known as resource nurse, will assign nurses to take care of 1 severely ill patients (1:1 nurses) or 2 moderately ill patients (1:2 nurses) with the expectation that both types of nurses will experience similar workload.

This project is motivated by several issues: (i) Evidence in literature that nursing workload, particularly overload, affect patient safety; (ii) Mandatory state requirement for hospital to develop patient load tool that guides staffing decisions; and (iii) Recent work within the project highlighted the major role of nursing workload in driving safety incidents and patient harms [3] [4].

First, there is ample evidence in the clinical literature that high nursing workload negatively impacts patient safety in the ICU [7] [8]. In addition, high nursing workload has been shown to increase patient's length of stay in the ICU, and adversely impacts the ability of nurses to monitor and treat patients [9] [10]. Finally, high nursing workload typically lower nursing jobs satisfaction and contribute to job burnout [11]. Finding a method to reduce nursing workload is likely to improve patient safety in ICUs and improve nursing job satisfaction.

Second, the state of Massachusetts recently passed a law requiring patient to nurse staffing assignments to be based on an established patient acuity tool [12]. However, currently BIDMC does not have a formalized tool to assess patient acuity. There was a need to develop an acuity tool to satisfy the legal requirement and this project aimed to contribute to such effort.

Third, based on the Risky States model developed in [3], the most significant drivers contributing to increased rate of harms in the ICUs is nursing workload. High nursing workload seems to cause elevated risk for harms across all ICUs. Developing a better mechanism to measure and cope with high nursing workload would lower the risk for harms throughout the entire system.

1.2 Problem Overview

The goal of this project was to create a prospective approach to model nursing workload based on available data that can inform better and more adaptive staffing decisions. This project focused on measuring and modeling nursing workload (how much work a nurse is doing) and not patient acuity (how ill the patient is). While the two are sometimes used interchangeably in the hospital settings, and are clearly partially correlated, they are also different concepts.

The first phase of the project (see Section 3) is focused on researching and understanding existing nursing workload scoring methods reported in the published literature. We found two fundamental types of approaches to measuring nursing workload: (i) Patient-based checklists that tally the interventions done for each patient with their respective weights; and (ii) Operator-based questionnaires that determine subjective measures for nursing workload based on retrospective assessment of the nurses. Commonly used patient-based metrics include Therapeutic Intervention Scoring System (TISS) [13], Nine Equivalents of Nursing Manpower Score (NEMS) [14], and Nursing Activities Score (NAS) [15]. Patient-based checklists provide a single retrospective workload score, for each patient, which is very useful when comparing patient workload. However, there are many significant limitations to the current approaches: (i) The current metrics are outdated and not customized to the BIDMC ICU workflows; (ii) The current metrics are useful only for retrospective analysis; (iii) The current metrics sparsely measure only average load for an average patient; (iv) Disruptions in nursing workflow are currently not captured; and (v) Current metrics do not take nurse staffing decisions into account, when determining nursing workload (they measure the load a patient generates, but not he resulting load on the nurses). Because of all of these limitations, patient-based metrics merely measure the work needed to take care of patients, and not nursing workload. The work from patients (patient workload) do not directly translate to nursing workload. Nursing workload is dividing patient workload among different nurses depending on the staffing decisions in the ICU. In this thesis, patient-based metrics, such as the TISS, will be known as patient workload metrics instead of nursing workload metrics.

The second phase (see Section 4.1) is focused on the development of an internal model to measure patient workload called the Nursing Intensity Scores (NIS). With consultation of senior nurses, we decided to use the TISS as the basis, and made significant modifications to reflect current medical practices and customizations for BIDMC specific nursing ICU workflow. The NIS is still a retrospective scoring system based on a checklist of patient interventions with a specific score for each interventions. After the NIS was developed, we wrote a computer software in Python to calculate NIS for all patients in the ICU for a two-year period (2012-2013).

The third phase (see Section 4.3) was to use NIS scores to study patient workload based on different patient clinical conditions. The goal was to develop a prospective method for analyzing patient workload using retrospective data. We decided to focus to a single ICU, MICU 6, for further observation and study. The most common patient conditions in MICU 6 in descending order of frequency are: (i) Chronic Obstructive Pulmonary Disease (COPD); (ii) Gastrointestinal (GI) bleed; (iii) Sepsis; (iv) Acute Respiratory Distress Syndrome (ARDS); and (v) Hyperglycemia. Previous research focused on understanding average workload of different patient conditions. In contrast, our approach captures variability in workload because variable load is what the nurses have to deal with constantly and it plays a disproportionally significant role in affecting patient safety in the ICU. Therefore, in addition to measuring average workload, we focused on capturing the variability of the workload as well. From the results, we can divide patient conditions into four categories based on average workload and variability:

- Low load, low variability: COPD, and None
- Low load, high variability: Hyperglycemia
- High load, low variability: ARDS
- High load, high variability: Sepsis, GI bleed

In addition, we used the level variability of the workload as a proxy for the predictability of workload by assuming that we could make a reasonable prediction for patient workload if variability is low and vice versa. Overall, the majority of patients had predictable workload, including a few patients who had high but predictable workload. At the same time, some patients had highly unpredictable workload.

The fourth phase of the project (see Section 5.1) was to understand the current state of nursing workload in the ICU environment by observing it firsthand and leveraging the scoring model that was developed. We shadowed all ICUs in BIDMC to get familiar with nursing workload. From our shadowing experience, we observed differences in patient types, nursing workflow, and staffing patterns between different ICUs in the hospital. To better understand nursing workload in MICU 6, we conducted a preliminary time and motion study. We identified three areas for further analysis: (i) Patient workload varied significantly for different patients; (ii) Nurses assigned two patients were much busier than nurses assigned one patient; (iii) There was inconsistent help given from nurses with less workload to nurses with heavy workload; and (iv) Nurses were constantly interrupted by disruptions in the ICU.

The fifth phase (see Section 5.3) was to assess the current relationship between staffing decisions in MICU 6, and the observed workload of nurses. We first studied the correlation between the number of nurses staffed and the total patient workload in MICU 6. This revealed that there was no correlation between the two (R^2=0.07, $p<0.0001$). Next, we studied the difference of workload between 1:1 and 1:2 nurses. We discovered that 1:2 nurses had workload that is almost 50% higher than 1:1 nurses (averaged NIS of 27.89 for 1:1 nurses versus 39.87 for 1:2 nurses). This stands in contrast to the expectations of the hospital that the overall load is balanced across nurses. Next, we studied the workload difference between resource nurses and regular nurses. We found that resource nurses had less direct nursing workload than regular nurses (averaged NIS of 30.12 for resource nurses versus 35.45 for regular nurses), which was expected, because resource nurses have other non-patient care related responsibilities. Therefore, we removed resource nurses from our comparison of workload between 1:1 nurses and 1:2 nurses. However, the gap between the two groups still persisted (averaged NIS of 27.99 for 1:1 nurses versus 39.74 for 1:2 nurses).

The last phase (see Section 6.4) of the project focused on the development of a potential solution approach to better match patient workload with nurse staffing. There are two approaches to improve the alignment between patient workload with nursing staffing: (i) Strategic approach to by changing the number of nurses in the ICU; and (ii) Operational approach by adjusting nursing assignments in real-time. After considering the government regulations, organizational challenges, and cultural differences, we recommended to focus on the operational approach to better balancing the nursing workload within the unit. To propose a plan and methodology, we leveraged ideas from operations management related to process flexibility. In particular, we developed a formalized nursing backup system, where the primary nurse would offload work to the backup nurse if he or she was overwhelmed.

In order to test the effectiveness of backup nurses on ICU operations, we modeled the MICU 6 environment and simulated different nursing backup systems. Our working definition was that *overworked* nurses experience at least 150% of the mean nursing workload over a two-year period in MICU 6. Using the above definition, we found that, on average, there was one overworked nurse every three shifts. Even under ideal and unrealistic assumption that workload could be divided evenly among all the nurses in the ICU, there were still 29 overworked nurses over the two-year period (2% of shifts).

Next step was to use the simulation to find a practical nursing backup plan that minimizes the number of overworked nurses and reduced the variability of workload within the ICU. The simulation used retrospective data to set up the ICU environment and transfer workload from the primary nurse to the backup nurse based on different scenarios of backup assignment plans. We simulated three different types of nursing backup assignment plans: (i) Buddy pairing; (ii) Buddy pairing with a resource nurse as the centralized backup; and (iii) Long chaining. Overall, long chaining performed the best (this approach reduced the number of overworked nurses by almost 80% when compared to no nursing backup plan), but due to complexity, we recommend buddy pairing with resource nurse support because it obtains good performance (reduces the number of overworked nurses by over 70% when compared to no nursing backup plan), and is far more practical to implement.

The next step of simulation was to determine the best method to pair nurses to serve as backup for each other. We simulated four different ways to pair nurses: (i) Random; (ii) Nurse to patient (N:P) ratio; (iii) Patient condition; and (iv) Combination of N:P ratio with patient condition. Overall, random pairing performed only slightly worse than optimized models, the combination of N:P ratio with patient condition (we called this the "predictive assignment") performed the best. Overall, the combination of buddy pairing with a resource nurse as the ultimate backup and predictive assignment of backup nurses yielded the best result with the most practical design. Specifically, it reduced the number of overworked nurses by 76% when compared to no nursing backup plan.

In this project, we established foundation work to obtain a prospective approach to analyze patient workload, and a simulation approach to model potential process improvements statistically within the ICU. The methods and tools developed in this project could hopefully be operationalized.

Based on the results of our project, we made the following recommendations as next steps for the project: (i) Develop a production implementation of the NIS system to measure nursing workload in ICUs; (ii) Pilot a nursing backup system in MICU 6; (iii) Improve IT integration for more accurate data to provide better inputs to the models; and (iv) Establish a process for evaluating process improvements in the ICUs. From the latest discussion with hospital administrators, there was a strong interest in developing a production implementation of NIS system and piloting a nursing backup system in MICU 6. We believe that if the NIS and nursing backup system prove to be successful, there will be a stronger impetus to adopt the other two recommendations. The logical next steps are to verify the NIS checklist, expand the study to other ICUs, and develop a mechanism to measure instantaneous nursing workload.

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2 Background

2.1 Beth Israel Deaconess Medical Center

BIDMC is one of the top research hospitals in the country [16], and a major teaching hospital of Harvard Medical School. The mission of BIDMC is to provide extraordinary care, where the patient comes first, supported by world class education and research [17]. BIDMC is one of the largest hospitals in the Boston region, with over 600 licensed beds, 50,000 annual inpatient discharges, 540,000 outpatient visits, and about 1 million patient encounters per year. BIDMC is also one of only five adult Level I trauma centers in Boston [18]. BIDMC has a world-class health information technology department, and was named the No. 1 technology innovator in the United States in this year's *InformationWeek* 500 [16].

BIDMC was formed by the merger of Beth Israel and Deaconess Hospital in 1996. However, two separate physical spaces still remain - the original Beth Israel campus, now called the East Campus, and the original Deaconess campus, now called the West Campus [19].

One of the missions of BIDMC is to promote excellence in patient care through sponsorship of innovation, education, and research in quality and safety. In 2013, BIDMC was awarded the American Hospital Association's McKesson Quest for Quality Prize. BIDMC has been recognized as a national leader for its efforts to improve quality and safety of care for all of its patients. In addition, The Leapfrog Group has recognized BIDMC as one of the nation's top hospitals for meeting standards for safe, high quality care [1]. A part of BIDMC's continued push for better healthcare quality is to establish a collaboration with MIT to use improve patient safety in the ICU.

2.1.1 Adult Intensive Care at BIDMC

The intensive care units are among the most complex and costly settings in healthcare delivery systems. They host the sickest patients that needs continuous monitoring and nursing care. At BIDMC, adult intensive care consists of 7 specialized ICUs, with a total of 77 patient beds. Different ICUs specialize in caring for patients with different surgical and medical conditions.

Table 2-1: Types of Intensive Care Units in BIDMC [5]

Name of Unit	Abbreviation	# of Beds
Medical Intensive Care Unit	MICU	16
Coronary Care Unit	CCU	7
Surgical Intensive Care Unit	SICU	7
Neurosciences Intensive Care Unit	Neuro ICU	7
Trauma Surgical Intensive Care Unit	T/SICU	13
Cardiovascular Intensive Care Unit	CVICU	14
Combined Medical/Surgical Intensive Care Unit	Finard ICU	13

The Medical Intensive Care Unit (MICU) provide critical care for patients with complex life-threatening medical conditions. Common diseases diagnosed and managed in the unit include acute respiratory distress syndrome (ARDS), sepsis, and gastrointestinal (GI) hemorrhage. Similar to the MICU, the Coronary Care Unit (CCU) provides critical care to patients with complex medical issues specific to the heart, such as heart attacks, unstable angina, and cardiac dysrhythmia. The Surgical Intensive Care Unit (SICU) provides critical care for patients on surgical services, especially post-surgery. The Neurosciences Intensive Care Unit (Neuro ICU) is similar to the SICU, but it specializes in providing care for post-neurological surgery patients and patients with neurological diseases, such as aneurysms, brain tumors, and stroke. The Trauma Surgical Intensive Care Unit (T/SICU) provides care for post-surgical patients, as well as patients who suffered significant trauma (e.g., vehicle collisions or gun violence). The Cardiovascular Intensive Care Unit (CVICU) specializes in providing critical care for patients with post-cardiac and post-vascular surgeries.

All ICUs in BIDMC are located in West Campus, except for the Finard Medical/Surgical ICU (Finard ICU). As the only ICU in the East Campus, Finard ICU is a comprehensive unit that provides critical care for all types of patients. Transfers from East Campus to ICUs in the West Campus are rare, due to logistical challenges associated with transporting patients by ambulance.

2.1.2 Care Teams at ICUs

Because BIDMC is a teaching hospital, the medical team can be quite large and rotates constantly. Table 2-2 shows the list of staffs in a typical ICU. The ICU care team is headed by an attending and assisted by a combination of interns, residents or fellows depending on the ICU. In addition, all surgical ICUs have surgical attendings for each patient, and some ICUs have nurse practitioners and/or physician assistants to assist with clinical care. Continuous intensive patient care is provided by nurses and patient care technicians. For patients on ventilators, specially trained respiratory therapists are assigned to monitor and assist the patients.

Table 2-2: The ICU Care Team (medical staff) [6]

Title	Job Description
Intensivists (also called Attendings)	Doctors specially trained in the care of seriously ill patients
Surgical Attendings (in all Surgical ICU's)	Surgeons overseeing a patient's needs related to a completed or anticipated surgery
Nurse Practitioners / Physician Assistants	Specially trained personnel with advanced degrees who work closely with the intensivists and attendings on clinical care
Interns, Residents or Fellows	Doctors who have graduated from medical school and who are at different levels of specialty training at the hospital
Nurses	Registered nurses who are assigned to one or two patients at a time and carry out much of the hour-to-hour care
Patient Care Technicians	Personnel who assist nurses and help patients with everyday care like bathing and hygiene
Pharmacists	Specially trained clinicians with expertise in medication management
Respiratory Therapists	ICU personnel who specialize in caring for patients with breathing problems and help monitor and support patients on ventilators

In addition to the medical team, a large team of support staff is responsible for the overall well-being of the patients and the functioning of the ICU. This team consists of social workers, case managers, pastoral care staff, and a unit coordinator [6].

2.1.3 Medical Intensive Care Unit 6

The Medical Intensive Care Unit 6 (MICU 6) was chosen as the pilot ICU for focused in-depth analysis and modeling. MICU 6 is one of two medical ICUs at BIDMC located in the Clinical Center Building with 8 patient beds.

MICU 6 is a closed unit, where the ICU attending have sole control and responsibility over the clinical care of patients within the ICU. This contrasts with the open surgical ICUs, where ICU attendings work with surgical attendings to develop and manage the clinical care for each patient. Alongside the attending at MICU 6, there are three interns and three residents who assist in the clinical care of patients. The clinical team is not only responsible for all 8 patients in MICU 6, but also up to 15 boarders, who are patients in other ICUs that are assigned to the care of MICU 6 team, for a total of 21 patients.

The continuous intensive patient care is delivered by a team of intensive care nurses, a patient care technician, and a respiratory therapist. The team of intensive care nurses is led by the *resource nurse*, who is a senior nurse responsible for the overall patient care in the ICU. In addition to the clinical team and the patient care team, there is a pharmacist and a unit coordinator dedicated to the ICU.

2.2 Nurse Staffing at BIDMC

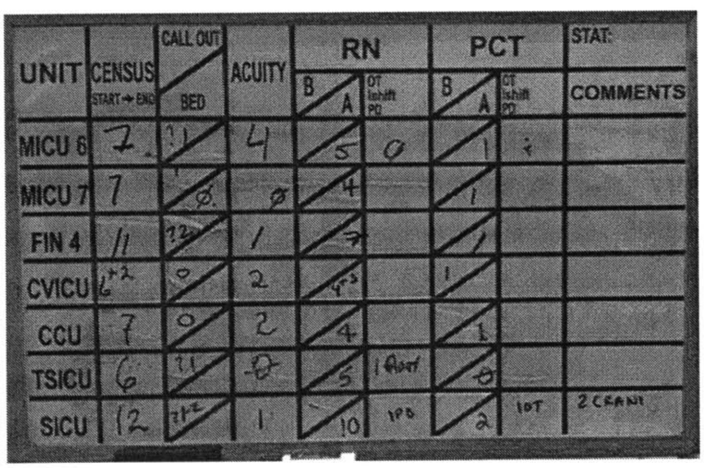
2.2.1 Nurse Staffing Processes in BIDMC ICUs

Nursing staff in BIDMC operates in two, 12-hour shifts, with changeover times daily at 7AM and 7PM. A typical nurse would work three 12-hour shifts in a week, and the nursing schedule is usually determined a month in advance. The scheduling is largely based on the preference of each nurse, but with the constraint that a minimum number of nurses must be on staff for each shift. That minimum number is different across different ICUs (e.g., 5 nurses in MICU 6, 4 nurses in Neuro SICU). However, for a variety of reasons, such as sickness or personal emergencies, not all scheduled nurses are always available on the day of. The ICU departments have a pool of *float nurses* that can be assigned to any particular ICU that is understaffed.

The float nurse assignments to ICUs is determined during daily *bed meetings*. There are two bed meetings each day, one at 3:30 AM to decide on the assignments for the day shift (7AM to 7PM), and one at 3:30 PM to decide on the assignments for the night shift (7PM to 7AM the next day). Bed meetings are attended by charge nurses, nursing managers, and the nursing coordinators. The purpose of the bed meeting is to look at nursing needs, in each ICU, based on expected patient workload, and assign flexible nurses to fill the gaps in staffing. The flexible nurses could come from the float pool, nurses who are on call, or in extreme cases, nurses that work overtime.

As for patient workload, currently BIDMC does not have a formalized metric to measure patient workload. Therefore, patient load is gauged based on the ad hoc experience of the senior nurses in the ICU. Current regulation dictates that a nurse could take care of no more than two patients at a time. Patients are considered acute and require 1:1 care if the patient needs one of specified interventions (e.g., continuous renal replacement therapy, patient cooling after cardiac arrest, etc) or has one of specified conditions (e.g., post open heart surgery, post liver transplants, etc) that require extensive monitoring or nursing care. To determine the staffing level needed, in each ICU, senior nurses would collect patient information, such as current patient count, expected called-out patients, and number of required 1:1 patients, for their own ICU. Due to the legal requirement for maximum number of patients per nurse, the total number of nursing staff could be calculate with the knowledge of 1:1 patients and the total number of patients in the ICU. For example, if the SICU has seven patients, with one patient who needs 1:1 care, this would imply a need of at least four nurses (one nurse assigned to one patient, and three nurses each assigned to two patients). In the bed meeting, senior nurses would discuss the number of patients with expected inflow (admissions) and outflows (called out) and the number of nursing staff on hand. Figure 2-1 shows an example of the board at the bed meeting, when nurse staffing decisions are made. With all the information at hand, the nursing coordinator decides to which units allocate patient admissions, and to which units allocate additional nurses.

Figure 2-1: Staffing Decision Board at Bed Meeting



2.2.2 Nurse Staffing Processes in MICU 6

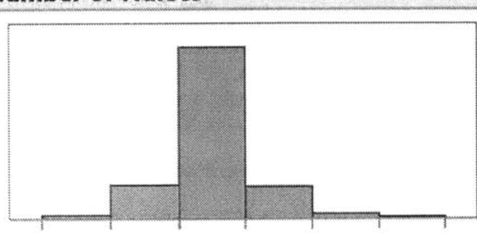
The nursing team in MICU 6 consists of over 30 nurses in total. In an average shift, five nurses are on staff, and one of those nurses, usually the ones with more experience, is designated as the resource nurse for that shift. The resource nurse is responsible for the entire unit and ensures all nurses have adequate means and knowledge to take care of patients. In addition, the resource nurse assigns nurses to patients for the next shift taking into account the acuity of patients, experience of nurses, and most importantly, preference to maintain assignments of nurses who took care of respective patients before. Moreover, the resource nurse helps the other nurses taking care of patients if a particular nurse is overwhelmed. Finally, the resource nurse is typically assigned one patient usually with lower acuity to allow for the additional time needed to help others.

MICU 6 has 8 beds, and Figure 2-2 shows that there are generally five nurses in the unit on every shift (mean: 5.01, standard deviation: 0.59). If MICU 6 is full (8 patients), then five nurses would usually be on shift. This means two 1:1 nurses (resource nurse generally gets a 1:1 assignment, where the patient is less acute), and three 1:2 nurses. This means that the MICU 6 could reasonably accommodate one severely acute patient, who needs 1:1 care, and seven less acute patients who could be handled with 1:2 care ratio. If a patient is discharged, the nurse caring for that patient would typically receive the next admission to MICU 6.

Figure 2-2: Number of Nurses in MICU 6.

Distributions

Number of Nurses



Quantiles		
100.0%	maximum	8
99.5%		7
97.5%		6
90.0%		6
75.0%	quartile	5
50.0%	median	5
25.0%	quartile	5
10.0%		4
2.5%		4
0.5%		4
0.0%	minimum	3

Summary Statistics	
Mean	5.0143639
Std Dev	0.5854138
Std Err Mean	0.0153105
Upper 95% Mea	5.0443968
Lower 95% Mean	4.984331
N	1462

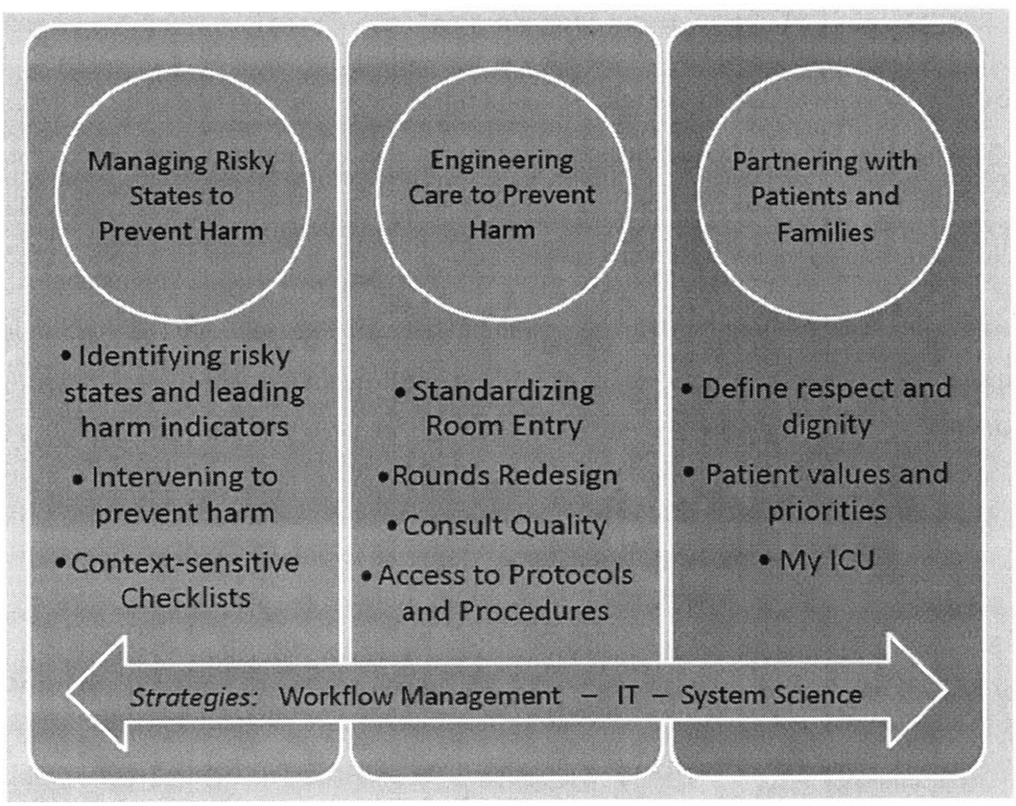
2.3 Moore Foundation Grant to BIDMC

On January 2014, BIDMC received a $5.3 million dollar grant from the Gordon and Betty Moore Foundation with the title: Optimizing ICU Safety through Patient Engagement, System Science and Information Technology. As part of the grant, BIDMC formed a partnership with MIT to develop IT innovations with patient engagement to eliminate preventable harm in the ICU. Preventable harm is any unanticipated event in a healthcare setting, resulting in death, or serious physical or psychological injury to a person or persons, not related to the natural course of the patient's illness. In addition, BIDMC joined a larger, Moore Foundation-led consortium of hospitals focused on improving ICU care, including Johns Hopkins Medicine, the University of California San Francisco, and Brigham & Women's Hospital in Boston [20].

The grant was created with the intent of addressing three interrelated barriers to the elimination of preventable patient harm: (i) Unreliable systems of care, coupled with a lack of sophistication in healthcare as to how to improve those systems, (ii) Failure to adequately engage patients and families in their own care, and (iii) Failure to spread successful innovation into non-academic settings, where the majority of healthcare is delivered in the United States [21].

The grant supports a 30-month project that is organized into three work streams: (i) Managing Risky States to Prevent Harm; (ii) Engineering Care to Prevent Harm; and (iii) Partnering with Patients and Families [21].

Figure 2-3: Characterization of work streams in Moore Grant [21]



2.3.1 Risky States Project

For the Risky States model, MIT is an external collaborator for building a predictive model that identifies environmental conditions (drivers) that elevate the level of risk for potential harms in ICUs. Two MIT research students have used statistical classification and clustering methods to identify those drivers. One of the early insights from this work is the identification of nursing workload as a key contributor to overall risk in the ICU [3] [4]. As a result, understanding and measuring nursing workload and developing formal processes for staffing decisions was added as a key follow up effort to the Risky States project.

2.4 Legal Requirement for Patient Acuity Measures

On June 30, 2014, the state of Massachusetts instituted a new law that limits the number of patients that can be assigned to a nurse in the ICU to no more than two [12]. The law calls for all hospitals, in consultation with staff nurses and other appropriate medical staff, to create an acuity tool to assess the stability of ICU patients. The acuity tool must be certified by the Massachusetts Department of Public Health. Using the acuity tool, ICU patient assignments for registered nurses would be set at one or two patients per nurse depending on the "stability of the patient" as assessed by the acuity tool and by the staff nurses in the unit, including the nurse manager or the nurse manager's designee when needed to resolve a disagreement. Thus, the law expressly provides staff nurses with input into patient assignments in the ICU.

After the new law was instituted, there was an increase sense of urgency for BIDMC to develop and validate an acuity tool to be used in the ICU. One of the candidates for the acuity tool was to use the nursing workload measure developed in this thesis to determine patient assignments.

3 Existing Methods for Measuring Nursing Workload and Its Impact on Safety

3.1 Importance of Nursing Workload

Hospital nurses experience higher workload than ever before, and this is becoming a major concern in the American health care system. Higher nursing workload affects more than just nurses; it could degrade quality of patient care, and ultimately raise the cost of healthcare throughout the entire system [22].

The demand for nurses is increasing because of population aging. Between 2000 and 2020, the United States population is expected to grow by 18 percent (31 million). The over-65 population, with more health care needs, is expected to grow even faster, at 54 percent (19 million) [23]. Unfortunately, the supply of nurses is not adequate to meet the current demand. The shortage is projected to worsen, as future nursing demand increases and nursing schools are not able keep pace with the increase. During nursing shortages, workload increases for those who remain in the job [24]. Compounding the issue is the fact that hospitals, in an attempt to control and cut cost down, have reduced nursing staffing, and implemented mandatory overtime policies. The additional hours have significantly increased nursing workloads for the remaining staffs [25]. Lastly, hospital nurses take care of sicker patients than in the past [26]. Although swelling healthcare costs are forcing healthcare organizations to reduce patient length of stay in hospitals, this has not reduced nursing workload levels, because of the intensive care required by these patients.

There are several important consequences of high nursing workload. Research shows that high nursing workload adversely affects patient safety [7] [8]. Additionally, higher nurse to patient ratio, with the assumption of less workload per nurse, has shown to reduce ICU length of stay and hospital length of stay [9]. Moreover, moderate level of nursing workload allowed nurses to provide better patient monitoring and surveillance because nurses were prepared to detect and treat complications [10]. Finally, nursing workload negatively affects nursing job satisfaction, which contributes to high turnover rate that in turn worsens the nursing shortage [11].

High workload is an even bigger concern in the ICU environment, where complex patient care is needed continuously. ICU nurses reported that high workload is one of the largest job stressors [27]. Effects of high workload on patient care are often associated with lack of time to perform important care tasks, and may lead to complications, poor patient outcomes, and even increased mortality. In addition, lack of time has a negative impact on communication between nurses and physicians, and between nurses and patients. In fact, according to research, poor communication is the root cause of two-thirds of preventable harms in the period between 1995 and 2005 [28]. High workload has longer-term effects as well. Studies show that sustained high workload leads to decreased job satisfaction, motivation, and even burnout [29]. Not only are there implications for patients, but there are implications for the hospital as well in that eventual burnout leads to increases costs related to nurse absenteeism and turnover [28].

3.2 Modeling ICU Nursing Workload in the Literature

Given the impact of high nursing workload in the ICU, there are several approaches found in research literature for measuring nursing workload. Before discussing nursing workload, a general definition of workload must be established. There are many definitions of workload in the existing literature, but all of them has three components: (i) An operator, using his or her resources to respond to (ii) An external physical or cognitive demand to (iii) Perform a certain task [28].

Two different approaches for measuring workload are proposed in the literature on ICU nurse workload: (i) *A patient-based approach* that uses data on nurse-patient ratio and patient acuity; and (ii) *An operator-based approach* that takes the experience of the "operator" into account. (The "operator," in this case, would be the ICU nurse.) These two approaches are not mutually exclusive, but they have different purposes. The first approach is typically used to inform budget decisions related to staffing levels (FTEs), and to measure process improvement results. The second approach is used for research activities, such as determining the amount of subjective nursing effort resulting from each activity [28].

The patient-based approach considers patient characteristics, such as acuity of the patient and time spent caring for the patient as a percentage of the total time. Nursing workload can be measured by tallying the interventions delivered to each patient, and then summing across all patients under the nurse's care. As a result, most of the patient-based measure of workload are checklist-based, with specific points for weight, assigned to each particular intervention to reflect its relative load [13]. This approach is often used as a budgeting tool for determining the staffing levels of ICUs by reviewing the past workload scores relative to nurse staffing. In addition, it is used to drive process improvements efforts to deploy nurses more efficiently and thereby reducing nursing associated costs [28].

The operator-based approach is essentially a human factors approach that considers characteristics of the nurse and interactions between the nurse and the work environment. Operator-based approach is used in research settings to examine causes of high workload and identify strategies to reduce workload and ultimately improve quality of working life for the nurse and quality and safety of care for the patient [28]. One method following the operator-based approach is to examine the physiological measures of workload at the individual level, such as ocular, cardiac, and respiratory responses and brain activity. These are indirect measures of workload, because they are based on an assumed relationship between cognitive activity and autonomic activity [30]. Another method is to use subjective feedback from the nurse to get information on how the nurse experiences different workload. One of the main ways to collect feedback is through surveys and self-assessments [31].

Because the purpose of this research is to inform staffing decisions, we will focus on patient-based approaches to measuring workload. The premise of patient-based approach is that direct nursing work scales proportionally with the number of procedures and interventions the patient receives. However, patient-based approaches merely compute the workload imposed by each patient, and do not account for the nurse taking care of the patient. Hence, patient-based measures do not capture the entirety of nursing workload.

One of the most popular measures is the Therapeutic Intervention Scoring System (TISS). Originally developed in 1974, the original purpose of the TISS was to measure severity of illness at the patient level and assess the corresponding nursing workload in ICUs [32]. The TISS has 76 checklist items, which are a list of specified interventions and patient conditions that are measured to assess load. In 1981, the Acute Physiology and Chronic Health Evaluation (APACHE) scores were introduced, using clinical severity of illness for benchmarking case mix and predicting outcomes [33]. The introduction of the APACHE scores made TISS less relevant for measuring severity of illness at the patient level. Therefore, later versions of the TISS focused on measuring nursing workload. The TISS was simplified in 1996 from the original 76 checklist items to 28 checklist items, which was given the name "TISS-28." An even more simplified version of the TISS was developed in 1997 and was name the Nine Equivalent of Nursing Manpower Score (NEMS). Finally, the Nursing Activity Score (NAS) was introduced in 2000 to measure a more comprehensive assessment of nursing workload.

In addition to the patient-based approach, an example of the operator-based approach has been included in this discussion. The NASA Task Load Index (TLX), was developed to measure workload in the aviation industry, but it has been proposed as a novel approach to measure nursing workload in the ICU. It is a questionnaire to nurses that evaluate nursing workload based on 6 parameters: (i) Mental demand; (ii) Physical demand; (iii) Temporal demand; (iv) Frustration; (v) Effort; and (vi) Performance [28].

3.2.1 TISS

The TISS was initially developed in 1974 by clinicians from Mass General Hospital (MGH) in United States to measure the severity of patients and corresponding nursing workload in ICU settings. The TISS is a scoring system based on 57 specific patient interventions. A committee of doctors and nurses assigned respective point values (on scale of 1 to 4) to specific interventions based on estimated time and effort required from the nursing staffs [32]. For each patient in the ICU, a TISS intervention is checked if it was performed within the last 24 hours. A tally of all checked interventions with their scores will indicate the workload that was performed on the particular patient. While in general, sicker patients are expected to have higher workload, that is not necessarily the case all the time.

Table 3-1: TISS Scoring Checklist [32]

4 POINTS

a. Cardiac arrest and/or countershock within 48 hours
b. Controlled ventilation with or without PEEP
c. Controlled ventilation with intermittent or continuous muscle relaxants
d. Balloon tamponade of varices
e. Continuous arterial infusion
f. Pulmonary artery line
g. Atrial or ventricular pacing
h. Hemodialysis in unstable patient
i. Peritoneal dialysis
j. Induced hypothermia
k. Pressure-activated blood infusion
l. G-Suit
m. Measurement of cardiac output
n. Platelet transfusions
o. IABA (intra-aortic balloon assist)
p. Membrane oxygenation

3 POINTS

a. Hyperalimentation or renal failure fluid
b. Pacemaker on standby
c. Chest tubes
d. Assisted respiration
e. Spontaneous PEEP
f. Concentrated K drip (>60 mEq/L)
g. Nasotracheal or orotracheal intubation
h. Endotracheal suctioning (non-intubated patient)
i. Complex metabolic balance (frequent intake and output, Brookline scale)
j. Multiple ABG, bleeding, and STAT studies
k. Frequent infusions of blood products
l. Bolus IV medications
m. Multiple (>3) parenteral lines
n. Vasoactive drug infusion
o. Continued antiarrhythmia infusions
p. Cardioversion
q. Hypothermia blanket
r. Peripheral arterial line
s. Acute digitalization
t. Active diuresis for fluid overload or cerebral edema
u. Active Rx for metabolic alkalosis or acidosis

2 POINTS

a. CVP (Central Venous Pressure)
b. >2 IV lines
c. Hemodialysis for chronic renal failure
d. Fresh tracheostomy (less than 48 hours)
e. Spontaneous respiration via E-T tube or tracheostomy
f. Tracheostomy care

1 POINT

a. ECG monitoring
b. Hourly V.S. or neuro V.S.
c. "Keep open" IV route
d. Chronic anticoagulation
e. Standard intake and output
f. Frequent STAT chems
g. Intermittent IV medications
h. Multiple dressing changes
i. Complicated orthopedic traction
j. IV antimetabolite therapy
k. Decubitus treatment
l. Urinary catheter
m. Supplemental oxygen (nasal or mask)
n. IV antibiotics

To verify the original TISS scores, TISS scores was calculated for patients in 4 categories clinically determined by physicians in the ICU [32]:

- Class I – routine patients that do not require critical care.
- Class II – stable patients that require overnight observation.
- Class III – stable patients that require intensive nursing and monitor, but their conditions are expected to remain stable, or improve.
- Class IV – unstable patients that require intensive nursing and physician resources.

The result showed that on average, Class I patients had the lowest scores, Class II had medium scores, Class III patients had higher scores, and Class IV had the highest scores. In addition, there was a significant separation in the average TISS scores, for each of the 4 different patient groups with [32].

As one of the first measures of patient acuity and nursing workload in the ICU, the TISS became a widely accepted method to classify critical care patients. The TISS has been used to determine severity of illnesses, establish nurse to patient ratios in ICU, assess current utilization of hospital intensive beds, and establish future needs and numbers in ICU beds [34].

3.2.2 TISS-76

In 1983, clinicians from Mass General Hospital (MGH) in United States updated the original TISS to include new procedures used in ICU settings. Innovations in critical care have added or modified therapeutic approaches and changed the acuity of some specific interventions. As a result, some interventions were omitted, some were added, and some had their points (weight) adjusted. In addition, guidelines were added to clarify ambiguous interventions that were prone to misinterpretations. The end result was a list of 76 interventions that became known as the TISS-76 [34].

The TISS-76 had been widely adopted across hospitals, both in United States and abroad, as a measure of nursing workload between groups of patients. However, there was some criticism on the TISS-76 [13]: (i) It was time consuming, requiring 3-5 minutes to score each patient, depending on the experience of the user; (ii) The scoring system was cumbersome and confusing because many interventions are similar, but with different weights; (iii) The interventions listed did not always reflect actual patient care activities by the nurse; and (iv) The TISS scored direct patient care activities, but it did not capture indirect patient care activities that are vital to the operations of the ICU (e.g., talking to patient's family and consulting with clinicians on the care plan for the patient).

Table 3-2: TISS-76 Scoring Checklist with Guidelines [34]

4 Points

a. Cardiac arrest and/or countershock within past 48 h[a]
b. Controlled ventilation with or without PEEP[a]
c. Controlled ventilation with intermittent or continuous muscle relaxants[a]
d. Balloon tamponade of varices[a]
e. Continuous arterial infusion[a]
f. Pulmonary artery catheter
g. Atrial and/or ventricular pacing[a]
h. Hemodialysis in unstable patient[a]
i. Peritoneal dialysis
j. Induced hypothermia[a]
k. Pressure-activated blood infusion[a]
l. G-suit
m. Intracranial pressure monitoring
n. Platelet transfusion
o. IABA (intra-aortic balloon assist)
p. Emergency operative procedures (within past 24 h)[a]
q. Lavage of acute GI bleeding
r. Emergency endoscopy or bronchoscopy
s. Vasoactive drug infusion (> 1 drug)

3 Points

a. Central iv hyperalimentation (includes renal, cardiac, hepatic failure fluid)
b. Pacemaker on standby
c. Chest tubes
d. Intermittent mandatory ventilation (IMV) or assisted ventilation
e. Continuous positive airway pressure (CPAP)
f. Concentrated K+ infusion via central catheter
g. Nasotracheal or orotracheal intubation[a]
h. Blind intratracheal suctioning
i. Complex metabolic balance (frequent intake and output)[a]
j. Multiple ABG, bleeding, and/or STAT studies (> 4/shift)
k. Frequent infusions of blood products (> 5 units/24 h)
l. Bolus iv medication (nonscheduled)
m. Vasoactive drug infusion (1 drug)
n. Continuous antiarrhythmia infusions
o. Cardioversion for arrhythmia (not defibrillation)
p. Hypothermia blanket
q. Arterial line
r. Acute digitalization—within 48 h
s. Measurement of cardiac output by any method
t. Active diuresis for fluid overload or cerebral edema
u. Active Rx for metabolic alkalosis
v. Active Rx for metabolic acidosis
w. Emergency thora-, para-, and peri-cardiocenteses
x. Active anticoagulation (initial 48 h)[a]
y. Phlebotomy for volume overload
z. Coverage with more than 2 iv antibiotics
aa. Rx of seizures or metabolic encephalopathy (within 48 h of onset)
bb. Complicated orthopedic traction[a]

2 Points

a. CVP (central venous pressure)
b. 2 peripheral iv catheters
c. Hemodialysis—stable patient
d. Fresh tracheostomy (less than 48 h)
e. Spontaneous respiration via endotracheal tube or tracheostomy (T-piece or trach mask)
f. GI feedings
g. Replacement of excess fluid loss[a]
h. Parenteral chemotherapy
i. Hourly neuro vital signs
j. Multiple dressing changes
k. Pitressin infusion iv

1 Point

a. ECG monitoring
b. Hourly vital signs
c. 1 peripheral iv catheter
d. Chronic anticoagulation
e. Standard intake and output (q 24 h)
f. STAT blood tests
g. Intermittent scheduled iv medications
h. Routine dressing changes
i. Standard orthopedic traction
j. Tracheostomy care
k. Decubitus ulcer[a]
l. Urinary catheter
m. Supplemental oxygen (nasal or mask)
n. Antibiotics iv (2 or less)
o. Chest physiotherapy
p. Extensive irrigations, packings or debridement of wound, fistula or colostomy
q. GI decompression
r. Peripheral hyperalimentation/Intralipid therapy

[a] Therapeutic Intervention Scoring System explanation code:

4-Point Interventions: (a) Point score for 2 days after most recent cardiac arrest. (b) This does not mean intermittent mandatory ventilation which is a 3-point intervention. It does mean that regardless of the internal plumbing of the ventilator, the patient's full ventilatory needs are being supplied by the machine. Whether or not the patient is ineffectively breathing around the ventilator is irrelevant as long as the ventilator is providing all the patient's needed minute ventilation. (c) For example, D-tubocurarine chloride, pancuronium (Pavulon), metocurine (Metubine). (d) Use Sengstaken-Blakemore or Linton tube for esophageal or gastric bleeding. (e) Pitressin infusion via IMA, SMA, gastric artery catheters for control of gastrointestinal bleeding, or other intra-arterial infusion. This does not include standard 3 ml/h heparin flush to maintain catheter patency. (g) Active pacing even if a chronic pacemaker. (h) Include first 2 runs of an acute dialysis. Include chronic dialysis in patient whose medical situation now renders dialysis unstable. (j) Continuous or intermittent cooling to achieve body temperature less than 33°C. (k) Use of a blood pump or manual pumping of blood in the patient who requires rapid blood replacement. (p) May even be the initial emergency operative procedure—precludes diagnostic tests, i.e., angiography, CT scan.

3-Point Interventions: (d) The patient is supplying some of his own ventilatory needs. (g) Not a daily point score. Patient must have been intubated in the ICU (elective or emergency) within previous 24 h. (i) Measurement of intake/output above and beyond the normal 24-h routine. Frequent adjustment of intake according to total output. (x) Includes Rheomacrodex. (bb) For example, Stryker frame, CircOlectric.

2-Point Interventions: (g) Replacement of clear fluids over and above the ordered maintenance level.

1-Point Intervention: (k) Must have a decubitus ulcer. Does not include preventive therapy.

3.2.3 TISS-28

In 1996, the TISS-28 was developed in Spain as a simplified way to measure patient acuity by reducing the number of therapeutic activities from the original 76 items down to 28 items. The reduced set was accomplished by removing the least frequent items through clinical assessment, eliminating items that have least contribution to outcome, and combining items that describe similar activities [13].

To validate the updated TISS-28 scores as a good proxy to nurse workload, the TISS-28 scores for over 10,000 patients was compared to the respective TISS-76 scores, and showed that TISS-28 explains 86% of the variation in TISS-76. In addition, there was a motion study, and more specifically, a multi-moment recording of nursing activities. At random time intervals throughout the day (about 30 times in 24 hours), nurses recorded activities in 6 different categories:

a) Activities in TISS-28.
b) Patient care activities not in TISS-28.
c) Indirect patient care, including activities related to but not in direct contact with the patient, such as contact with family, and maintaining supplies.
d) Organizational activities, such as meetings, trainee supervision, and research.
e) Personal activities, which includes activities for the nurse, such as taking breaks or going to the restroom.
f) Others.

The conclusion was that TISS-28 explained 43% of nursing time across all patient severity [13].

One advantage of the updated TISS is the ability to calculate scores by using data from electronic patient record without any input from nursing staffs. Currently, many implementations of TISS are calculated electronically [35]. In addition, there is a conversion from 1 TISS-28 point to 10.6 minutes of nursing time. However, because TISS-28 only accounts for 43% of nursing workload, the conversion from TISS-28 points to minutes of nursing time is not accurate. Overall, TISS is a better indicator of relative nursing workload (higher score means higher workload) than estimating the absolute nursing workload (1 points is always equal to 10.6 minutes of nursing time).

Table 3-3: TISS-28 Scoring Checklist with Guidelines [13]

Table 1. Therapeutic Intervention Scoring System-28

	Points
Basic Activities	
Standard monitoring Hourly vital signs, regular registration and calculation of fluid balance	5
Laboratory. Biochemical and microbiological investigations	1
Single medication. Intravenously, intramuscularly, subcutaneously, and/or orally (e.g., gastric tube)	2
Multiple intravenous medication More than one drug, single shots, or continuously	3
Routine dressing changes. Care and prevention of decubitus and daily dressing change	1
Frequent dressing changes. Frequent dressing change (at least one time per each nursing shift) and/or extensive wound care	1
Care of drains All (except gastric tube)	3
Ventilatory Support	
Mechanical ventilation. Any form of mechanical ventilation/assisted ventilation with or without positive end-expiratory pressure, with or without muscle relaxants, spontaneous breathing with positive end-expiratory pressure	5
Supplementary ventilatory support Breathing spontaneously through endotracheal tube without positive end-expiratory pressure: supplementary oxygen by any method, except if mechanical ventilation parameters apply	2
Care of artificial airways. Endotracheal tube or tracheostoma	1
Treatment for improving lung function. Thorax physiotherapy, incentive spirometry, inhalation therapy, intratracheal suctioning	1
Cardiovascular Support	
Single vasoactive medication. Any vasoactive drug	3
Multiple vasoactive medication. More than one vasoactive drug, disregard type and doses	4
Intravenous replacement of large fluid losses. Fluid administration >3 L/m²/day, disregard type of fluid administered	4
Peripheral arterial catheter	5
Left atrium monitoring Pulmonary artery flotation catheter with or without cardiac output measurement	8
Central venous line	2
Cardiopulmonary resuscitation after arrest; in the past 24 hrs (single precordial percussion not included)	3
Renal Support	
Hemofiltration techniques. Dialytic techniques	3
Quantitative urine output measurement (e.g., by urinary catheter à demeure)	2
Active diuresis (e.g., furosemide >0 5 mg/kg/day for overload)	3
Neurologic Support	
Measurement of intracranial pressure	4
Metabolic Support	
Treatment of complicated metabolic acidosis/alkalosis	4
Intravenous hyperalimentation	3
Enteral feeding. Through gastric tube or other gastrointestinal route (e.g., jejunostomy)	2
Specific Interventions	
Single specific intervention in the intensive care unit. Naso- or orotracheal intubation, introduction of pacemaker, cardioversion, endoscopies, emergency surgery in the past 24 hrs, gastric lavage. Routine interventions without direct consequences to the clinical condition of the patient, such as radiographs, echography, electrocardiogram, dressings, or introduction of venous or arterial catheters, are not included	3
Multiple specific interventions in the intensive care unit. More than one, as described above	5
Specific interventions outside the intensive care unit Surgery or diagnostic procedures	5

Criteria of exclusion are applied in four conditions: "Multiple intravenous medication" excludes "single medication", "mechanical ventilation" excludes "supplementary ventilatory support", multiple vasoactive medication" excludes "single vasoactive medication", "multiple specific interventions in the intensive care unit" excludes "single specific interventions in the intensive care unit"

3.2.4 NEMS

The Nine Equivalents of Nursing Manpower Score (NEMS) was developed by the same lead author as TISS-28, with the goal of finding a method to score nursing workload that is simpler than TISS-28. The NEMS only has 9 interventions instead of the 28 in TISS-28. The selection of items for NEMS is done by judgment of the authors. The weighting of the items uses "multivariate regression techniques through the origin on the developmental sample with 2000 records, and using the original TISS-28 score per record as the predicted score value." In effect, the NEMS is made to be as close to the TISS-28 as possible [14].

Table 3-4: NEMS Scoring Checklist [14]`

Item	B coefficient	Points
1. Basic monitoring: hourly vital signs, regular record and calculation of fluid balance	8.928	9
2. Intravenous medication: bolus or continuously, not including vasoactive drugs	5.545	6
3. Mechanical ventilatory support: any form of mechanical/assisted ventilation, with or without PEEP (e. g., continuous positive airway pressure), with or without muscle relaxants	11.559	12
4. Supplementary ventilatory care: breathing spontaneously through endotracheal tube; supplementary oxygen any method, except if (3) applies	3.415	3
5. Single vasoactive medication: any vasoactive drug	7.304	7
6. Multiple vasoactive medication: more than one vasoactive drug, regardless of type and dose	11.664	12
7. Dialysis techniques: all	5.962	6
8. Specific interventions in the ICU: such as endotracheal intubation, introduction of pacemaker, cardioversion, endoscopy, emergency operation in the past 24 h, gastric lavage; routine interventions such as X-rays, echocardiography, electrocardiography, dressings, introduction of venous or arterial lines, are not included	5.163	5
9. Specific interventions outside the ICU: such as surgical intervention or diagnostic procedure; the intervention/procedure is related to the severity of illness of the patient and makes an extra demand upon manpower efforts in the ICU	5.826	6

The cross-validation indicates that the NEMS correlates with the TISS-28 very well. For the cross-validation sample, the mean TISS-28 is 26.13±10.38, and the mean NEMS is 26.17±9.38 with an R^2 of 0.7616. On the independent sample, the R^2 is much lower at 0.59 [14]. Other publications have confirmed the validity of the NEMS by finding a strong correlation between the TISS-28 and NEMS, both at the time of patient admission and discharge (0.888 and 0.885; $P < 0.001$) [36]. Overall, NEMS is easier to measure than TISS-28; however, it lacks the granularity across patient populations.

3.2.5 NAS

The Nursing Activity Score (NAS) was developed by the same group that created the TISS-28 and NEMS, due to the shortcomings of TISS-28, particularly the fact that 34.3% of the nursing time being spent on patient care is not included in TISS-28. To account for the additional nursing workload, 5 new items and 14 subitems were added to the list of therapeutic interventions in TISS-28. To identify the new items, a group of doctors and nurses brainstormed regarding a broad list of additional measures, and then rated the initial list based on their opinion for the relevance to nurse workload. Then, a more descriptive list was identified with measureable attributes, and a work sampling study was conducted [37].

Table 3-5: NAS Checklist Score [37]

	Basic activities	Score
1	Monitoring and titration	
1a	Hourly vital signs, regular registration and calculation of fluid balance	4.5
1b	Present at bedside *and* continuous observation *or* active for 2 hrs or more in any shift, for reasons of safety, severity, or therapy such as noninvasive mechanical ventilation, weaning procedures, restlessness, mental disorientation, prone position, donation procedures, preparation and administration of fluids or medication, assisting specific procedures	12.1
1c	Present at bedside *and* active for 4 hrs or more in any shift for reasons of safety, severity, or therapy such as those examples above (1b)	19.6
2	Laboratory, biochemical and microbiological investigations	4.3
3	Medication, vasoactive drugs excluded	5.6
4	Hygiene procedures	
4a	Performing hygiene procedures such as dressing of wounds and intravascular catheters, changing linen, washing patient, incontinence, vomiting, burns, leaking wounds, complex surgical dressing with irrigation, and special procedures (e.g. barrier nursing, cross-infection related, room cleaning following infections, staff hygiene)	4.1
4b	The performance of hygiene procedures took >2 hrs in any shift	16.5
4c	The performance of hygiene procedures took >4 hrs in any shift	20.0
5	Care of drains, all (except gastric tube)	1.8
6	Mobilization and positioning, including procedures such as: turning the patient; mobilization of the patient; moving from bed to chair; team lifting (e.g. immobile patient, traction, prone position)	
6a	Performing procedure(s) up to three times per 24 hrs	5.5
6b	Performing procedure(s) more frequently than 3 times per 24 hrs, or with two nurses, any frequency	12.4
6c	Performing procedure with three or more nurses, any frequency	17.0
7	Support and care of relatives and patient, including procedures such as telephone calls, interviews, counseling; often, the support and care of either relatives or patient allow staff to continue with other nursing activities (e.g., communication with patients during hygiene procedures, communication with relatives while present at bedside, and observing patient)	
7a	Support and care of either relatives or patient requiring *full dedication* for about 1 hr in any shift such as to explain clinical condition, dealing with pain and distress, difficult family circumstances	4.0
7b	Support and care of either relatives or patient requiring *full dedication* for 3 hrs or more in any shift such as death, demanding circumstances (e.g., large number of relatives, language problems, hostile relatives)	32.0
8	Administrative and managerial tasks	
8a	Performing routine tasks such as processing of clinical data, ordering examinations, professional exchange of information (e.g., ward rounds)	4.2
8b	Performing administrative and managerial tasks requiring *full dedication* for about 2 hrs in any shift such as research activities, protocols in use, admission and discharge procedures	23.2
8c	Performing administrative and managerial tasks requiring *full dedication* for about 4 hrs or more of the time in any shift such as death and organ donation procedures, coordination with other disciplines	30.0
Ventilatory support		
9	Respiratory support: any form of mechanical ventilation/assisted ventilation with or without positive end-expiratory pressure, with or without muscle relaxants, spontaneous breathing with or without positive end-expiratory pressure with or without endotracheal tube supplementary oxygen by any method	1.4
10	Care of artificial airways: endotracheal tube or tracheostomy cannula	1.8
11	Treatment for improving lung function: thorax physiotherapy, incentive spirometry, inhalation therapy, intratracheal suctioning	4.4
Cardiovascular support		
12	Vasoactive medication, disregard type and dose	1.2
13	Intravenous replacement of large fluid losses. Fluid administration >3 L/m^2/day, irrespective of type of fluid administered	2.5
14	Left atrium monitoring: pulmonary artery catheter with or without cardiac output measurement	1.7
15	Cardiopulmonary resuscitation after arrest, in the past period of 24 hrs (single precordial thump not included)	7.1
Renal support		
16	Hemofiltration techniques, dialysis techniques	7.7
17	Quantitative urine output measurement (e.g., by indwelling urinary catheter)	7.0
Neurologic support		
18	Measurement of intracranial pressure	1.6
Metabolic support		
19	Treatment of complicated metabolic acidosis/alkalosis	1.3
20	Intravenous hyperalimentation	2.8
21	Enteral feeding through gastric tube or other gastrointestinal route (e.g., jejunostomy)	1.3
Specific interventions		
22	Specific intervention(s) in the intensive care unit: endotracheal intubation, insertion of pacemaker, cardioversion, endoscopies, emergency surgery in the previous 24 hrs, gastric lavage; routine interventions without direct consequences to the clinical condition of the patient, such as: radiographs, echography, electrocardiogram, dressings, or insertion of venous or arterial catheters, are not included	2.8
23	Specific interventions outside the intensive care unit: surgery or diagnostic procedures	1.9

In the items 1, 4, 6, 7, and 8, only one subitem (a, b, or c) can be scored; the weights represent the percentage of time spent by one nurse on the activity mentioned in the item, if performed.

There were two parts of the work sampling study. The first part was the registration of nursing activities by outside experts, similar to the TISS-28. The second part was a multi-moment recording study that ask nurses to record their activities into one of four categories: (i) Items scored at patient level; (ii) Activities not relating directly to patient, and not medical; (iii) Activities for the nurses themselves; and (iv) The remaining activities that could not be scored into any of the previous categories. Based on the MMR, the team calculated the weights of each item based on the time a nurse spent on these items. Each point corresponds to the 1% of nursing time in 24 hours. The maximum number of points is 177, which means that the patient needs 1.7 nurses continuously for 24 hours. The weights were calculated using the MMR to record the number of occurrences certain activity was performed and then normalized the result by the total number of that activity mentioned on the MMR. Overall, NAS captures 81% of nursing activities [37].

NAS has been wildly used in measuring ICU nurse workload since its publication in 2000. Recently, NAS became the standard in measuring nursing workload in ICUs [15] [38]. NAS captures a much higher percentage of nursing activities than the TISS, and the scoring system is much more intuitive. However, the scoring is not as simple as TISS because there is no obvious ways to score some items without direct nurse inputs.

3.2.6 Other Approaches

One of the operator-based approaches to measuring nursing workload is the NASA TLX. It is a subjective load index calculated using questionnaires to nurses on patient demand. It was developed over 20 years ago to measure workload in aviation, and it has become one of the most widely used instruments to assess overall subjective workload. The TLX has been proven in many different industries and the questionnaires are not industry specific, so it can be applied to healthcare ICU environment. The TLX consists of 6 scales including: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Frustration (FR), Effort (EF), and Performance (PE). The study used over 700 surveys from nurses working in 8 different hospitals and 21 ICUs [28].

Table 3-6: NASA TLX Questionnaire[28]

The following questions deal with the workload that you experience in your job. Please put an 'X' on each of the following six scales at the point that matches your overall experience of workload.

	Low	High
1. **Mental demand.** How much mental activity is required to perform your job (thinking, deciding, calculating, remembering, looking, searching, etc.)?		
2. **Physical demand.** How much physical activity is required to perform your job (e.g., pushing, pulling, turning, controlling, activating, etc.)?		
3. **Temporal demand.** How much time pressure do you feel due to the rate or pace at which the tasks or task elements occurred?		
4. **Effort.** How hard do you have to work (mentally and physically) to accomplish your level of performance?		
5. **Performance.** How satisfied are you with your performance at your job?		
6. **Frustration level.** How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent do you feel about your job?		

Results showed that the different methods to measure workload of ICU nurses, such as patient-based and operator-based workload, were only moderately correlated (NASA TLX with NAS:

r=0.45, p<0.01), or not correlated at all (NASA TLX with Nurse-Patient-Ratio (NPR): r=0.10, p>0.05). Further results showed that among the operator-based instruments, the NASA TLX was the most reliable and valid questionnaire to measure workload, and that NASA TLX can be used in a healthcare setting [28].

3.3 Limitation of Current Measurements

There are several major limitations in the current sets of nursing workload measurements. First, both approaches are useful primarily only for retrospective analysis of workload, but not as much for prospective modeling. In addition, current methods do not capture instantaneous load. Furthermore, patient-based approaches, such as the TISS and NAS, suffer from three limitations: (i) Frequently outdated due to critical care innovations; (ii) Do not consider interactions between patients and extra load due to task switching; and (iii) Consider average times among patient population. Finally, operator-based approaches suffer from different set of limitations: (i) Require cumbersome questionnaires and surveys; (ii) Hard to determine objectivity; and (iii) Create incentive to influence the scoring system.

The biggest issue with both patient-based and operator-based approaches is the lack of ability to do prospective analysis on anticipated workload. Both approaches calculate nursing workload retrospectively after the fact, with little focus on being able to predict what the workload is going to be at the beginning of the shift. This limits the usefulness of nursing workload measurements to inform adjustments in decisions. Another major issue with the current approaches is that they do not measure instantaneous load. For example, if a patient has sudden cardiac arrest, two to three nurses are needed to take care of the patient, leaving significantly fewer nurses to care for other patients.

Current patient-based approaches to workload measurement have many major shortcomings. One shortcoming discussed in literature is the fact that it does not capture all the direct and indirect nursing care to patients [28] [37]. In addition, there are several other challenges. First, the scores need frequent updates to the scoring checklist to match innovations in critical care medicine that modify nursing workflow significantly. For example, cooling patients immediately after cardiac arrest significantly improves survival rate and has been widely adopted across all ICUs. In this case, the scores need to be updated to account for the additional workload to cool patients. Second, none of the scores account for the interactions of other patients within the ICU to the overall nursing workload. When a patient has a cardiac arrest, three to four nurses are pulled into the room, leaving the other patients with much fewer nursing staff. Third, the scores do not consider the workload demand of frequent task switching between patients, and this is prominent in nurses who have to take care of more than one patient. Finally, all patient-based scores are calculated as an average workload for particular interventions. However, patients are widely different and the variation among different patient types is not considered.

Operator-based approaches, such as the NASA TLX, face a different set of challenges. The most prominent is the need for constant surveys and questionnaires. In the digitalized world, patient-based scoring checklists can be mostly automated by examining patients' electronic medical records (EMR) [39]. However, this cannot be done for subjective, survey-based approaches in measuring nursing workload. Second, because of lack of objectivity in the measures, it is hard to compare different ICUs directly. Finally, the measures creates an incentive for nurses and hospital administrators to influence the surveys if staffing and/or budget is based on workload.

3.4 Workload Measurement and Staffing

When researching nursing workload's impact on ICU staffing decisions, the majority of papers focused two main topics: (i) Nurse to patient ratio versus average nursing workload to determine the number of nurses needed for budgeting; and (ii) Nurse to patient ratio versus patient outcomes to determine the number of nurses needed for safety analysis. However, none of them examine how anticipated nursing workload should impact staffing decisions and shift design other than determining the long run number of staffed nurses in the ICU.

Many of the nursing workload measures, such as TISS, have a way of converting workload score to nursing hours through a simple conversion rate, which, for TISS, is 10.5 minutes/TISS point [13]. Publications would use the converted nursing hours to do retrospective analysis of nursing staffing versus required nursing load based on the workload measures. The main focus is to identify the current state of the system by looking at nursing staffing from a cost (budget) perspective with the goal of minimizing nurse staffing where possible [38] [15] [35]. The danger of this approach is that variability in patient load is not accounted in the analysis. This could cause the hospital to understaff nurses to the average workload in a particular ICU, instead of leaving spare capacity to handle variability.

The other body of research involves nurse-to-patient ratio and its impact on patient safety. The main goal is to study the minimum number of nurses needed for the ICU to provide safe care with nursing workload being a side measure or a normalization method for the acuity of patients. Many of these analyses concluded that higher nurse staffing level is typically associated with lower failure-to-rescue rates, lower inpatient mortality rates, and shorter hospital stays [7] [40]. However, it is difficult to operationalize the lessons from such studies by increasing the number of nursing staff in the ICU because of real world reasons, such as budgetary constraints, thus limiting the operational values of this research.

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4 Characterization of Patient Workload

Because there are so many factors impacting nursing workload, the traditional approaches do not accurately portray a complete picture. In fact, the patient-based checklist approaches to measuring nursing workload only capture the patients' characteristics/clinical conditions, and the nursing workflow to treat those patients. To not confuse patient load (acuity) with nursing workload, we would call the updated patient-based checklist scores, such as TISS, as a measurement of patient workload because it measures the workload per patient.

Our work expands over the existing measurement strategies to examine how other factors impact nursing workload. First, staffing decisions determine how the workload is distributed to each nurse. Second, nurse experience determines how fast the work is being conducted. Third, variability factors into the overall instantaneous stress nurses experienced in the ICU. Finally, disruptions interrupt the nursing workflow and incur task switching penalties.

The first step in measuring nursing workload was to understand how much workload is required to take care of a patient.

4.1 Development of Nursing Intensity Scores

When we attempted to examine patient workload in ICUs across BIDMC, we realized that there was no formalized tool to assess patient workload. Our approach was to update one of the patient-based checklist scores and adapt it to the state of the art ICU practices, particularly at BIDMC. Specifically, we developed a new workload score called Nursing Intensity Scores (NIS).

When selecting a method for measuring patient workload, we based the decision on several criteria. The first criteria was the level of accuracy in the measuring the actual workload. The second criteria was the effort required to compute the scores. Finally, the third criteria was the potential impact on the behavior of individuals. For accuracy, we were more interested in obtaining a good measure of the relative nursing workload (e.g., patients with more needs should always have higher scores than patients with less needs), rather than direct conversion of workload score to nursing care time (e.g., 1 point in TISS is 10.6 minutes of nursing care). In addition, we wanted to minimize the effort required to compute the score, whether it was done by nurses or by administrators. Since nurses were already spending over 30% of time on documentation, we did not want to increase that percentage even further. Finally, we had to take into consideration the potential response of individuals to a given scoring method. This was an especially saddle issue if the scoring system had created a perverse incentive to misreporting. For example, if nurses knew the scores could have significant negative impact on their staffing, they could potentially be inclined to manipulate the numbers, in order to influence staffing decisions.

After considering all the factors above, we chose the TISS-28, a patient-based checklist system developed in 1996 (Section 3.2.3), as the basis for measuring nursing workload. We decided in favor of the patient-based checklist approach, instead of the operator-based survey approach (Section 3.2.6), because the latter requires additional documentation and can easily be "gamed." Another decision was the choice between the TISS-28 and NAS. Both scores were slightly outdated with some workflows that do not capture the up-to-date nursing workflow in United States. The NAS (Section 3.2.5) measures direct nursing care more closely. However, there are five important parts of NAS that require human surveys and questionnaires. Therefore, it suffers from the same problems as operator-based approaches, Even though the TISS-28 measures a smaller percentage of direct nursing care, it has proven in many ICU settings to be accurate (i.e., a higher score means higher workload), and the checklist can be automatically calculated using EMR data.

There have been many critical care innovations since TISS-28 was published in 1996, and as a result, the checklist needed to be updated and customized to fit the BIDMC ICU nursing workflow. Meetings with senior nurses and clinicians from different ICUs were conducted to discuss required changes to the original TISS-28. The old checklist was updated with new language to reflect the addition of new procedures, modification of some scores, and changing some of the activities to include all patients in ICU. The new checklist, called the NIS, is the basis for measuring patient workload throughout this thesis. Table 4-1 shows the individual items of the NIS, with green items as the major areas of modification. Updates to reflect critical care innovations are adding inventions to PA catheter categories, and substituting dialysis with CRRT (workflow change as well). Workflow changes include routine medications to all patients, changing category to include IV insulin medication, and chest PT for all patients.

Table 4-1: Nursing Intensity Score in BIDMC

Basic Activities	**Points**	**Renal Support**	**Points**
Standard monitoring (All Patients)	5	CRRT	8
Routine Lab draw (All Patients)	1	Measuring Urine output (all patient)	2
Routine medication (All Patients)	2	Diuresing (Lasix)	3
IV insulin/ meds with extensive monitoring	3		
Routine dressing changes (All Patients)	1	**Neurologic Support**	
Care of drains All	3	ICP drain	4
Pressure ulcer	1		
		Metabolic Support	
Ventilatory Support		acidosis/alkalosis	4
On a vent	5	TPN/OPN	2
Need O2 delivery	2	Tube feeds	3
Has a trache	1		
Chest PT (All Patients)	1	**Specific Interventions**	
		Single procedure done in ICU	3
Cardiovascular Support		Multiple procedures done in ICU	5
Single vasoactive medication	3	Travel (OR, Cath lab, ERCP)	5
Multiple vasoactive medication	4		
1.5 L IVF/blood products per shift	4		
Arterial catheter (in access line/invasive)	2		
PA Catheter, LVAD, Tandem heart, Impella, PiCO, ECMO, Alsius, Artic Sun, Heart mate, Blakemore massive transfusion ordered	8		
Central venous line	2		
Code blue in last 24	3		

To score a patient, one must identify the patient activities from the NIS checklist, and then tally the points to get a single score. A patient with NIS of 0-20 is considered low workload (example: called out patient that required only oxygen assisted breathing device). A score of 21-40 is considered moderate workload (e.g., critical but stable patient that requires ventilator support, single vasoactive drug, over 1.5L of blood, single bedside procedure, and travel to the OR). Finally, a score of 41+ is considered high workload (e.g., critical and unstable patient that required ventilator support, tracheotomy tube, multiple vasoactive drugs, over 1.5L of blood, arterial catheter, one-to-one care, central venous line, treatment for acidosis, single bedside procedure, and travel to the OR).

One of the advantages of the NIS is the ability to automate the score calculation for each patient. After the NIS was established, we developed a computer program in Python (Python 3.4.2 with Pandas 0.15.2 for large data manipulation and analysis) to do retrospective analysis of patient workload based on 2-years (2012-2013) of patient data in BIDMC ICUs. We used several data sources including patient admission records, patient medical records, and departmental procedure records. The program identified for each patient, the respective list of interventions over 24-hour window and multiplied by associated points (weights), and then sum them up to get the NIS for that patient. We worked with the nurse consultants from the Moore project to understand the whereabouts of individual components in the BIDMC's EMR (MetaVision) in order to obtain all the data needed to complete the NIS. After the whereabouts of each component were discussed, a data support specialist retrieved all patient records and stored them on a shared drive. The Python program processed individual data files and modified the list of interventions accordingly. For some interventions, such as providing over 1.5L of fluids during a shift, additional processing was added to calculate if a patient satisfied the criteria. The NIS was calculated, for each patient, in each shift for all ICUs in BIDMC.

To validate the computer-calculated NIS, we conducted data source review and random sample verification with the help of nursing consultants. For data source review, we cross-referenced each data source entry with the intended guidelines from the NIS to eliminate any discrepancies in data input. For random sample verification, we randomly chose patients and studied the interventions from the NIS to see how well they matched with the results from the computer-calculated NIS. The objective of the random sampling verification was to identify bugs in the computer algorithm. After the verification steps, we validated that computer program calculates the NIS as intended.

4.2 Selection of MICU 6 as Pilot ICU

Even though the goal was to develop a nursing workload measurement methodology that would encompass all ICUs at BIDMC, it was hard to cover all areas because the organization of each ICU was different, the patient population was distinct, and workflow was customized to individual ICUs.

There is a major difference in how the clinical care is organized in surgical units versus medical units. The MICUs are closed units (ICU care team are in charge for the care plan of patients), and the SICUs are open units (surgical care team are in charge for the care plan of patients while, the ICU care team are there for critical care support). In addition, the patient population is very different among ICUs and therefore, the nursing workflow of ICUs are very different. For example, a nurse in the SICU could take care of post-surgical patients with constant need for wound care, while a nurse in the MICU could take care of medical patients with a myriad of possible ailments, and finally, a nurse in CCU could take care of cardiac patients with constant need for patient cooling and other cardiac resuscitation measures. In terms of workload, post-surgical patients tend to have a spike in workload immediate after surgery, while workload for medical patients do not have such pattern.

Because the ICUs are quite different, there was a need to select an ICU for a pilot study. The Medical ICU 6 (MICU 6) was chosen as the pilot for in-depth analysis and experimentation, because it is a closed unit, with a culture that is open to change. Even though the results of our analysis are directly applicable only to the MICU 6, the methodology of our research is applicable for analyzing all types of ICUs throughout the hospital.

4.3 Prospective Approach to Patient Workload

One of the goals of the project was to develop a prospective approach to predict workload and capture the aspect of variability; this could hopefully be used in the future to inform staffing decisions. One idea was to examine workload based on different patient conditions. Previous research is focused on understanding retrospectively the average workload of different patient conditions. In contrast, our approach captures variability in workload because the variable and instantaneous load is what the nurses have to constantly face. Moreover, it has a potentially significant role in affecting patient safety in ICU. Therefore, in addition to measuring nominal average workload, we focused on capturing the variability and predictability of the workload as well.

After compiling the NIS for each patient and each shift in MICU 6 over the two-year period, we investigated the statistics of patient workload as a function of patient conditions. To measure the NIS with patient conditions, we identified common patient conditions in MICU 6, and gathered data for patients, who had those conditions. We assessed the NIS of patients with these conditions. First, we identified patient conditions affecting the highest number of patients by using a combination of intuition from time and motion study, expert opinion from nursing consultants, and common conditions from random sample verification of NIS. In total, we identified five major patient conditions in MICU 6: (i) Sepsis; (ii) Chronic Obstructive Pulmonary Disease (COPD); (iii) Acute Respiratory Distress Syndrome (ARDS); (iv) Gastrointestinal (GI) bleed; and (v) Hyperglycemia. Second, we gathered data for patients with the above conditions with the help from data support specialist. For sepsis and ARDS, we used the criteria based on published medical guidelines [41] [42]. Since COPD is a chronic disease, we looked for previous medical history of COPD. For GI bleed, we examined patients who took GI prophylaxis, because the drug is given to patients with active GI bleed or are highly susceptible to GI bleed. For hyperglycemia, we checked if any patients were given insulin intravenously within the first two shifts to stabilize blood sugar level. Finally, the data on patient conditions was combined with the NIS for each patient to create a list with the NIS matched to patient conditions.

After combining the NIS with patient condition, the results were saved into csv format, then imported to SAS JMP Pro 11.2.0 (64-bit) software to conduct statistical analysis of the data.

The premise of examining patient workload based on patient conditions was to analyze the predictability of certain patient conditions in terms of the workload patients with these conditions have. Our intuition was that some conditions have high average load, but could still be predictable, while some have averaged lower load but are unpredictable (highly variable). For our analysis, we related variability to predictability.

Investigating patient load among patient conditions was problematic because many patients have more than one condition. The goal is to identify patient conditions based on mean load and variation of load, when compared to the overall population. The analysis was separated into two methods: (i) Distribution analysis of the primary patient conditions, and (ii) Statistical analysis for interactions of patient conditions. We also analyzed separately workload over the first 24-hour of admission.

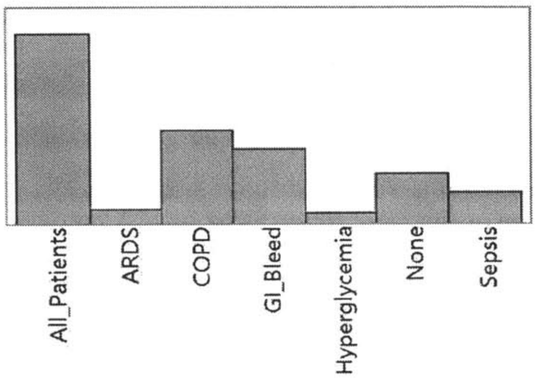
4.3.1 Load of Different Patient Conditions

Figure 4-1 shows the distribution of number of patients in each patient condition categories. "All Patients" is the control group that represents all patients in MICU 6. The five patient conditions categories are "ARDS", "COPD", "GI Bleed", "Hyperglycemia", and "Sepsis". The "None" category represents patients who did not have any of the above conditions. There were a total of 1803 patients, with a large number of patients, who had COPD (878) or GI bleed (711), a moderate number of patients, who had sepsis (280) or none of the conditions listed (470), and a small number of patients who had ARDS (134) or hyperglycemia (83). As we already mentioned, some patients have more than one condition.

Figure 4-1: Distribution of Patient Conditions

Distributions

Categories



Frequencies

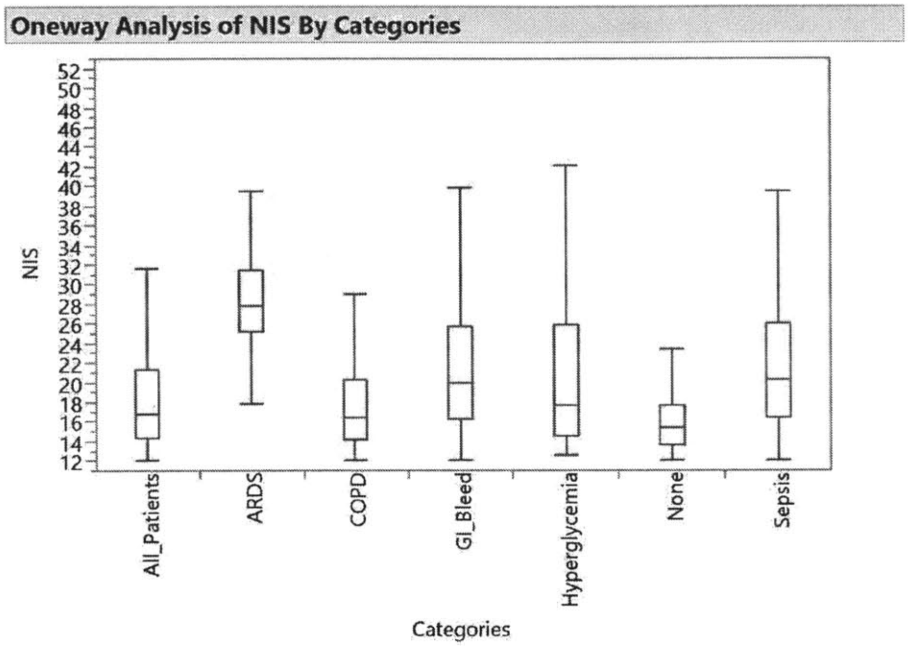
Level	Count	Prob
All_Patients	1803	0.41363
ARDS	134	0.03074
COPD	878	0.20142
GI_Bleed	711	0.16311
Hyperglycemia	83	0.01904
None	470	0.10782
Sepsis	280	0.06423
Total	4359	1.00000

N Missing 0
7 Levels

Figure 4-2 shows the box plots for examining patients in MICU 6 based on patient conditions. The Y-axis represents the mean NIS per shift during each patient's stay in the ICU. The X-axis represents patient categories. From the chart, we can characterize patient load among different patient conditions based on two parameters, mean load and variability. Figure 4-3 shows the quadrants for each patient condition.

- Low load, low variability: COPD, and None
- Low load, high variability: hyperglycemia
- High load, low variability: ARDS
- High load, high variability: Sepsis, GI bleed

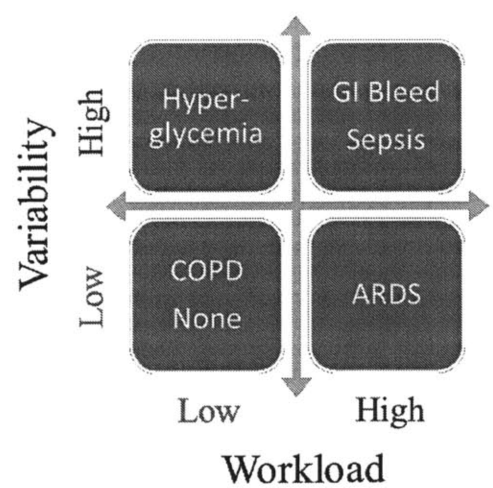
Figure 4-2: Patient Load among Primary Patient Conditions



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
All_Patients	12	13	14.33333	16.75	21.25	27.17265	52.71429
ARDS	17.83333	22.86834	25.19688	27.86111	31.40132	36.87576	45.83333
COPD	12	12.8	14.2	16.5	20.2	26.47857	43.5
GI_Bleed	12	14	16.28571	20	25.7	30.90891	48
Hyperglycemia	12.5	13	14.5	17.66667	25.95652	33.34444	52.71429
None	12	12.5	13.6	15.4	17.60625	21.5	34.5
Sepsis	12	14.275	16.4381	20.35417	26.05769	33.39167	52.71429

Figure 4-3: Characterization of Load Based on Load and Variability



By combining the distribution of patient population among different conditions and the characterization of patient conditions, we concluded that:

- The majority of patients are relatively predictable
- A few patients had high load, but were predictable
- Some patients were highly unpredictable, but we know these patients had the conditions of GI Bleed, Sepsis, and/or Hyperglycemia

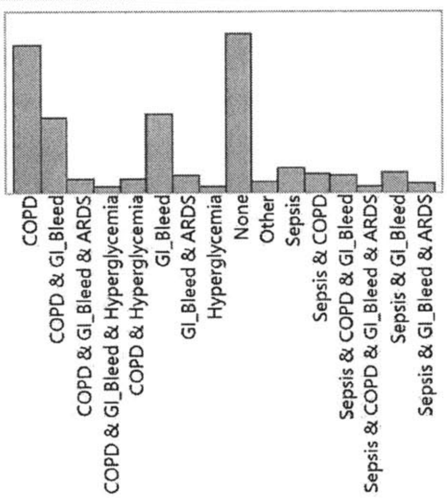
4.3.2 Interactions of Patient Conditions

To eliminate the effects of cross-terms and interactions of patient conditions in the previous analysis, we decided to perform a one-way analysis of patient conditions. Specifically, we considered the 32 possible pairwise combinations. MICU 6 had only 1803 patients over 2 years, and the sample size was too small for any meaningful analysis on some of the combinations. Combinations with small sample size (cutoff of N < 10) were categorized in the "Other" condition. Figure 4-4 shows the distribution of patient conditions for one-way analysis. The conditions with most patients were "None", "COPD", "COPD & GI Bleed", and "GI Bleed". This was not surprising given the distribution of patients from Figure 4-1.

Figure 4-4: Distribution of Patient Conditions for One-Way Analysis

Distributions

Categories



Frequencies

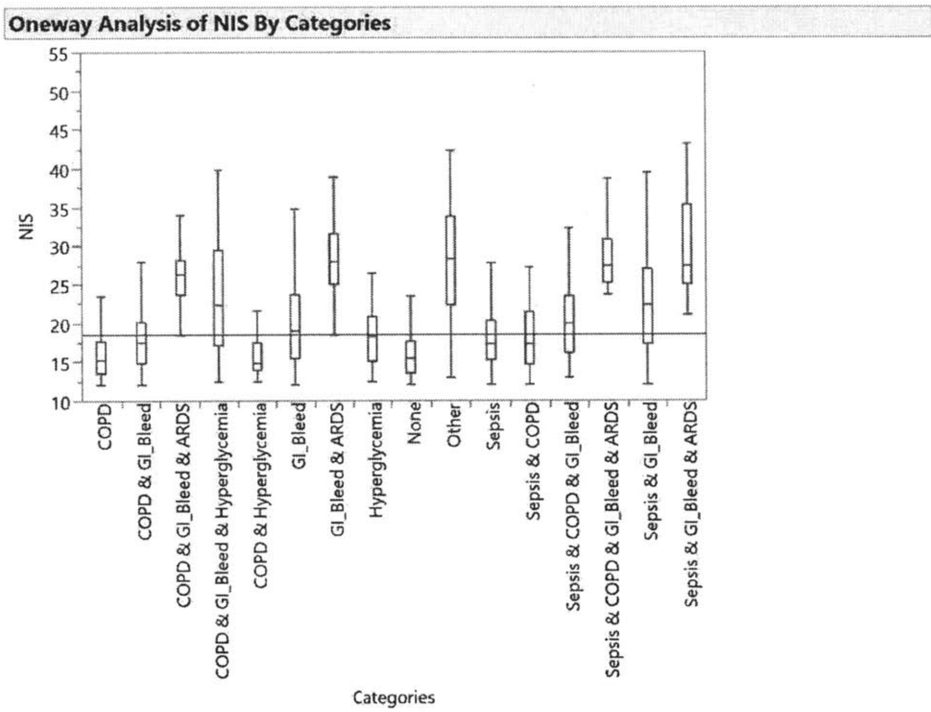
Level	Count	Prob
COPD	438	0.24293
COPD & GI_Bleed	221	0.12257
COPD & GI_Bleed & ARDS	38	0.02108
COPD & GI_Bleed & Hyperglycemia	14	0.00776
COPD & Hyperglycemia	36	0.01997
GI_Bleed	231	0.12812
GI_Bleed & ARDS	48	0.02662
Hyperglycemia	13	0.00721
None	470	0.26068
Other	29	0.01608
Sepsis	69	0.03827
Sepsis & COPD	52	0.02884
Sepsis & COPD & GI_Bleed	49	0.02718
Sepsis & COPD & GI_Bleed & ARDS	15	0.00832
Sepsis & GI_Bleed	55	0.03050
Sepsis & GI_Bleed & ARDS	25	0.01387
Total	1803	1.00000

N Missing 0

16 Levels

Figure 4-5 shows the patient load among different patient conditions. The Y-axis represents the mean NIS during each patient's stay in the ICU. The X-axis represents patient conditions. The horizontal line at NIS 18 points is the grand mean workload per shift across all patients. The patient load has widely varying characteristics depending on the patient condition.

Figure 4-5: Patient Load for One-way Analysis of Patient Conditions



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
COPD	12	12	13.65	15.29167	17.66667	21	41
COPD & GI_Bleed	12	13.26667	14.86667	17.5	20.18333	23.93333	36.66667
COPD & GI_Bleed & ARDS	18.36364	20.36355	23.73128	26.29524	28.26645	31.226	37.59574
COPD & GI_Bleed & Hyperglycemia	12.5	13.85	17.125	22.4	29.47917	39.275	39.8
COPD & Hyperglycemia	12.5	12.705	13.89286	14.92857	17.5625	22.11746	43.5
GI_Bleed	12	13.7	15.5	19.08	23.66667	27.90919	42.57143
GI_Bleed & ARDS	18.41176	22.575	24.93438	28	31.62782	36.63333	45.83333
Hyperglycemia	12.5	13.23333	15	18.33333	20.95238	25.1	26.5
None	12	12.5	13.6	15.4	17.60625	21.5	34.5
Other	13	15.66667	22.46429	28.37209	33.77513	37.88889	52.71429
Sepsis	12	14	15.29167	17.33333	20.35417	26	43
Sepsis & COPD	12	13.33333	14.6	17.4	21.45294	24.09167	34.33333
Sepsis & COPD & GI_Bleed	13	14.25	16.19048	19.94737	23.57487	29	35.7027
Sepsis & COPD & GI_Bleed & ARDS	23.625	23.682	25.2	27.4359	30.87786	40.84065	42.69091
Sepsis & GI_Bleed	12	14.71667	17.33333	22.375	27	35.1	48
Sepsis & GI_Bleed & ARDS	21	22.09593	25.04739	27.36364	35.35	41.41556	43.125

Figure 4-6 shows the analysis of mean (ANOM) and analysis of variance (ANOVA) method to examine different patient conditions.

For the ANOM, the dot represents the mean of the individual group, the UDL is the upper decision line, and the LDL is the lower decision line. Any individual group mean not contained in this interval is deemed significantly higher than the overall average of all groups if it lies above the UDL. Similarly, any group mean that falls below the LDL is declared significantly lower than the overall group average. Any group mean that falls between the intervals is not significantly different than the overall average of all groups.

This is the same for ANOVA, except the dot represents the variance of the individual group. Any individual group variance not contained in this interval is deemed significantly higher than the overall average variance of all groups if it lies above the UDL. Similarly, any group variance that falls below the LDL is declared significantly lower than the overall group average variance. Any group variance that falls between the intervals is not significantly different than the overall average variance of all groups.

Figure 4-6: ANOM and ANOVA for Patient Conditions

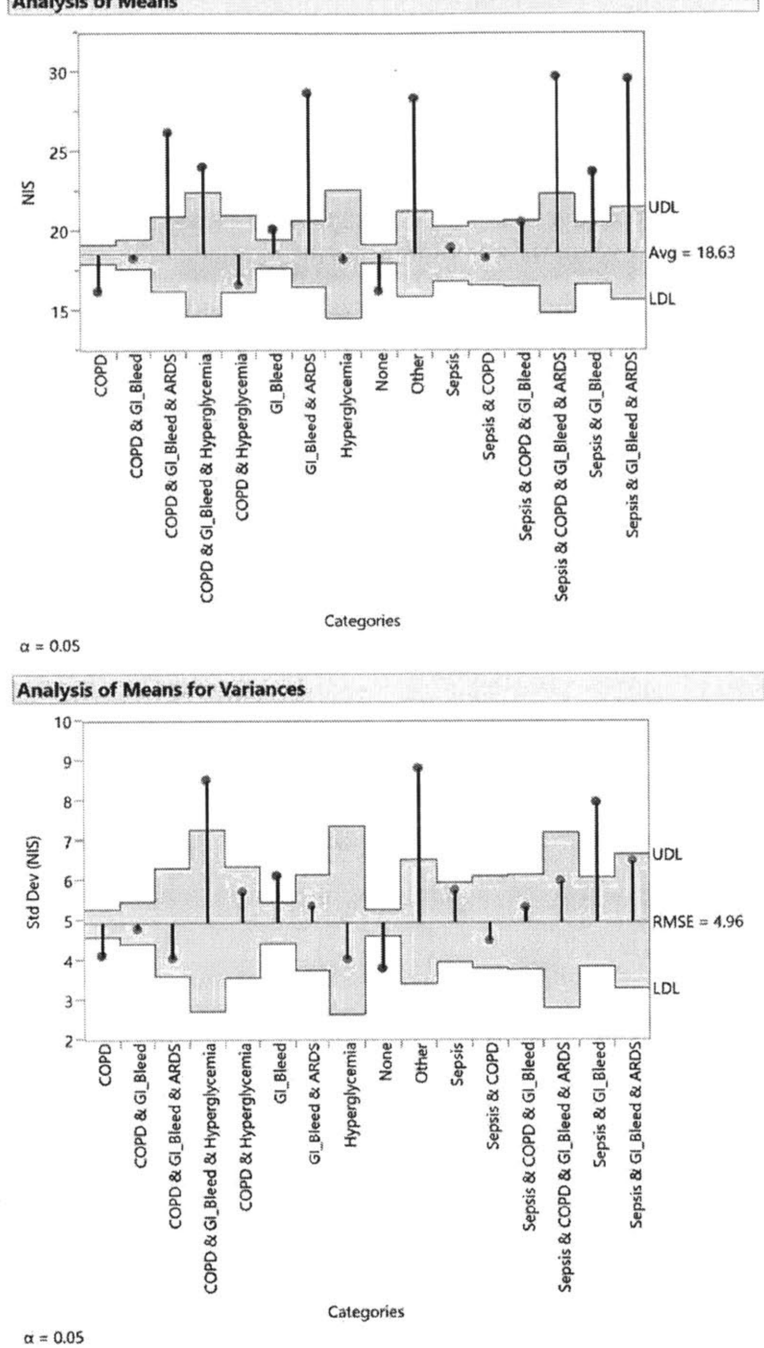


Table 4-2 shows the result from ANOM with patient conditions that had above or below the average load.

Table 4-2: Results from ANOM

High Load	Low Load
COPD with GI bleed and ARDS	COPD only
COPD with GI bleed and hyperglycemia	None of the conditions listed
GI bleed only	
Other combinations	
COPD with Sepsis, GI bleed, and ARDS	
Sepsis with GI bleed and ARDS	
Sepsis and GI bleed	

Table 4-3 shows the result from ANOM with patient conditions that had higher and lower variation than the overall patient population.

Table 4-3: Results from ANOVA

High Variability	Low Variability
COPD with GI bleed and hyperglycemia	COPD only
GI bleed only	None of the conditions listed
Other combinations	
Sepsis and GI bleed	

Combining the results from ANOM and ANOVA, we concluded that there were two main categories of patient conditions: high load and high variability, vs. low load and low variability. Table 4-4 shows the patient condition in each of these two categories with the number of patients in each category.

Table 4-4: Characterization of Patient Condition Based on Load and Variability

High Load & High Variability (# of Patients)	Low Load & Low Variability (# of Patients)
COPD with GI bleed and hyperglycemia (14)	COPD only (438)
GI bleed only (231)	None of the conditions listed (470)
Other combinations (29)	
Sepsis and GI bleed (55)	

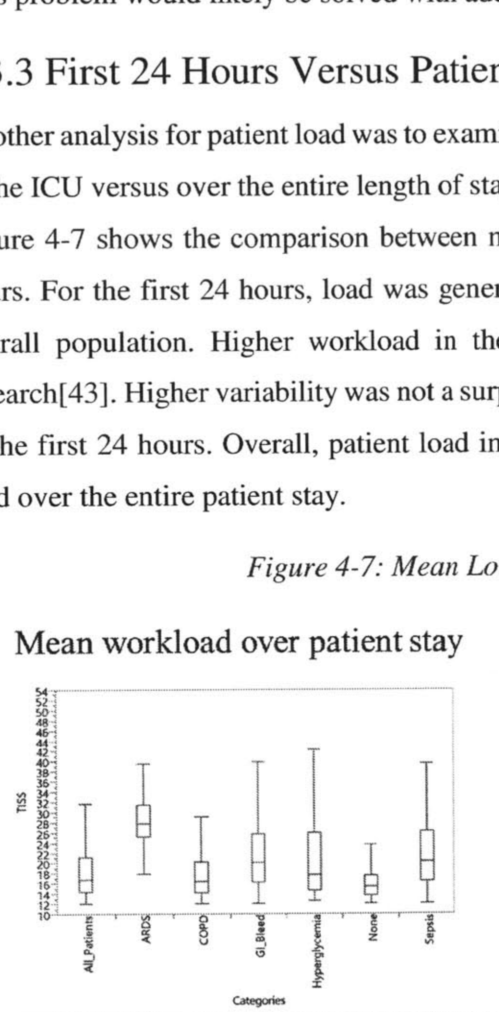
When comparing results from Table 4-4 to Figure 4-3, the low load & low variability conditions matched exactly, and the high load & high variability conditions also matched up quite well. However, Table 4-4 lacks conditions for high load & low variability and low load & high variability. This was not surprising, because the conditions for these two categories had small sample sizes (i.e., ARDS with 138 patients, and Hyperglycemia with 83 patients), and when separated into different combinations, it lacked the statistical power to generate significant results. This problem would likely be solved with additional data samples.

4.3.3 First 24 Hours Versus Patient Stay

Another analysis for patient load was to examine load and variability for the patient's first 24 hours in the ICU versus over the entire length of stay (method used for Section 4.3.1 and Section 4.3.2). Figure 4-7 shows the comparison between mean load over patient's stay vs load in the first 24 hours. For the first 24 hours, load was generally higher and variability was also higher than the overall population. Higher workload in the first 24 hours was expected based on previous research[43]. Higher variability was not a surprise, either, as the patients were generally less stable in the first 24 hours. Overall, patient load in the first 24 hours had similar characteristics as the load over the entire patient stay.

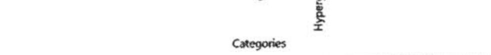
Figure 4-7: Mean Load vs Load in First 24 Hours

Mean workload over patient stay



Quantiles							
Level	Minimum	10%	25%	Median	75%	90%	Maximum
All_Patients	12	13	14.33333	16.75	21.25	27.17265	52.71429
ARDS	17.83333	22.86834	25.19688	27.86111	31.40132	36.87576	45.83333
COPD	12	12.8	14.2	16.5	20.2	26.47857	43.5
GI_Bleed	12	14	16.28571	20	25.7	30.90891	48
Hyperglycemia	12.5	13	14.5	17.66667	25.95652	33.34444	52.71429
None	12	12.5	13.6	15.4	17.60625	21.5	34.5
Sepsis	12	14.275	16.4381	20.35417	26.05769	33.39167	52.71429

First 24 hours



Quantiles							
Level	Minimum	10%	25%	Median	75%	90%	Maximum
All	12	12	14	18	24	32	62
ARDS	18	25	28	33	38	42	53
COPD	12	12	14	17	23	31	53
GI_Bleed	12	14	16	21	29	37	62
Hyperglycemia	12	12.7	14	19	33	42.6	53
None	12	12	13	15	20	25	41
Sepsis	12	14	16	22	30	38	60

4.4 Discussion of Patient Workload

Based on our findings, we can divide most of patients in MICU 6 into five conditions: COPD, GI bleed, Sepsis, ARDS, and hyperglycemia. In addition, the majority of patients were predictable, a few patients had high load but were predictable, and some patients were highly unpredictable. When dividing patients into unique combinations of patient conditions, most of the results were consistent with the primary patient condition analysis above; however, more data is needed to analyze the complete picture. Overall, we believe the classifying patients based on conditions is an excellent approach for prospective analysis of patient workload.

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5 Current State Analysis in MICU 6

After developing the NIS to measure patient workload in ICU, we leveraged it to analyze the current state workload in ICU. In addition to using data to compute and analyze workload at the ICUs, we shadowed nurses and doctors to observe the interactions between doctors, nurses, and patients. After shadowing, we collected preliminary observation data to identify potential areas of focus for further investigation. We also gained a much better understanding of the staffing patterns and organizational limitations faced by the hospital. Finally, we studied nurse staffing data and analyzed the effect of patient workload on staffing decisions.

5.1 Shadowing and Time Studies

In order to measure patient workload, we must first understand patient workload. The best way to do this was by shadowing nurses and observing patient workload first hand. We shadowed every ICU in BIDMC at least for one shift to witness the complexity of each ICU. Then, we shadowed MICU 6 over a two-month period to get a better understanding of the patient types, nursing workflow, and patient workload in the ICU. After gaining comprehensive understanding of relevant healthcare knowledge and nursing workflow, we conducted brief, "time and motion" studies to generate initial insights into measuring nursing workload. For 10 shifts, we captured the start and end time of different nursing processes, such as drawing labs, cleaning patients, and giving medication. In addition, we captured the number of *interruptions* (events that disrupt the workflow of the nurse to stop doing the current task) a nurse would face on a given shift to gauge the level of focus a nurse could dedicate to each patient.

Some initial insights gathered from observations and time and motion study:

1. There was no standardized processes for nursing workflow. For example, some nurses would conduct a brief patient assessment before giving morning medication, while other nurses would bring morning medication into the room before conducting patient assessment.
2. Patient workload seemed to be heavily dependent on the clinical acuity of the patient, but also from how demanding were the patients and families, and nursing experience.

3. A significant portion of patient workload was routine, such as assessing patients every 4 hours, turning patients every 2 hours, and giving medication to patients as prescribed.
4. Nurses spent about 30-35% of the time documenting patient vital signs, medication changes, and nursing activities. These documentation times are not directly measured in the current NIS implementation.
5. 1:2 nurses seemed to be busier than 1:1 nurses partially due to constant task switching between the two patients, even though the expectation was that they should have similar workloads. In addition, the distance between two patients are usually close (next bed, or two beds away), but occasionally, they can be on the opposite sides of the ICU.
6. In a shift, a typical nurse had over 25 major interruptions, such as patient family interactions, discussions with clinicians and other members of the care team about the patient, and requests from other nurses to care for other patients, that caused stoppage in workflow, and 1:2 nurses had even more interruptions.
7. For a nurse who took care of 2 patients, it was challenging for an outside observer to separate the task related to each patient, because tasks were generally batched together. For example, a nurse would pick up medication for both patients and document the changes for both patients in one sitting.
8. While less busy nurses were expected to help busier nurses, this was not necessarily true most of the time.

Given our observations, one idea we explored was to estimate patient workload based on routine tasks that need to be performed for patients with particular medical conditions. Figure 5-1 lists the routine events for a typical ventilated, heavy size, and fully sedated patient.

Figure 5-1: List of routine task with time it takes to do each one

Vented+A1:N27, heavy size, sedated														
		Med	(a line or CVP)				(trach only	(no assist)				(peg line)		batch with turnin
	PO meds	Slow presser	IV check & give drug	general asses & chart	RASS	System check	Suction	Turn only(2 people)	Mouth Care	Hygiene	CHG Bath	Labs	Gastric tub	Vented Restrains
7:00														
8:00	15 min		10 min	25 min	5 min	5 min	10 min		5 min	20 min			5 min	5 min
9:00														
10:00		6 min						15 min						5 min
11:00														
12:00				20 min					3 min	20 min			5 min	5 min
13:00														
14:00							10 min	15 min						5 min
15:00														
16:00		6 min		20 min					3 min	20 min			5 min	5 min
17:00														
18:00								15 min						5 min
19:00														
20:00	15 min		10 min	25 min	5 min	5 min			3 min	20 min	30 min		5 min	5 min
21:00							10 min							
22:00		6 min						15 min						5 min
23:00														
0:00				20 min					3 min	20 min			5 min	5 min
1:00														
2:00								15 min						5 min
3:00							10 min					10 min		
4:00				20 min					3 min	20 min			5 min	5 min
5:00														
6:00								15 min						5 min
Medication (add them up depending on patients)														
difference in oral meds vs feeding tubes														
crush meds	<8 15 mins													
	>8 20 mins													
IV med	5 min/med (miminum batching)													
Need to check POE in beginning of shift, after rounds														

Even though a large portion of patient workload tasks was routine, at least 25% of workload was unexpected (e.g., unexpected procedures, patient hygiene, patient's family interactions, and extra workload due to deteriorating patient conditions). In addition, the amount of time required to perform each tasks varied depending on the patient type (i.e., physically heavy and sedated patients require at least two to three nurses to turn and clean, while such tasks are much quicker for lighter and alert patients), and nursing experience (i.e., an experienced nurse can combine separate but closely related tasks together to speed up the overall workflow, while an inexperienced nurse would do them separately). Finally, 1:2 nurses would combine tasks from different patients together to save time, but the precious timing of each task was impossible to model and forecast. Because of all these differences and variability, patient workload was extremely difficult to measure accurately.

5.2 Operational Challenges to Staffing in ICU

After observing patient workload, our next step was to understand how patient workload was divided up into workload for each individual nurse, as a function of staffing decisions. Staffing decisions are dependent on the number of nurses in the ICU and how those nurses are assigned to take care of patients. Changing the number of nurses working in the ICU at any given time is a hospital level strategic decision that needs to be determined before the start of every shift. Changing nursing assignments to care for patients is a tactical decision that can be made in real time on a shift by shift basis.

Staffing decisions in ICU are limited by three major constraints, which limit its operational efficiency. First, the number of patients and their clinical acuity are often uncontrollable, and moreover, unpredictable. This limits the ability of the hospital to forecast nursing staffing ahead of time. Second, the hospital operates on a tight fiscal constraint, and there is a limited budget for nursing staff, which limits the number of staffed nurses available at any given time. Compounded with the effect of the natural uncertainly in nursing staff because of sudden illnesses or personal emergencies; this makes nurse staffing in ICUs more unpredictable and challenging to manage. Finally, the small size of individual ICUs, and the independent nature of each ICUs due to clinical specialties and organizational structure, limit the communication and interaction across the organization. This makes sharing of resources even more challenging.

ICUs in BIDMC attempt to overcome these issues mainly through bed meetings and informal load sharing mechanism between nurses. Bed meetings (meetings before every shift to discuss staffing decisions in each ICU) are intended to alleviate these challenges at the hospital level, while informal load sharing is used to address these challenges at the unit and shift level. In the ICU, if a nurse is overwhelmed, that nurse would potentially request for help, or other nurses would potentially come to her assist her. Often times, the resource nurse would be able to identify the spike in nursing workload, and either provide assistance or request other nurses to provide assistance. If the unit is too overwhelmed, such as when a patient is having cardiac arrest, the resource nurse often request other ICUs to provide assistance. Currently, there is no standardized process for the resource nurse to request assistance. The resource nurse would call the nursing manager to do one of two things, either call up every ICU to request extra nurse(s), or if that does not work, call nurses not currently on staff to come in for overtime. Some nurses felt the informal mechanisms were useful in balancing workload, but from our observations, they were not practiced consistently, depending on the specific personnel working in the ICU on a specific shift.

5.3 Evaluating Staffing Patterns at MICU 6

In order to examine the current staffing decisions in MICU 6, we developed several metrics based on the NIS described in Section 4.1. The first metric was looking at the correlation between the numbers of nursing staff to the overall patient load in the ICU. The second metric was measuring workload of individual nurses. The last metric was comparing the workload between 1:1 and 1:2 nurses, regular nurses and resources nurses. The goal was to formalize a process for measuring workload within MICU 6 and to identify potential areas of improvement using operations principles.

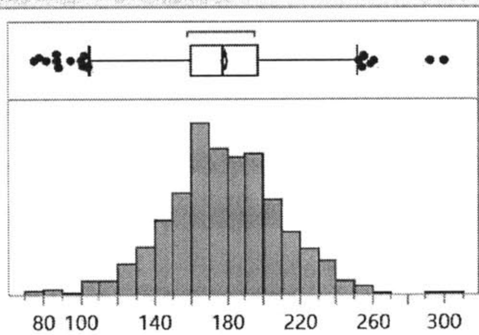
5.3.1 Nurse Staffing to Load

We calculated the overall patient load per shift by combining the NIS for each patient and each shift in MICU 6 over the two-year period (2012 to 2013). The goal was to understand the overall variability of workload in MICU 6. Figure 5-2 shows the distribution of overall patient workload per shift in MICU 6. The mean is 178.1, and the standard deviation is 29.8. There are some outliners, especially at the right end with a maximum of 300 overall patient workload. Since there are at most 8 patients in MICU 6, this means that the average workload per patient in that particular shift is 37.5, which is considered high workload. Even though the variability in the total load is a priori not very high, the ability for nurses to absorb higher than average load might be limited.

Figure 5-2: Distribution of Overall Patient Workload per Shift in MICU 6

Distributions

Shift NIS for MICU 6



Quantiles

100.0%	maximum	300
99.5%		254.37
97.5%		237
90.0%		217
75.0%	quartile	197
50.0%	median	177
25.0%	quartile	160
10.0%		141
2.5%		117.575
0.5%		96.575
0.0%	minimum	75

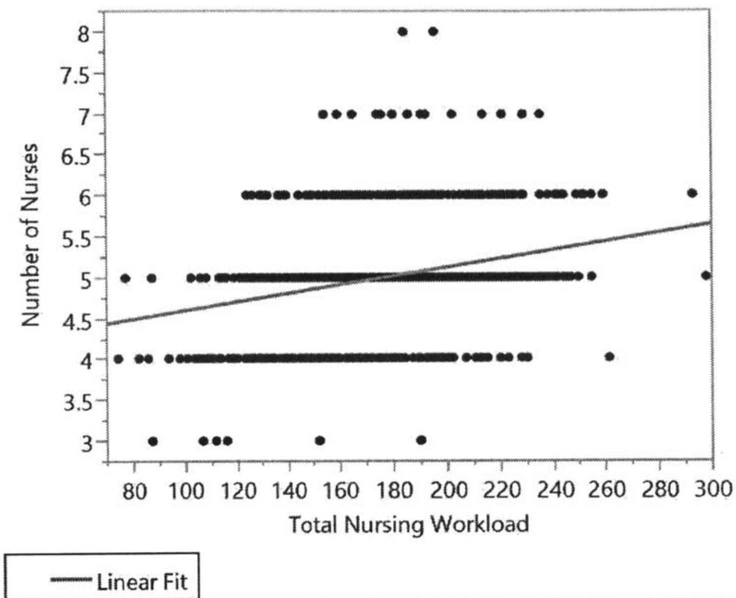
Summary Statistics

Mean	178.07319
Std Dev	29.778226
Std Err Mean	0.7787986
Upper 95% Mea	179.60087
Lower 95% Mean	176.5455
N	1462

Next, we analyzed the correlation between the nurse staffing level and patient load to determine whether staffing levels are adapted to changing workload. More specifically, we were interested to see if the number of nurses in MICU 6 varied with respect to the overall workload in the unit. To calculate the number of nurses in each shift, we obtained staffing data over the same period of time. Then, we mapped the total patient load with number of nurses, for each shift. Figure 5-3 shows a scatter plot with the number of nurses on the Y axis and the total patient load on the X axis, for each shift. The result shows that there is no apparent correlation between the number of nurses and total patient load ($R^2 = 0.07$, $p < 0.0001$). This indicates that nurse staffing in MICU 6 is in general not dependent on patient load, which could lead to overstaffing in some shifts and more importantly, understaffing in others.

Figure 5-3: Correlation Analysis between the Number of Nurses and Patient Load

Bivariate Fit of Number of Nurses By Total Nursing Workload



Linear Fit

Number of Nurses = 4.0856474 + 0.0052386*Total Nursing Workload

Summary of Fit

RSquare	0.070592
RSquare Adj	0.069956
Root Mean Square Error	0.564566
Mean of Response	5.014364
Observations (or Sum Wgts)	1462

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	35.34536	35.3454	110.8926
Error	1460	465.35300	0.3187	**Prob > F**
C. Total	1461	500.69836		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.0856474	0.08942	45.69	<.0001*
Total Nursing Workload	0.0052386	0.000497	10.53	<.0001*

5.3.2 Nursing Load

Subsequent to measuring workload at the unit level, we conducted a study of the workload at the individual nurse level. To calculate nursing workload, we had to match each patient to the nurse, who was responsible for taking care of that patient during that shift. However, in the current BIDMC IT system, there is no explicit way of doing so. The methodology we developed was to use the process that every nurse must write a nursing note, for each patient the nurse is assigned to take care. This process is supposed to be done before the end of each shift; however, due to heavy workload, sometimes this is not done in time before the shift ends. In that case, the nursing notes were usually written within the next 4 hours after the shift ended. In order match patients to nurses, we obtained all nursing notes written over the two year period. Then we cross-checked them with the staffing data in MICU 6, and assigned patients to each nurse in the ICU. Next, we calculated the NIS for all patients, and obtained the nursing workload by summing up scores for all patients assigned to each nurse. The result was the per shift nursing workload scores for all nurses in the ICU over the two-year period. However, there are some limitations in our analysis of nursing workload. The current model: (i) Does not account for help that nurses might give to each other informally during the shift, especially in extreme cases; (ii) Does not include extra nurses from other ICUs during crisis time; and (iii) Does not match every patient to a nurse because of missing nursing notes.

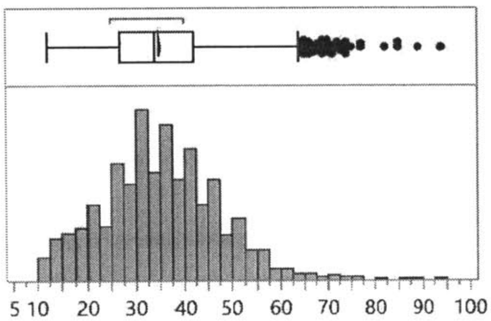
5.3.3 Distribution of Nursing Load

After calculating the nursing workload for all nurses in MICU 6, we studied the distribution of nursing workload. Figure 5-4 shows the individual nursing workload distribution in MICU 6. The distribution is right-skewed with a relatively long right tail. The mean is 34.75, and standard empirical deviation of 11.44. About 10% of nurses had a nursing workload of over 50, which equates to the workload of an extremely acute ICU patient. Overall, there was a wide range (82) of nursing workload over the two-year period.

Figure 5-4: Distribution of Nursing Workload in MICU 6

Distributions

Nursing Load



Quantiles

100.0%	maximum	94
99.5%		69
97.5%		57
90.0%		50
75.0%	quartile	42
50.0%	median	34
25.0%	quartile	27
10.0%		19
2.5%		14
0.5%		12
0.0%	minimum	12

Summary Statistics

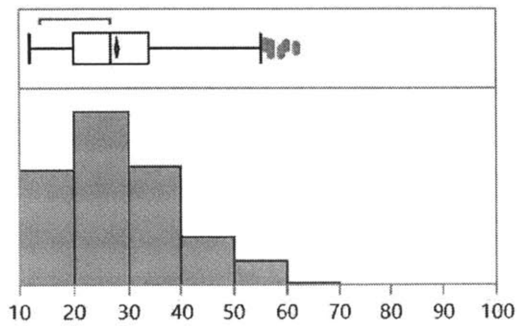
Mean	34.751149
Std Dev	11.443954
Std Err Mean	0.1371739
Upper 95% Mea	35.020052
Lower 95% Mean	34.482247
N	6960

Recall that the goal of nursing staffing assignment was to balance the load among nurses. Specifically, the intention is to assign heavy workload patients to 1:1 coverage and lighter patients to 1:2 coverage such that in general, all nurses have about equal total workload. Following on the observation that this is often not obtained, we studied this topic further. Figure 5-5 shows the nursing workload between 1:1 and 1:2 nurses in MICU 6. Note that 1:1 nurses have a mean workload of 27.89 and standard deviation of 10.51, while 1:2 nurses have a mean workload of 39.87 and standard deviation of 9.21. Our results indicate that 1:2 nurses had almost 50% more workload than 1:1 nurses, which invalidated the expectation that both groups should have similar workload. In addition, our calculation did not account for the task switching incurred when a nurse has to take care of 2 patients simultaneously. When task switching impact is included, the workload of 1:2 nurses would be even higher. Therefore, our model is underestimating the workload of 1:2 nurses, and thereby underestimating the imbalance of load between 1:1 and 1:2 nurses. However, resource nursing workload was included in this analysis, and because the assertion that resource nurses usually have 1:1 assignments with lighter workload, it is possible that resource nurses could have skewed the results.

Figure 5-5: Nursing Workload between 1:1 and 1:2 Nurses

Distributions Ratio=1:1

TISS



Quantiles

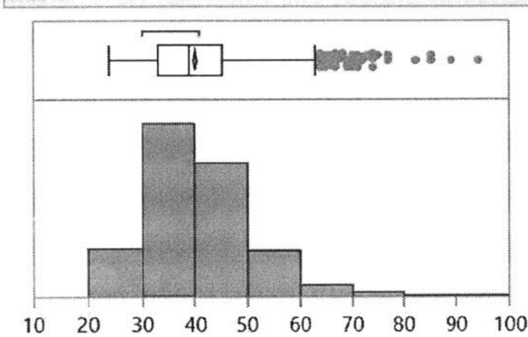
100.0%	maximum	62
99.5%		56
97.5%		52
90.0%		43
75.0%	quartile	34
50.0%	median	27
25.0%	quartile	20
10.0%		15
2.5%		12
0.5%		12
0.0%	minimum	12

Summary Statistics

Mean	27.892809
Std Dev	10.513869
Std Err Mean	0.1927286
Upper 95% Mea	28.270704
Lower 95% Mean	27.514914
N	2976

Distributions Ratio=1:2

TISS



Quantiles

100.0%	maximum	94
99.5%		71
97.5%		61
90.0%		52
75.0%	quartile	45
50.0%	median	39
25.0%	quartile	33
10.0%		29
2.5%		26
0.5%		24
0.0%	minimum	24

Summary Statistics

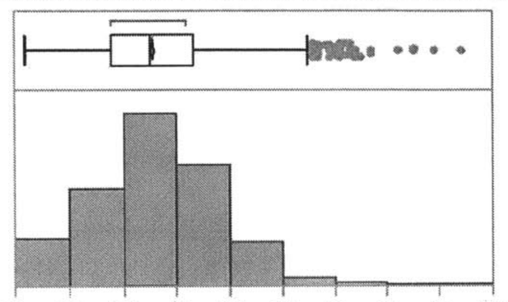
Mean	39.874247
Std Dev	9.2116029
Std Err Mean	0.1459404
Upper 95% Mea	40.160372
Lower 95% Mean	39.588122
N	3984

Another assertion we wanted to test was whether resource nurses have lighter load than normal nurses, because the resource nurse has more non-direct clinical care responsibilities area within the ICU than just patient care. Figure 5-6 shows the distribution of workload for resource nurses and for non-resource nurses. The mean workload for normal nurses (Resource=False) is 35.45 with standard deviation of 11.39, while the mean workload for resource nurses (Resource=True) is 30.12 with standard deviation of 10.72. Our results shows that resource nurses do indeed have less workload than normal nurses, which backs up the assertion.

Figure 5-6: Nursing Workload between Normal and Resource Nurses

Distributions Resource=False

TISS



Quantiles

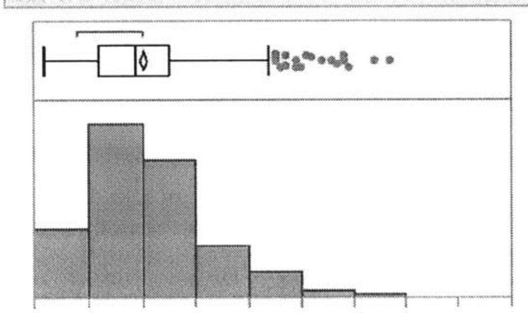
100.0%	maximum	94
99.5%		69
97.5%		58
90.0%		50
75.0%	quartile	43
50.0%	median	35
25.0%	quartile	28
10.0%		20
2.5%		14
0.5%		12
0.0%	minimum	12

Summary Statistics

Mean	35.447438
Std Dev	11.387462
Std Err Mean	0.1464028
Upper 95% Mea	35.73444
Lower 95% Mean	35.160436
N	6050

Distributions Resource=True

TISS



Quantiles

100.0%	maximum	77
99.5%		68
97.5%		54
90.0%		45.9
75.0%	quartile	35
50.0%	median	29
25.0%	quartile	22
10.0%		18
2.5%		14
0.5%		12
0.0%	minimum	12

Summary Statistics

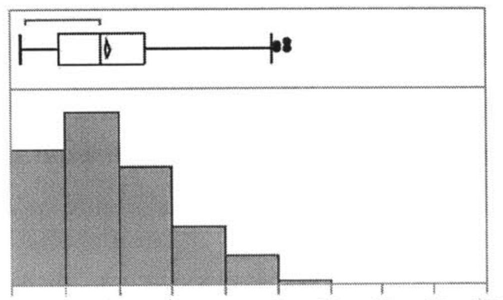
Mean	30.121978
Std Dev	10.724342
Std Err Mean	0.3555085
Upper 95% Mea	30.819691
Lower 95% Mean	29.424265
N	910

When resource nursing workload was excluded from the analysis of 1:1 and 1:2 nurses, the results were still the same: 1:2 nurses have almost 50% more workload than 1:1 nurses. Figure 5-7 showed the result of 1:1 and 1:2 nursing workload, excluding resource nursing workload. The 1:1 nurses have mean workload of 27.99 with standard deviation of 11.06, and 1:2 nurses have mean workload of 39.74 with standard deviation of 9.14. Our results show that the difference in workload between 1:1 nurses and 1:2 nurses was the result of the current patient-to-nursing assignment regulations.

Figure 5-7: Nursing Load between 1:1 and 1:2 Nurses w/o Resource Nurses

Distributions Ratio=1:1

TISS



Quantiles

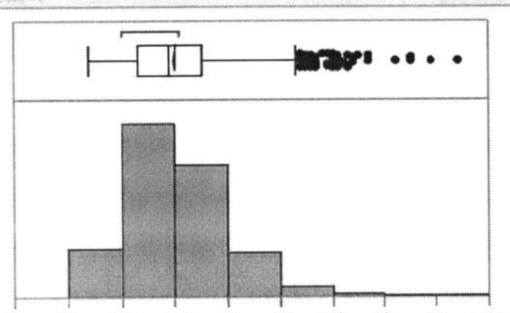
100.0%	maximum	62
99.5%		56.95
97.5%		53
90.0%		45
75.0%	quartile	35
50.0%	median	27
25.0%	quartile	19
10.0%		14
2.5%		12
0.5%		12
0.0%	minimum	12

Summary Statistics

Mean	27.989588
Std Dev	11.060251
Std Err Mean	0.2353245
Upper 95% Mea	28.451069
Lower 95% Mean	27.528108
N	2209

Distributions Ratio=1:2

TISS



Quantiles

100.0%	maximum	94
99.5%		71
97.5%		61
90.0%		52
75.0%	quartile	45
50.0%	median	39
25.0%	quartile	33
10.0%		29
2.5%		26
0.5%		24
0.0%	minimum	24

Summary Statistics

Mean	39.736527
Std Dev	9.1397336
Std Err Mean	0.1474726
Upper 95% Mea	40.025659
Lower 95% Mean	39.447395
N	3841

5.4 Discussion of Current State Analysis in MICU 6

Based on our observations, we identified several potential areas for further investigation as well as many operational constraints that must be taken into account. Because the ICUs have little to no control over the number of patients and how sick the patients are, they must be able to dynamically adapt to the changing patient workload, via staffing decisions.

When analyzing current state of staffing decisions in the MICU 6, we discovered that staffing levels in MICU 6 are not adapted to changing patient workload. The result is that some shifts have low nursing workload, while other shifts have extremely high nursing workload. In addition, we looked at the difference in workload between 1:1 and 1:2 nurses and noticed that in general 1:2 nurses have significantly more workload than 1:1 nurses, even after we took out resource nurses from our analysis. After analyzing the current states of MICU 6, we decided to focus on identifying methods to ensure better balance between different nursing workload.

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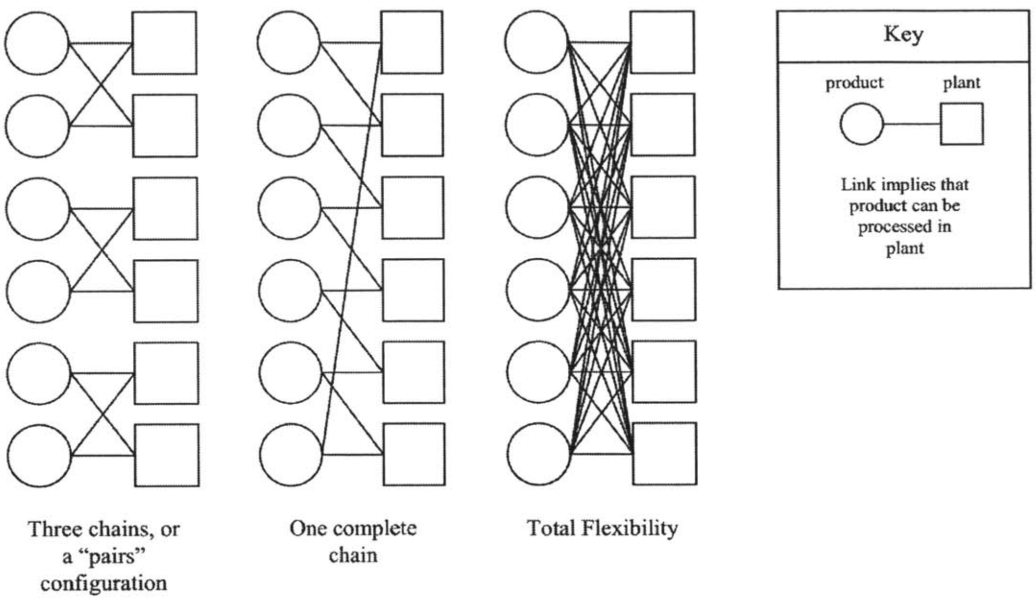
6 Solution Approaches and Results

One method to better balance nursing workload is to enable flexibility within the system to respond to sudden changes in workload demand. However, there are many organizational, legal, and practical constraints within the system to restrict the solution space. Instead of focusing on matching nurse staffing with patient workload, we decided to focus on balancing the workload between 1:1 and 1:2 nurses. Our idea was to improve process flexibility by implementing a *nursing backup system* that would designate a backup nurse for each nurse in the ICU. When a nurse is overwhelmed, a backup nurse can step in and offload work from the original nurse. We simulated different nursing backup systems and different nursing backup assignment options. We also explored ways to optimize the decision in which nurses backup each other based on load predictability.

6.1 Process Flexibility and Risk Pooling

Process flexibility has been widely used in manufacturing and supply chain settings to reduce risk and cope with uncertainties and variability in the system. In manufacturing, process flexibility is implemented to obtain the capability to produce different types of products in the same manufacturing plant or on the same production line [44]. The goal of supply chain flexibility is to improve market responsiveness in the face of uncertain future product demand. There are two types of process flexibility, limited flexibility and full flexibility. Limited flexibility is relatively easy and less expensive to implement, while full flexibility offers more versatility. However, in many settings, an optimized limited flexibility approach could have a performance that is very close to one of full flexibility [45]. In particular, Jordan & Graves [45] introduce the concept of *chaining* as a group of products and plants which are all connected, directly or indirectly, by product assignment decisions. In terms of graph theory, a chain is a connected graph. Within a chain, a path can be traced from any product or plant to any other product or plant via the product assignment links. Specifically, no product in a chain is built by a plant from outside that chain and no plant in a chain builds a product from outside that chain [45]. The long chain concept is illustrated in Figure 6-1. Full flexibility has the most flexibility, but one complete chain, also known as long chain, configuration performs remarkably close to full flexibility, even with much fewer links. Finally, the performance of separate "pairs" configuration is considered suboptimal compared to that of the long chain configuration, but it is still significantly better than having no flexibility in the system [46].

Figure 6-1: Flexibility Configurations [46]



Risk pooling is another important method used in supply chain management to reduce risk and cope with uncertainties and variability in the system [47]. Risk pooling suggests that demand variability is reduced if one can aggregate different demand streams, for example, across locations, across products or even across time. By aggregating demand streams, it becomes more likely that high demand from one stream will be offset by low demand from another. The result is a reduction in variability and a better system to respond to changes from the environment.

6.2 Potential Solutions and Challenges

In operations, matching supply of nurses with demand of patients would ensure patients receive sufficient nursing care without overstraining the nursing budget. As discussed in Section 5.2, ICUs have highly variable and unpredictable patient load, and there is no simple method to control for the incoming patient demand variability. Therefore, the supply of nurses must be able to adapt to the unpredictable nature of patient load.

One implementation approach is to use the concept of process flexibility to move nurses from an ICU with less workload to another ICU with relatively high workload. When an ICU is overwhelmed, it will request help and other ICUs will send nurses over in a well-defined and structured process. This is different from the current system because the new approach will introduce a well-defined and objective process to signal which ICUs are in need of assistance, and which ICUs can provide nurses to assist.

Another implementation approach is to use the concept of risk pooling to create risk pool of nurses who are unaffiliated with any ICU. Nurses in the risk pool can join a particular ICU that is overwhelmed. A cross ICU analysis is needed to determine the number of nurses needed in the risk pool, but our experience suggests that a few centralized nurses would suffice (similar to limited flexibility). This system is similar to the floating nurses system already implemented in BIDMC. The biggest difference is that a risk pool of nurses are not assigned to any ICU at the beginning of the shift, but rather move around to overwhelmed ICUs when the need occurs.

These two systems are not mutually exclusive. Overall, establishing either system will substantially buffer against the variability in patient load, and a combination of the two works the best. In order for either system to function, nurses must be cross trained to work in different ICUs. Currently, ICUs have specializations that would take years for nurses to cross train. However, there are many opportunities in ICUs that do not require specializations. For either system, nursing care needs to be standardized as much as possible across all ICUs and nurses need to be trained to accustom to the peculiarities in each ICU.

It is not straightforward to apply the two textbook operations solutions described above to ICU staffing decisions at BIDMC because of government regulation, organizational challenges, and cultural resistance. First, current government regulations require Massachusetts hospitals to assign a maximum of two patients per nurse [12]. This limits the flexibility of the ICUs to create a risk pool of nurses because risk pool nurses are not assigned to any particular patients and more nurses are needed in order to satisfy the legal requirement. Adopting this approach in ICUs could create a prohibitory fiscal constraints on the hospital budget because ICU nurses are expensive, and additional budget for a risk pool of nurses could be untenable. Second, ICUs in BIDMC are organized as a collection of small, independent ICUs with a different nursing management structure, which would cause significant administrative challenges in creating a risk pool or flexibly moving nurses across ICUs. Third, cultural differences among ICUs cause skepticism among nursing staff and make the sharing of nursing staff more challenging. Due to the different patient workflow of each ICU, what looks like heavy nursing workload is different from one ICU to the next. Cultural differences cause other ICUs to be skeptical of the request for additional nursing staffs and reduce the willingness to help. Because of these challenges, other approaches to improve staffing decisions must be considered.

6.3 Backup Nursing Assignments

Instead of changing the supply of nurses in the ICU, we will examine methods to balance the workload of nurses within the unit level. As we showed in Section 5.3.3, 1:2 nurses in MICU 6 have significantly more workload than 1:1 nurses, even when 1:1 and resource nurses are not taken into account. There are two methods to balance workload within a unit specifically: improving the process by which nurses are assigned to care for each patient, and increasing flexibility in case the nursing load is unpredictably high. Currently, nursing assignments are determined by the resource nurses using best judgment based on a number of factors, such as clinical acuity of patients, experience of nurses, and continuity of nursing care for patients. Due to the complex number of factors in determining nursing assignment, it is relatively challenging to develop a formalized system that is definitively better than the current system. Nevertheless, we propose creating backup nursing assignments that would be activated when a nurse is overwhelm by offloading work to a backup nurse. Backup assignments system is a way to implement process flexibility.

6.4 Modeling Nursing Backups in ICU

In order to estimate the impact of backup assignments on the overall nursing workload of MICU 6, we decided to simulate different backup assignment plans. We used two years of patient data and nursing assignments to recreate the nursing workload environment for every shift in MICU 6. Then, we simulated nursing workload under different backup assignments plans and measured the effectiveness of each.

6.4.1 Modeling Formulation

The goal of the simulation was to decide on the assignment plan that can best provide flexibility to the unit. In the simulation, we are keeping the original assignments the same (between a nurse and a patient), and the only thing we are simulating is the backup paring assignment. However, “best” can be challenging to define. For our simulation, we wanted to find the backup method that minimizes the overloaded nurses after implementing the backup assignment mechanism. We defined *overworked* nurse as a nurse that experiences a workload that is 150% or higher relative to the mean nursing workload over the two-year period (mean nursing workload is 34.7, so overworked nurse has a load of 52 or higher).

The structure of the model was to transfer workload score from the primary nurse to the backup nurse, when the primary nurse needed help and the backup nurse had the capacity to help. In our simulation, we experimented with the threshold of when a primary nurse would request help from the backup nurse (called request help threshold in simulation) and the limit when a backup nurse would stop helping the primary nurse (called help limit in simulation). Based on simulation results, and more importantly, logical reasoning, we decided that a nurse would request help when workload was over the mean workload, and a backup nurse would continue to help when workload was below the overworked threshold. In the case that the primary nurse was over the request help threshold and the backup nurse was below the help limit, workload would be shared between the nurses evenly.

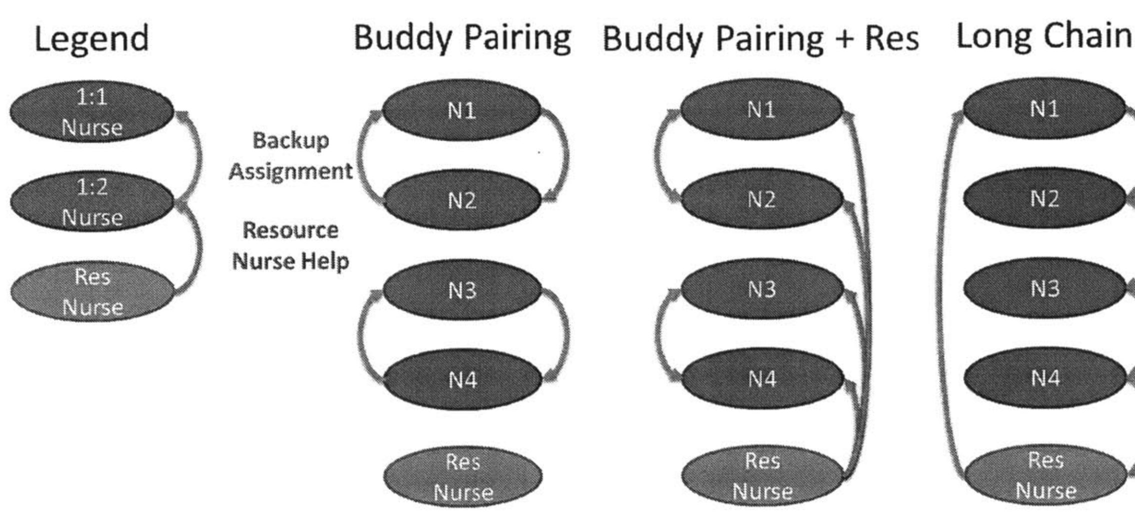
The simulation was coded in Python (Python 3.4.2 with Pandas 0.15.2 for large data manipulation and analysis) with the NIS for each patient and nursing workload scores as the main source of input. The ICU was simulated through objective language with classes for shift, nurse, and patient. First, the program reads the NIS and creates a patient object for each shift the patients are in the ICU. The patient object consists of NIS for the patient, the nurse who took care of the patient, and the patient’s conditions. Then, the program reads the nursing assignment and creates a nurse object for each shift the nurse works in the ICU. The nurse object consists of the nurse’s workload, nurse to patient ratio, resource nurse, and the list of patients. Finally, a shift object is created and consists of every shift over the two-year period. This included of all nurses and patients on that shift.

After the ICU environment was modeled, we implemented the assignment of backup nurses for each of the approaches we decided to model. The actual assignments of patients to nurses was randomized to eliminate any peculiarity with the starting environment. Then, a function distributes the workload between primary nurses and backup nurses based on the request help threshold and help limit parameters. Finally, a function calculates the number of overworked nurses and the standard deviation of nursing workload after the assignment plans. The result is output to a csv file for statistical analysis using SAS JMP Pro 11.2.0 (64-bit).

6.4.2 Modeling Results for Nursing Backup Assignment Plan

Several backup assignment plans were tested to determine the viability in MICU 6 environment. Figure 6-2 shows the three backup assignment plans we tested: (i) Buddy pairing, (ii) Buddy pairing with resource nurse help; and (iii) Long chain. Buddy pairing is pairing 1:1 nurses with 1:2 nurses as backup for each other. Buddy pairing with resource nurse is pairing 1:1 non-resource nurses with 1:2 non-resource nurses as backup for each other, and having the resource nurse backup the entire unit. Long chain is for Nurse A to backup Nurse B to backup Nurse C and so forth. Long chain is actively used in supply chain and manufacturing. The goal of long chain is to share workload as evenly as possible. An extra limitation was added into the long chain model by restricting the amount of workload that could be transferred to another nurses to 33% of mean nursing workload over the two-year period. This limitation was needed because otherwise, workload would be evenly distributed across the system.

Figure 6-2: Simulated Backup Assignment Plans



The results of the simulated backup assignment plans were compared to the original model and the ideal model. The original model was the ICU model without any backup assignments. The ideal model was a hypothetical best case scenario where workload was divided evenly among all nurses in the shift. The ideal model established the best possible result for any workload sharing model without changing the number of nurses or the total patient load.

Table 6-1 shows the number of overworked nurses and coefficient of variation of nursing workload, for each of the assignment plans. The original model had 503 overworked nurses with a coefficient of variation of workload of 0.34. With a total of 1460 shifts over a two-year period, there was approximately 1 out of 3 shifts where at least one nurse was overworked. This is potentially concerning, because, as discussed in Section 3.1, overworked nurses negatively affect patient safety and nursing job satisfaction. Even with the ideal model, there were still 29 nurses who were overworked during the two year period.

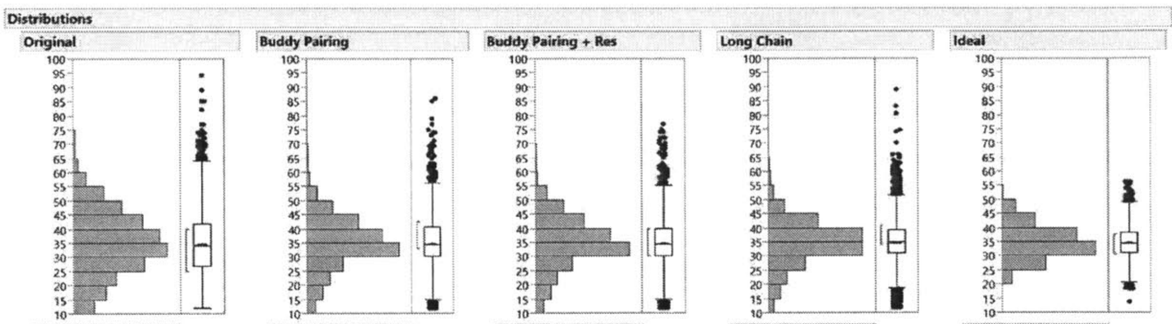
With a simple buddy pairing model, the number of overworked nurses was reduced by 67% to 164 nurses and the Coefficient of Variance (CV) of workload was reduced to 0.27. A more complex buddy pairing with resource nurse support model reduced the number of overworked nurses by 76% (10% more than the simpler buddy pairing model) to 121 nurses and reduced the CV of workload to 0.27. The long chain had slightly better performance; it reduced the number of overworked nurses by 78% to 110 nurses and reduced the CV of workload to 0.23.

Table 6-1: Number of Overworked Nurses and CV of Workload for Backup Assignment Plans

Assignment Plan	Overworked Nurses	CV of Workload
Original (No Plan)	503	0.34
Buddy Pairing	164	0.27
Buddy Pairing + Res	121	0.27
Long Chain	110	0.23
Ideal Model	29	0.17

Figure 6-3 shows the nursing workload distribution for all backup assignment plans in a graphical format. As discussed in Section 5.3.3, the original nursing workload was a right-skewed distribution with long right tail. The buddy pairing model distorted the right-skewed distribution by redistributing workload from nurses at the extreme and moving them towards the middle, and thereby significantly increasing the number of nurse with medium or slightly above medium workload. The buddy pairing with resource nurse model had similar effect as the buddy pairing model, but with a better ability to move more nurses from the extreme to middle load. The long chain model was even better at redistributing workload, and it created a much narrower right-skewed distribution, with fewer nurses at the right tail. The ideal model had the narrowest distribution with the fewest number of nurses at the right tail, but it was still a normal distribution because of the differences in total patient load to number of nurses for each shift.

Figure 6-3: Nursing Workload Distribution for Backup Assignment Plans



Quantiles		Original	Buddy Pairing	Buddy Pairing + Res	Long Chain	Ideal
100.0%	maximum	94	86	77	89	56.25
99.5%		69	62	60.195	59.195	50.6
97.5%		57	51	51	49.1859	46.995
90.0%		50	45.5	46	43.375	42.4
75.0%	quartile	42	40.5	40	39.3438	38.2
50.0%	median	34	34.5	34.5	35	34.4
25.0%	quartile	27	30	30	31	31
10.0%		19	22	22	24.1313	27.8
2.5%		14	15	15	16	23.805
0.5%		12	12	12	12.1006	21.6
0.0%	minimum	12	12	12	12	14

Summary Statistics	Original	Buddy Pairing	Buddy Pairing + Res	Long Chain	Ideal
Mean	34.751149	34.751149	34.751149	34.751149	34.751149
Std Dev	11.443954	9.1545306	9.032676	7.8457676	5.7164191
Std Err Mean	0.1371739	0.1097315	0.1082709	0.0940439	0.0685203
Upper 95% Mea	35.020052	34.966257	34.963393	34.935504	34.88547
Lower 95% Mean	34.482247	34.536042	34.538905	34.566795	34.616829
N	6960	6960	6960	6960	6960

6.4.3 Modeling Results for Nursing Backup Pairing Methods

The next simulation was to test the methods in which nurses were assigned to backup other nurses. This is most relevant when trying to pair nurses to backup each other. The intent was to use criteria that was based on information available at the beginning of the shift to best simulate informational uncertainties when the pairing happened.

There were five pairing methods: (i) Random; (ii) Based on nurse to patient ratio; (iii) Based on patient condition; (iv) Based both nurse to patient ratio and patient condition; and (v) Ideal pairing based on retrospective data. The based backup assignment plan for this simulation was the buddy pairing with resource nurse model. The first method was randomly pairing nurses together. The second method was to pair nurses based on nurse to patient (N:P) ratio by pairing 1:1 nurses with 1:2 nurses as much as possible. The third method was to pair nurses based on patient conditions by pairing nurses, who took care of high risk patients with nurses who took care of low risk patients.

High risk patients had predictably high workload and low risk patients had predictably less workload. Based on results from Section **Error! Reference source not found.**, we identified patients with high risk as having ARDS, and patients with low risk as having COPD, or none of the patient conditions. The fourth method was to pair patients based on both nurse to patient ratio and patient conditions. The fifth method was the theoretically best case scenario by retrospectively pairing nurses with the highest workload with nurses with the least workload.

Table 6-2 shows the results of all five pairing methods along with the original model. Models using random and N:P ratio pairing had the same results with 121 overworked nurses and CV of workload at 0.27. Models using patient condition pairing performed better with 115 overworked nurses and CV of workload at 0.27. Model using both N:P ratio and patient condition pairing performed the best with 108 overworked nurses and CV of workload at 0.26. Finally, ideal pairing model using retrospective data had 49 overworked nurses with CV of workload at 0.23. The ideal pairing model was worse than the ideal backup assignment model in 6.4.2 because ideal pairing model restricted to distributing workload between pairs of nurses, instead of evenly distributing workload among all nurses in the unit.

Table 6-2: Number of Overworked Nurses and CV of Workload for Backup Pairing

Backup Pairing Plan	Overworked Nurses	CV of Workload
Original (No Plan)	503	0.34
Random	121	0.27
N:P Ratio	121	0.27
Patient Condition	115	0.27
N:P Ratio & Patient Condition	108	0.26
Ideal Pairing	49	0.23

6.5 Discussion for Nursing Backup Simulations

Results from simulation and modeling showed that backup assignments made significant improvements over the current state. Based on simulation, long chain was the best backup assignment plan; however, it can be difficult and confusing to implement in the ICU. Buddy pairing did not perform as well, but it is much easier to implement and understand. According to senior nurses, an informal buddy pairing system already exists in the ICU, so the improvement from buddy pairing model could be less because the original state was not as bad as currently modeled. The buddy pairing with resource nurse as the ultimate backup support was just an extension to the current responsibilities of the resource nurse in MICU 6. Based on complexity of design and improvement to nursing care, buddy pairing with resource nurse was the best model to implement in MICU 6.

Another critical issue to consider was the process of pairing nurses together as backups. From our simulation, even pairing the nurses in random manner would significantly improve over the current state. In fact, random pairing was equal to or slightly worse than any prospective pairing models. In terms of overall improvement, pairing nurses based on N:P ratio and patient condition was the best. Because of the patient details and patient workload modeling required, this model could be considered as predictive assignment. As with many predictive models, the assignment would improve with larger volume and better accuracy of data. Therefore, the predictive assignment model could be improved over time.

7 Results and Next Steps

7.1 Results

After analyzing nursing workload in BIDMC ICUs, and more specifically MICU 6, we discovered three main operational challenges: (i) Patient workload is highly variable and unpredictable; (ii) Staffing levels in MICU 6 are not adapted to changing patient workload; and (iii) Workload among individual nurses is unbalanced, with 1:1 nurses doing almost 50% more nursing work than 1:2 nurses.

We identified two solutions to mitigate the operational challenges faced by MICU 6: (i) A prospective approach to analyze patient workload based on patient conditions; and (ii) A nursing backup system to better balance workload among individual nurses.

First, we developed the foundation to a prospective approach to predict workload and capture the aspect of variability by examining workload based on different patient conditions. This could hopefully be used in the future to inform staffing decisions to better match nursing staffing levels with changing patient workload. We discovered that, the majority of patients had predictable workload, including a few patients who had high but predictable workload. At the same time, some patients had highly unpredictable workload.

Second, we created backup nursing assignments that would be activated when a nurse is overwhelm by offloading work to a backup nurse. This could help balancing workload among individual nurses by using process flexibility. We simulated various backup assignments in order to estimate the impact of backup assignments on the overall nursing workload of MICU 6. We discovered that, overall, the combination of buddy pairing with a resource nurse as the ultimate backup and predictive assignment of backup nurses yielded the best result with the most practical design.

Even though the results of our analysis are directly applicable only to the MICU 6, the methodology of our research is applicable for analyzing all types of ICUs throughout the hospital.

7.2 Next Steps

7.2.1 Verification of Nursing Intensity Scores

Even though the current NIS was derived from the widely used TISS-28 checklist, it has not been verified at the BIDMC ICU environment. Verifying the NIS with data collection is important because it gives the NIS additional credibility. Time and motion study and/or expert opinions could verify the NIS in one of two ways

A time and motion study will be a more involved process that needs the cooperation from many stakeholders, from hospital administrators, clinician staffs, nursing staffs, and even patients in the ICU. A possible time and motion study method is to perform a multi-moment recording (MMR) of nursing activities, similar to the one used to verify the NAS. During a two-week period, nurses will record activities from a set checklist at random intervals throughout the day (about 30 moments in 24 hours). At the same time, an independent staff member will conduct a registration of nursing activities (RNA) of care for patients in the ICU using the NIS checklist. Estimation of time spent on each item can be calculated using the work sampling method, which is the relative time spent on each activity that can be estimated by taking concurrent samples of work-related activities. By combining the RNA as the basis for work sampling method with MMR as the concurrent time samples, the items and weights of NIS can be verified [15].

A simpler method to verify the NIS is to use expert verification. A cross-disciplinary panel of experts from nursing care and human factors studies needs to discuss the merits of NIS within the ICUs of BIDMC. If the panel is satisfied with the accuracies of NIS to reflect nursing care in the ICUs, then the NIS is verified to BIDMC standards.

7.2.2 Development of Support Tool based on Nursing Intensity Score

We recommend that BIDMC develop an operational decision support tool based on the NIS system to better understand current nursing workload, as well as satisfying the state regulation to use a nursing acuity tool for nursing assignments. Operationalizing the NIS into IT system at BIDMC will allow leveraging it to support decisions. The architecture of the current NIS system is optimized for retrospective study only, due to differences in database input, environment objects, and output formatting. We recommend BIDMC develop a prospective tool to analyze patient workload using NIS for operational decision support.

Our retrospective study was based on data files gathered by the hospital data analysts using manual prompts retrieve data from the database. For a production system, we propose changing the program to be able to automatically pull data continuously for all patients. Furthermore, database headers should be standardized or preprocessed to ensure compatibility. Finally, database inputs should be verified in an automated system to ensure the data is accurate and complete for all fields before being consumed by the program in order to avoid data corruption.

In addition to changing database inputs, the entire system architecture should be changed from the current way of calculating NIS for a group of patients simultaneously to calculating NIS for individual patients continuously. This involves changing the current databased optimized architecture, such as using Pandas, to a more customized object oriented structure. Finally, we propose exploring new ways to output NIS results to reflect the needs of a real-time system. This should include the principles for user interface design into the program by considering learnability, efficiency and safety.

Overall, we propose an agile approach in designing and verifying a real-time NIS system. This will ensure usability and functionality of the system will suit the needs of BIDMC ICUs as much as possible.

7.2.3 Pilot Nursing Backup System

We recommend piloting the nursing backup system in MICU 6 and measuring results to assess the validity of our simulation. Nursing backup simulation results show that buddy pairing nurses using predictive assignments with resource nurse as the ultimate backup is the best option. However, our simulation shows that even a simple buddy pairing backup system should balance ICU nursing workload dramatically. Therefore, we recommend starting a small-scale pilot in MICU 6 to formalize the process of pairing nurses to backup each other. We understand that the nursing backup system already happens informally within the ICU. What we want to do is to expand it to a formalized process so backup nurses will be assigned before the beginning of the shift. A formalized process will designate backup nurses when it is calm so that when things get hectic, nurses will know who to reach out to for backup, thereby avoiding miscommunication issues.

We recommend measuring the results of the pilot study both quantitatively and qualitatively. Quantitative methods of measuring pilot results includes retrospective studies based on NIS for the unit, and the overall number of harms. Additional measures to gauge the operational parameters of the nursing backup system should be created: the number of times backup nurses helped primary nurses, the type of work that backup nurses assisted with, and level of primary nurses' workload reduced by backup nurses. In addition to quantitative methods, we recommend assessing the pilot using qualitative methods in order to get a complete picture of the impact from nursing backup system. Qualitative methods includes surveying nursing staffs on the perceived usefulness of the system, conducting anonymous patient questionnaires gauge the effect on overall patient care, and polling hospital administrators on the assess the burden of the system. By using a combination of quantitative and qualitative methods, BIDMC will have all the information to assess the overall feasibility of using nursing backup system in the ICU.

7.2.4 Examination of Different ICUs

Another important area for future work is to expand the current nursing workload study conducted in MICU 6 to other ICUs within the hospital. Expansion of the study to other ICUs is important because nursing workload in MICU 6 is potentially different from other ICUs. For example, the typical conditions and the types of interventions might be significantly different across ICUs. Therefore, the current findings may not apply to nursing workflow in other ICUs. In order to understand nursing workload in other ICUs, a standardized process proposed in Section 7.2.7 must be established. To expand workload studies to other ICUs, BIDMC should do the following:

- Identify key patient conditions that is based on individual ICUs
- Study workload and variability of different patient conditions
- Assess and model staffing decisions based on the customized workflow of individual ICUs
- Simulate process improvement results
- Pilot to get feedback
- Evaluate the overall system performance
- Roll out to the finalized plan to the entire ICU

By following the process above, many of the programs and models developed for the current study can be reused for studies of other ICUs. This will save time and resource for the hospital to expand learnings to all ICUs.

7.2.5 Measuring Instantaneous Load

A concept we developed during our research was to measure instantaneous nursing workload. The main advantage of measuring instantaneous load is the ability to objectively indicate which nurses are overwhelmed and which nurses have the ability to help in real time. A mechanism to measure instantaneous load coupled with a warning system will allow proactive and consistent support and backup. In addition, an instantaneous measurement system would provide an unbiased tool to arbitrate staffing in a risk pooling system or flexible staffing system.

Even though we did not measure instantaneous workload in our study, we believe it is possible because most of nursing workload is very routine and predictive. During our discussions with clinicians and senior nurses, we were told that even for highly variable patient workload, it is possible to gauge the instantaneous workload based on real time patient data. Generally, patient vital signs will change before additional drastic interventions to the patient. Using patient data coupled with expected procedure schedules, we believe it is possible to map out patient workload in fine gradients (every 5 minutes or less) to provide instantaneous workload measurements.

7.2.6 Measuring Disruptions and Task Switching

A study to measure disruptions and task switching penalties on nursing workflow would highlight their impact on disrupting the flow in the ICUs. When we were shadowing and observing in the ICUs, we noticed nurses were constantly interrupted by external disruptions that caused them to stop the task they were doing and switch to handle the disruption. This caused inefficient workflow because there is set-up time involved during every task switch. We believe identifying the types of disruptions, quantifying their occurrences, and recording their impact on nursing workflow would be important next steps in understanding the intricacies of nursing workload. The goal of the study is to identify potential areas for process improvements to reduce the number of disruptions in the ICUs.

7.2.7 Process for Evaluating Process Improvements

We recommend the hospital to formalize a process for continuously improve healthcare operations. In our research, we divided our work into three parts: discovered possible issues through observations and discussions, identified the issue by measuring the current state using data, and modeled possible improvement for expected results. Following our research, we hope MICU 6 will pilot our recommendations, evaluate the results, and eventually implement them throughout the ICU. Because the patient safety is involved in ICU process changes, we recommend modeling the possible effects before piloting. Finally, we recommend a formalizing a five-step process to all process improvements in the ICU: discover, assess, model, pilot, and evaluate.

7.2.8 Improving Healthcare IT System

We recommend that BIDMC improve their current healthcare IT system to provide more accurate information for assessing and analyzing ICU operations. One of the challenges we encountered throughout our research project was difficulty in getting accurate information on essential components of ICU operations, such as the care team that took care of the patient while in the ICU. Another challenge was the lack of integration between different healthcare IT systems employed throughout the hospital, such as not being able to find out which patients had GI procedures, because the GI team employs a completely different system. Overall, the hospital had a large quantity of information on patients, but severely lacked information on staffing and hospital operations.

As a result of lacking critical pieces of data from the current system, our study of ICU operations was not as complete as it could have been. In order for a more accurate review of hospital operations to work, we propose the following additions to BIDMC's IT system:

- Integrate different IT systems employed throughout the hospital into a unified system for information sharing and distributing
- Collect information on hospital staffing in a systematic way to be able to identify the care team of the patient
- Create an interface into the existing system to specify why a patient is in the ICU and the latest diagnosis

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