The Influence of Hospital Resource Factors on Adverse Health Outcomes

Tolulope Abe

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

2017

Reading Committee:

Linda Ng Boyle, Chair

Richard Lee Storch

Shan Liu

Program Authorized to Offer Degree:
Industrial & Systems Engineering

University of Washington

Abstract

The Influence of Hospital Resource Factors on Adverse Health Outcomes

Tolulope Abe

Chair of the Supervisory Committee:
Chair & Professor Linda Ng Boyle
Industrial & Systems Engineering

Background: The research featured in this dissertation aims to determine the association between resource factors and adverse health outcomes in a hospital setting. Past studies have examined this association using patient populations from a single hospital admission source, such as the emergency or surgical departments. These studies have employed various statistical methods such as logistic regression, weighted least squares regression, and Cox proportional hazard modeling. To date, a more holistic approach that accounts for multiple hospital resource factors (number of beds available, number of staff available, and daily patient volume) as well as outcomes of readmission and mortality have not been studied extensively across different patient populations. As differences can be observed given patient age, admission sources, and existing health conditions, these patient characteristics are important to consider and model. Few studies have also accounted for the hierarchical data structures of the unit-patient relationship and explored how demand for and supply of services and resources, such as patient to staffing ratios, effect the hierarchical data structures.

Objectives: This research study seeks to identify the influence of controllable hospital resource factors on two (2) adverse health outcomes: 1) 30-day readmission and 2) in-hospital mortality.

Research Aims: The following research aims will be addressed:

- *Aim 1*: Determine the patient risk factors that influence the risk of each adverse health outcome.
- *Aim 2*: Determine the hospital resource factors that influence the risk of each adverse health outcome.
- *Aim 3*: Determine if the risk-adjusted association between hospital resources and adverse health outcomes differ by nursing unit. If so, determine if demand:supply ratio measures, including bed occupancy and staffing ratios, contribute to the unit-to-unit variation.

Methods: Binomial & LASSO logistic regression methods are used to relate explanatory variables to patient health outcomes. The explanatory variables included in hospital resource factors are nurse staffing volume, bed availability, admission volume, discharge volume, day and time of admission, and day and time of discharge. The adverse health outcome (response) variables are 30-day readmission and in-hospital mortality. The model accounts for patient characteristics such as age, severity of illness, risk of mortality, and admission source. The hospital setting used for this study was the University of Washington Medical Center. The study population included all patients who were discharged from the medical center between January 1st, 2012 and July 30th, 2015.

Potential Contribution: Such research can help hospital decision/policy makers determine resource capacity and healthcare delivery needs in order to mitigate the occurrence of adverse patient outcomes.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

To my advisor, Professor & Chair Linda Boyle—Thank you for your guidance throughout my Ph.D. journey. I have learned a great deal from you academically and professionally, and I am honored I had the opportunity to work with you.

To my Reading Committee—Thank you for your support and guidance throughout the Ph.D. process and beyond. I appreciate the time you dedicated towards the successful completion of my academic pursuits.

To the Industrial & Systems Engineering Faculty & Staff: Thank you for all your support since I entered the department and for cheering me on all the way to the finish line!

To Kenny & Sarah Gimbel-Sherr—Thank you for giving me the opportunity to work with and learn from both of you. I am inspired by all you have done and continue to do to improve the welfare of those in need.

To Jan Harrison, the Seattle Chapter of the ARCS Foundation, and the Althea Stroum Family—Thank you for your generous contribution towards my education.

To my family—I owe all my accomplishments to the many sacrifices you have made for my education. Thank you for your unconditional love and limitless support.

DEDICATION

to dad, mom, james, and mikey

—i love you.

Chapter 1

INTRODUCTION

Hospitals are comprised of multiple, complex processes within an overarching healthcare delivery system that consists of inputs, transforming processes, and outputs [1]. Inputs include patient demand, providers, purchasers, and suppliers, while outputs consist of a patient health outcomes, resource utilization, and overall perception [1]. The transforming processes are comprised of various clinical, management, and ancillary processes required to provide healthcare services to meet patient demand. These transforming processes occur in different departments and nursing units where patients receive care including both outpatient (e.g. emergency department, surgery department) and inpatient (e.g. medical/surgical units, intensive care units) treatment areas. From the patient's perspective, a patient should receive quality care in a timely manner with minimal delays [2], however this may not always be possible due to limited capacity and resource constraints [3]. Imbalances between patient demand and hospital resource factors adversely impact healthcare delivery outcomes, including cost and quality of care issues [3].

Healthcare Systems Engineering is an interdisciplinary engineering field focused on the evaluation and design of healthcare delivery systems. Within this discipline, quantitative analytical methods are used to study and unveil healthcare delivery system design alternatives to improve efficiency and effectiveness. The Hill-Burton Act of 1946 provided universities funding to collaborate with hospitals on performance improvement projects [4]. Since the act was in place, interdisciplinary teams consisting of industrial and system engineering researchers and healthcare administration have developed partnerships aimed at improving healthcare delivery systems worldwide. Recently, the U.S. Department of Health and Human Service's Agency for Healthcare Research and Quality (AHRQ) collaborated with healthcare and industrial and system engineering experts to identify how industrial and systems engineering methods can be applied to develop an ideal health care delivery system [5]. Within their final report, participants categorized research agenda items under the following three main research requirements for industrial and systems engineering knowledge innovation:

- *System monitoring*: improve system assessment and communication of improved assessments to stakeholders
- *System modeling*: improve understanding of system components and their interactions
- *System modification*: improve system efficiency and effectiveness through transformation

These three research requirements provide direction on future research areas. The exploratory study presented in this dissertation aims to provide insight on all three requirements, mainly centered on systems modeling.

1.1 Adverse Patient Health Outcomes

There are various measures, ranging from financial to clinical quality, that can be considered patient health outcomes. The standard of clinical care delivered by a health care organization impacts a hospital's patient safety standards. Of the 100+ Agency for Healthcare Research and Quality (AHRQ) evidence-based quality indicator measures, the Centers for Medicare/Medicaid (CMS) have focused on 30-day risk-adjusted mortality and readmission rates for their hospital reimbursement and public reporting programs for Medicare beneficiaries treated for certain conditions, such as heart failure and pneumonia [6].

For this dissertation, 30-day readmission to the same hospital and in-hospital mortality measures will be the patient health outcome measures of interest. These measures have been used by researchers as surrogate patient safety measures [7]. Although readmission and mortality rates are declining [8], these patient health outcomes continue to be important measures of overall quality of care and patient safety.

In addition to strategies to reduce preventable mortality, hospitals and healthcare agencies have attempted to reduce preventable readmissions due to their association with lower quality of care [9]. Up to 48% of readmissions may be preventable [10]. In 2011, Medicare spent an estimated $17Billion on preventable readmissions [11], and there were 3.3Million readmissions costing US hospitals $41.3Billion [12]. Beginning October 1st, 2012 under the Affordable Care Act, the Readmissions Reduction Program reduced Medicare reimbursement to hospitals with excessive readmission rates [13]. Reducing readmission and mortality rates are beneficial for hospitals, healthcare agencies, and patients.

1.2 Hospital Resource Factors

Access to human, bed, and equipment resources in the hospital setting directly affect the healthcare delivery timeliness and safety. For instance, when hospital inpatient beds are filled to capacity with admitted patients, an emergency department (ED) may become overcrowded, resulting in increased wait times for patients seeking care in the ED as well as extended ED boarding times for patients who have been admitted and are awaiting an inpatient bed. In this dissertation, hospital resources include nursing staff, hospital beds, and equipment. Ideally, when resources are available, patients arriving to the hospital would be seen by a healthcare provider upon arrival without experiencing delays in care. Similarly, patients discharged during times when resources are available would receive detailed, easy–to–follow after care and medication education since nursing staff would have more time to spend at their patient's bedside [10]. During weekends and evening shifts, it is possible that diagnostic equipment and beds are unavailable due to the lack of healthcare providers required to set up the equipment or bed [14]. In this study, it is hypothesized patients admitted and discharged during times with limited resource availability will have greater likelihood of experiencing adverse health outcomes.

1.3 Literature Review

Previous research has found evidence in hospital resource availability and patient health outcomes for specific patient populations. Resource availability can be divided into three main categories: staffing levels; resource-related temporal factors; and bed occupancy. The following summarizes the findings for each hospital resource factor category and adverse patient health outcome.

1.3.1 Hospital Resource Factors & Mortality

Nurse Staffing & Mortality

Researchers have determined associations between limited staffing resources and increased risk of mortality. Aiken et al. (2002) found increased mean patient-to-nurse staffing ratios, regardless of specialty type and shift, were associated with 30-day risk-adjusted mortality for general, vascular, and orthopedic surgery patients [15]. Needleman et al. (2011) found increased exposure to shifts where nurse staffing levels fell below target for ≥ 8 hours and shifts with high patient turnover (e.g. admissions, transfers, and discharges) were associated with increased risk of in-hospital mortality [16]. For surgery patients aged ≥ 50 years old, increased nurse workload measured as number of patients divided by number of nurses on a given unit, was also associate with increased risk of mortality for surgery patients treated in 300 hospitals across 9 European countries [17]. Increased nursing workload measured as the ratio of occupied to nursing staffed beds had an association with increased in-hospital mortality throughout a patients stay for patients treated in an adult intensive-care unit in the United Kingdom [18].

Similarly, increased staffing levels were found to be associated with decreased mortality rates. For 3763 US hospitals, in-hospital mortality rates for Medicare patients decreased as registered nurse staffing per occupied bed increased [19]. Increased staffing levels for patients aged 20 to 85 years of age who were treated in cardiac surgery post-operative units in 114 Belgian hospitals had a reduced risk of mortality [7]. For patients ≥ 65 years old who were admitted through the ED and had a common discharge diagnosis (i.e. acute myocardial infarction (AMI), congestive heart failure, gastrointestinal bleeding, hip fracture, pneumonia, or stroke), researchers found increased staffing levels measured as the ratio of registered nurses to patient-days were associated decreased risk of in-hospital mortality [20].

Resource-Related Temporal Factors & Mortality

Discharge time of the day ([21]; [22]; [23]) and day of the week ([24]) where resources are limited, such as the night shift and weekends, were found to have associations with increased risk of mortality compared to regular business hours and weekdays. Researchers found an association between after-hours discharges (i.e. discharges between 6pm to 6am) and post-Intensive Care Unit (ICU) mortality for patients discharged from ICUs included in the Australian and New Zealand Intensive Care Society Adult Patient Database (ANZICS APD) [21]. Similarly, for patients featured in the ANZICS APD discharged from and ICU between 6pm to 6am had both a higher readmission and mortality rate [23]. For adult patients admitted to ICUs in Calgary Health Region in Alberta, Canada, admissions and discharges at night (from 6:00pm to 7:59pm) were independently associated with mortality, however weekend admissions and discharges (that occurred from 12:00am Saturday to 11:59pm Sunday) were not associated with in-hospital mortality [22]. Regarding day of admission and/or discharge, researchers found patients admitted to an acute care in hospital California during the weekend (from 12:00am Saturday to 11:59pm Sunday) had an increased risk of in-hospital mortality [24]. Admission outside business hours (i.e. after 4:00pm to before 7:00am Monday through Friday and all day on weekends) was associated with an increased risk of in-hospital and 30-day mortality for patients $\geq$ 16 years old who were admitted to all medicine units excluding pediatric, psychiatric, and surgical departments in all Denmark hospitals [25]. In addition to the association found between nurse staffing levels and increased risk of mortality, Schilling et al. (2010) also found an association between weekend admission and admission during influenza season and in-hospital mortality [20]. Researchers found patients who were experiencing an AMI and were admitted during the weekend had a lower likelihood of receiving invasive cardiac procedures, a measure of access to care, and an increased likelihood of 30-day mortality [26]. ICU patients $\geq$ 16 years old who were discharged from Northern Hospital in Melbourne during the night shift (i.e. 10:00pm to 7:30am) had an increased risk of mortality [27]. Similar to the findings of the association between nurse staffing levels and patient health outcomes, the association between resource-related temporal factors is expected since limited access adversely affects the timeliness of treatment. Patients requiring immediate diagnostic or therapeutic tests who are admitted during ”off-hours” may experience longer wait times compared to similar patients admitted when these service are accessible during regular business hours.

Although research showed associations between off-hours admission or discharge timing and increased risk of mortality, some researchers also showed refuting outcomes. Morales et al. (2003) did not find an association between night admission (i.e. admission after 5:00pm and before 7:00am) for medical ICU patients treated at Saint Mary's Hospital in Rochester, MN and increased in-hospital mortality [28]. Similarly, Santamaria et al. (2015) did not find an association between after-hours discharge (i.e. between 6:00pm to 6:00am) for patients discharged from 40 ICU's in Australia and New Zealand and subsequent mortality [29]. Ensminger et al. (2004) found patients admitted to Mayo Clinic's ICU did not have an increased risk of in-hospital mortality [30]. Wunsch et al. (2004) found admission time of day and day of week was not associated with in-hosptial mortality for patients treated in ICUs in England, Northern Ireland, and Wales [31]. In summary, the outcomes associated with temporal factors and mortality are diverse, and this may be related to the study design and available data.

Bed Availability & Mortality

Researchers have also explored the lack of hospital resources in terms of bed availability and the influence on mortality. Observational studies have assessed the impact of emergency department (ED) overcrowding ([32]; [33]; [34]; [35]). Richardson (2006) found patient arrival to the ED during high ED occupancy was associated with increased risk of 10-day mortality at Canberra Hospital in Australian [32]. Sprivulis et al. (2006) found an association between admitted patients who arrived to the ED during both high ED & hospital occupancy and mortality 2-days and 7-days after arrival [33]. Additionally, researchers found that increased ED crowding was associated with increased risk of inpatient mortality for patients admitted through the ED of Californian acute care facilities [34]. Increased delays, measured by the amount of time admitted ICU patients were held in the emergency department waiting for an inpatient bed, was associated with in-hospital mortality [36]. Iapichino et al. (2004) found that increased ICU occupancy was associated with increased mortality for 89 ICUs in hospitals across 12 European countries [37]. Robert et al. (2012) found delayed admission to the ICU had an association, albeit non-significant, with increased 28-day mortality for patients treated at 25 ICUs in France [38]. Madsen et al. (2014) found high bed occupancy was associated with an increased risk of both in-hospital and 30-day readmission [25]. Fisher et al. (2000) found an association between increased hospital capacity and increased mortality for Medicare beneficiaries [39].

Similarly, researchers also found reduced bed occupancy was associated with reduced risk of mortality. Geelhoed & de Klerk (2012) found reduced overcrowding strategies in the ED resulted in reduced risk of 30-day mortality for patients admitted from the ED within tertiary hospitals in West Australia [40]. Similarly, Boden et al. (2015) found strategies to reduce medical unit bed occupancy resulted in reduced mortality for a general hospital in the United Kingdom [41]. These associations are expected since increased bed occupancy will reduce the ability for patients from various admission sources, including the emergency department and the post-anesthesia care unit, to be admitted to a nursing unit where they would receive the required level of care. Instead of being admitted, these patients are held in temporary areas unequipped for admitted patient care.

Conversely, Pines et al. (2009) showed that occupancy in terms of high ED waiting room census was associated with increased risk of mortality for patients with acute coronary syndrome [42], however an increased number of admitted patients during ED stay and the delay in transfer to an inpatient bed were not associated with increased mortality. Viccellio et al. (2009) found no association between patients admitted from the ED who experienced hospital overcrowding, measured in terms of admitted patients being held in an inpatient unit hallway until an inpatient bed becomes available, and in-hospital mortality [43]. Iwashyna et al. (2009) found no association between ICU patients admitted on days with high census and increased mortality for patients treated at 108 ICUs [44]. In situations where volume is measured as the number of surgical procedures performed annually, the association between increased volume and decreased mortality is indicative of increased experience and skill [45]. Researchers have noted that the lack of an association between increased bed capacity and reduce mortality may be likely due to the lack of available data associated with external factors related to both bed capacity and mortality [39]. Additionally, when studies are performed across multiple hospitals such as the Birkmeyer et al. (2002) and Fisher et al. (2000) study, detailed patient demographic and health condition characteristics may not be readily available or standardized across all sites ([45]; [39]).

1.3.2 Hospital Resource Factors & Readmission

Nurse Staffing & Readmission

Similar to the staffing level effect on mortality, researchers observed an association between staffing levels and readmission. Increased nurse staffing levels were associated with a reduction in unplanned readmissions for patients between 20 to 85 years old who received coronary artery bypass surgery or heart valve procedures at 114 Belgian hospitals [7]. Acute care hospitals in Maryland participating in the Affordable Care Act's Hospital Readmission Reduction Program (HRRP), a program penalizing hospitals for excessive readmission rates for Medicare beneficiaries, had lower estimated readmission rates when they had higher staffing levels [46]. For acute myocardial infarction (AMI), heart failure, and pneumonia patients treated in a California, Pennsylvania, and New Jersey hospital, increased patient to nurse ratio was associate with increase 30-day readmission rates [47]. For children presenting to the hospital with common medical-surgical conditions, an increase in nurse-to-patient ratio was associated with an increased risk of 15-30 day readmission [48]. These associations are expected since increased staffing levels would reduce the chance of delayed care during the patient's hospital visit, allowing the patient to receive appropriate care. It has been hypothesized that nursing shortages may result in increased readmission because it may adversely affect the nurses ability to provide adequate after care and medication education prior to the patient being discharged. Improper education may result in the patient's health declining after discharge, requiring the patient to be readmitted. In a review of previous studies, Butler et al. (2011) found that the addition of nursing staff to assist with discharge education did not result in decreased readmission or mortality for patients [49]. These findings may indicate that increased overall staffing levels, not only additional discharge nurses, may assist in the prevention of readmissions.

Resource-Related Temporal Factors & Readmission

Time of day and day of week were also found to have an association with risk of readmission. ICU patients discharged after-hours (6:00pm-6:00am) were found to have an increased risk of readmission for patients discharged from an Australian or New Zealand ICU participating in Australian and New Zealand Intensive Care Society Adult Patient Database (ANZICS APD) [21]; [23]; [50]). Similar to the study findings regarding the association between resource-related temporal factors and mortality, it is expected that readmissions would increase if patients are discharged during time periods where resources cannot be accessed. For instance, a patient discharged during off-hours may not be able to access specialty care, but a decision is made to discharge the patient to reduce costs associated with increased length of stay. Consequently, associations have been found between shortened length of stay for patients in the ICU and increased likelihood of readmission [51]. In cases of short length of stay and off-hours discharge, required patient care is commonly inaccessible, possibly explaining the association with increased readmission.

Bed Availability & Readmission

Limited bed capacity were found to have an association with readmission. High patient turnover, measured as the number of annual patient discharges per bed, was associated with increased risk of 30-day readmission for patients treated in a psychiatric hospital [52]. Patients admitted to a neuroscience critical care unit on days with high patient inflow (patient admissions to the ICU ≥ 10) had an increased risk for unplanned readmission to the ICU within 72 hours of being transferred to a nursing unit providing lower level of care [53]. Chrusch et al. (2009) found that increased quarterly bed occupancy is associated with both increased risk of premature deaths and ICU readmissions at a Canadian tertiary teaching hospital, while Town et al. (2014) found reduced ICU bed availability is associated with increased risk of readmission for patients discharged from a academic medical center ICU ([54]; [55]). Additionally, Blom et al. (2015) found an association between patients discharged during times with high inpatient bed occupancy and increased risk of 30-day readmission [56]. Reduced bed availability has the potential to affect patient care throughout the patient's stay. Upon admission through the ED during times with high bed occupancy, an admitted patient may be held in the ED or placed in the hallway until a bed becomes accessible ([57]; [43]). During their hospital stay, high bed occupancy may increase staff workload, which has been found to have an adverse effect on patient health outcomes ([18]; [58]). Both instances may adversely affect the care received during the hospital stay, resulting in readmissions.

1.3.3 Controlling for Patient Risk Factors

The aforementioned research studies controlled for variables that are considered risk factors for their given patient populations. The risk factors controlled in mortality studies were similar to readmission studies. Controlled patient risk factors include: age; gender; race; existing health conditions, such as diabetes, stroke, and cancer; socioeconomic factors, such as marital status and education level; temporal factors, such as season, day of week, and shift; severity of illness; risk of mortality; admission source; types of diagnostic and therapeutic procedures provided; length of stay; diagnosis categories; intensity of treatment; laboratory test findings; insurance payor; number of previous readmissions; and discharge location. In addition to studies exploring the associations between limited hospital resource factors and patient health outcomes, other research assessed the associations between patient risk factors and mortality and/or readmission. The patient risk factors included in these studies mirrored the patient risk factors included in the resource factors studies.

Age, sex, pre-existing health conditions/comorbidities ([59]; [60]; [61]; [62]; [63]); admission through the emergency department [15]; admission type/source ([17]; [30]); elective surgery [64]; payor type [62]; ICU procedures [36]; and length of stay ([65]; [66]; [67]) have been included in studies aimed at finding associations between potential patient risk factors and mortality.

Age, sex, ethnicity ([68]; [69]; [70]; [71]); previous admissions ([68]; [48]); pre-existing health conditions/comorbidities ([72]; [70]; [73]); severity of illness [74]; and admission source [50] have been included in studies aimed at finding associations between potential patient risk factors with readmission.

A portion of studies included unit- and/or hospital-level factors. Nursing-unit factors include nurse gender; staffing level; education level; and years of experiences. Hospital factors include staffing level; number of beds; location (ie. urban or rural); annual patient volume; technology; teaching status; and ownership ([15]; [7]; [75], [16]).

1.3.4 Patient Populations

The patient population featured in adverse health outcome studies generally focused on the patient health outcomes of the following patient populations: Medicare patients; patients admitted to or discharged from the ICU; patients admitted from the ED; or patients admitted after surgery. Few studies have used a hospital's entire patient population that also considered difference in age groups, insurance types, and admission sources.

Patient populations that were assessed for mortality studies include surgery patients ([15]; [17]; [7]); acute myocardial infarction (AMI) patients ([62]; [26]); pneumonia patients within the ICU [76]; intensive/critical care unit (ICU) patients ([64]; [18]; [21]; [77]; [28]; [23]; [29]; [30]; [31]; [78]; [79]; [54]; [80]; [44]; [22]); emergency department admissions ([24]; [36]; [32]; [33]; [34]; [43]; [40]; [42]; [35]; [41]); medicare patients ([45]; [19]; [39]); neonatal [81]; patients admitted to medicine units [25]; pediatric patients [58]; and AMI, congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), pneumonia, and stroke patients [75].

Patient populations that were assessed for readmission include intensive/critical care patients ([64]; [53]; [54]; [7]; [63]; [82]; [21]; [77]; [23]; [50]; [55]); adult Coronary Artery Bypass Grafting (CABG) patients [7]; heart failure and pneumonia [83]; medicare beneficiaries ([46]; [47]); and pediatric patients [48].

The selection of AMI, CHF, and pneumonia patient populations may be explained by the public reporting of hospitals' patient health outcome performance as well as hospital reimbursement programs for Medicare beneficiaries with these health conditions ([6]; [13]). Additionally, pneumonia, CHF, and COPD, and patients who have post-procedure complications are some of the most common health conditions treated in US hospitals ([62]; [76]). Focusing on these patient populations addresses health outcomes for the majority of patients treated in hospitals and would assist hospitals with obtaining the maximum reimbursement. The intensive/critical care unit patient population may have been of interest, especially for the readmission studies, due to the higher costs of providing care related to increased resource consumption for higher acuity patients ([64]).

Although specific patient groups included in the previous literature were selected based on the patients groups with highest hospital utilization, resource factors may also affect other patient groups who present to the hospital with less common health conditions or who are treated in nursing units who typically care for lower acuity patients. Future studies planning to include all patient populations should include the aforementioned risk factors to account for the differences in patient health outcomes between the various patient groups.

1.4 Problem Statement

To date, research has not explored the association between resource factors levels on both the day of admission and the day of discharge with readmission and mortality for all patients regardless of age, admission source, nursing unit, and health condition. Assessing associations for all patients throughout the hospital would provide a better understanding of how hospital resource factors affect patient health outcomes. Consequently, the patient- and nursing- unit risk factors for all patients have not been identified.

Depending on data availability and study aim, previous research has focused on resource factors during each shift ([55]; [18]), during the time of admission ([34]; [38]), or during the time of discharge [53]. Typically mortality studies assess variables during day of admission, while readmission studies assess variables during the day of the last discharge. It is hypothesized that dynamic levels of resource factors throughout a patient's length of stay can effect patient outcomes. For this reason, resource factors will be assessed on both the day of admission and day of discharge for each patient.

Supply and demand measures, such as patient to nurse staffing ratios and bed occupancy, have been included in similar studies, however the supply and demand of hospital service has not been included in similar studies. Service-mix is defined as the scope and range of services provided [84]. The scope and range of medical specialties offered by a nursing unit, also known as service lines, can be used to measure service-mix. Demand for these services can be measured as the number of patients within a given unit who are treated under a service line offered by a given unit. Both supply and demand measures have been included in studies in order to account for the heterogeneity amongst different hospitals [84]. Including both supply and demand at the unit level accounts for the both the supply of resources available to patients and the demand of those resources in terms of resource utilization.

Service mix variables include the number of services offered and the number of procedures performed [84]. The available dataset used for the research described in this dissertation does not provide data on the number of procedures performed specifically at the patient level, however service and service line information is provided in the report. The University Health System Consortium, a consortium of academic health systems in the US of which UWMC is a member, has defined a set of services lines as a means to standardize groups of services across their different health systems. Within UWMC, a service is defined as the primary specialty service a patient requires during their hospital stay. A patient is classified under a service based on the medical specialty needs and medical team providing care.

The difference in the association between hospital resource factors and patient health outcomes between units may be due to the number of resources and/or the variety of services offered from unit to unit. The number of resources offered by a unit can be measured by the number of nursing staff and beds. It is hypothesized that an increase in the number of resources results in a decreased risk of adverse health outcome. It is hypothesized that more service variety offered on a nursing unit, which could be indicative of nurse workload complexity, may adversely affect patient health outcomes. Research identifying the hospital resource factors occurring on the patients day of admission and/or on their day of discharge, while controlling for supply and demand measures for each unit, can help healthcare providers determine methods to mitigate the occurrence of readmissions and mortalities.

1.5 Statement of Purpose

This research will focus on the relationship between resource factors on a patient's day of admission and discharge and the patient-specific, evidence-based outcome measures of risk-adjusted 30-day risk adjusted readmission and mortality within the hospital setting.

The resource factors included in the study are as follows:

Registered Nurse (RN) Unit Staffing: The number of registered nursing staff, not including other healthcare providers such as physicians and licensed practical/vocational nurses, on a nursing unit who are scheduled to work during the shift of a patient's admission to a unit, discharge from a unit, or death in a unit

RN Unit Vacationing: The number of nursing staff on a nursing unit who are scheduled to be on vacation during the shift of a patient's admission to a unit, discharge from a unit, or death in a unit

Unit Bed Availability: The number of beds on a nursing unit that are not occupied by another patient on the day of a patient's admission to a unit, discharge from a unit, or death in a unit. This is calculated as the midnight census subtracted from the number of beds offered by the unit.

Admissions to the Unit (Resource limitation Proxy Measure): The total number of patients who were admitted to the same nursing unit on the day of a patient's admission to a unit, discharge from a unit, or death in a unit

Discharges from the Unit (Resource limitation Proxy Measure): The total number of patients who were discharged from the same nursing unit on the day of a patient's admission to a unit, discharge from a unit, or death in a unit

Weekend (Resource limitation Proxy Measure): A patient's admission to a unit, discharge from a unit, or death in a unit between 12:00am Saturday to 11:59pm Sunday

Evening Shift (Resource limitation Proxy Measure): A patient's admission to a unit, discharge from a unit, or death in a unit between 3:00pm to 10:59pm

Night Shift (Resource limitation Proxy Measure): A patient's admission to a unit, discharge from a unit, or death in a unit between 11:00pm to 6:59am

The count of admissions to and discharges from nursing units will serve as proxy measures for nursing workload, and an association with increased risk of adverse health outcomes is hypothesized. Evening shift, night shift, and weekend measures will serve as a proxy measures for the availability of diagnostic and therapeutic services. Patient characteristics, such as age, gender, sex, and existing health conditions, are factors that may be associated with resource factors variables and patient health outcome variables. The various distributions of patients for each patient characteristic may confound the comparison between system and patient health outcome variables. For this reason, patient risk factors significantly associated with each adverse health outcomes will be identified and adjusted accordingly in order to observe accurate associations for the hospital resource factors. Additionally, unit-level characteristics, such as service provision complexity, and the demand for these resources and services, may further confound the association. The following are the definitions of demand and supply ratio measures, where the demand is measured in terms of census and the supply is measured in terms of beds, staffing, and services offered:

Census:Bed Ratio: The number of patients occupying a bed divided by the number of beds offered on the nursing unit at the time of a patient admission to a unit, discharge from a unit, or death in a unit

Census:Staff Ratio: The number of patients occupying a bed divided by the number of nursing staff working on the nursing unit at the time of a patient admission to a unit, discharge from a unit, or death in a unit

Census:Service Ratio: The number of patients occupying a bed divided by the number of services offered by the unit at the time of a patient admission to a unit, discharge from a unit, or death in a unit

1.6 Research Questions

The following research questions and hypotheses are to be examined:

Research Question 1 (RQ1): What are the patient risk factors that could potentially influence the association between resource factors and in-hospital mortality and 30-day readmission?

It is hypothesized that increased risk of 30-day readmission and mortality risk will be significantly impacted by patient risk factors such as age, sex, existing health conditions, higher severity of illness, higher risk of mortality, admission source, and length of stay. The inclusion of significant risk factors will result in the risk-adjustment of the models to be examined in RQ2 and RQ3.

Research Question 2 (RQ2): What are the hospital resource factors that impact in-hospital mortality and 30-day readmission rates?

Based on the literature, it is hypothesized that each resource factors variable has an independent association with both adverse health outcome measures.

This RQ will be addressed with crude and risk-adjusted models: 1) 30-day readmission as a function of significant resource factors variables and 2) in-hospital mortality as a function of significant resource factors variables. Simple logistic regression models will be developed to observe the relationship between each isolated resource factors variable and each patient health outcome to identify the variables with the most significance. Since all patients groups are included in the study and health outcomes likely vary based on various patient risk factors, the crude models will need to account for variation introduced by risk factors in order to compute more accurate resource factors effects. Multiple logistic regression models will then be developed to observe the influence of the significant resource factors, significant patient risk factors, and each patient health outcome.

Research Question 3 (RQ3): Does the association between hospital resource factors and the risk-adjusted 30-day readmission and in-hospital mortality (as defined in RQ2) differ by nursing unit? If so, do unit-level demand and supply ratio measures explain the unit-to-unit variation?

It is hypothesized that demand and supply at the unit-level are risk factors that may result in differences between the resource factors to patient health outcome associations from unit-to-unit. The research question will be addressed using both patient- and unit-level risk adjustment of the models produced in RQ1 and RQ2. To date, service mix measures have not been included as covariates when studying associations between resource factors and patient health outcomes.

1.7 Research Implications

The findings made from this research can be used for hospital operations and healthcare delivery process planning in order to mitigate the risk of readmission and mortality. Policies can be developed or revised in an attempt to control resource factor levels found to significantly influence adverse patient health outcomes.

1.8 Organization of the Dissertation

The next four chapters of this dissertation include the methods and data analyses to address each research question: Chapter 2 goes over RQ1, Chapter 3 goes over RQ2, Chapter 4 goes over RQ3. Chapter 5 uses the overall model developed in Chapter 3 & 4 to develop prevalent health condition models. Lastly, Chapter 6 provides a summary and discussion of the contributions and limitations of the proposed study and suggested future work. The appendices includes a glossary of the variables included in dataset used for this study and the R programming codes used for the statistical analyses.

Chapter 2

INFLUENCE OF PATIENT RISK FACTORS ON ADVERSE HEALTH OUTCOMES

2.1 Introduction

The first research question (RQ1) addresses the potential patient risk factors that influence the association between resource factors and in-hospital mortality and 30-day readmission. Based on the literature (Chapter 1), there are several patient risk factors associated with adverse health outcomes for those treated in an acute care hospital. Demographic information such as the patient's home county, lack of housing status, and primary language spoken; admission/discharge details such as discharge location (e.g. home or skilled nursing facility); and health condition information, such as patient receiving palliative and hospice care, have not been studied for general patient populations.

Previous research showed variables associated with readmission are not necessarily associated with mortality [64]. Hence, separate models were created for each adverse health outcome. It is hypothesized 30-day readmission and mortality risk are significantly associated with age, sex, existing health conditions, severity of illness, risk of mortality, admission source, and length of stay groups.

2.2 Method

2.2.1 Data Overview

The Human Subjects application 50094 EB "Association among Patient Demographics, Throughput, and Health Outcomes" was approved by the University of Washington Institutional Review Board (IRB) in Subcommittee EB under Expedited Category 5 meeting all requirements for approval outlined in 45 CFR 46.111 on September 2nd, 2015.

Upon IRB approval, a report titled “Patient Detail Report” was provided for this study from the University of Washington Medical Center (UWMC). This report features patient-level and unit-level information, such as patient demographics, patient health conditions, and service(s) provided by the unit, for each individual patient encounter. The UWMC's *Center for Clinical Excellence's Clinical Analytics & Amalga Team* provided the Patient Detail Report on December 18th, 2015. Each row of the report corresponds to an individual patient encounter at the hospital, where a patient encounter is defined as a single patient visit. The population included in this report were all patients admitted and discharged from this hospital between January 1st, 2012 to July 30th, 2015. A total of 71959 patient visits were available for this time frame. The full list of variables included in the report are featured in Appendix A.

2.2.2 Adverse Health Outcomes Data

The administrative data collected at every discharge includes health outcomes observed between the time the patient was admitted to the hospital to the time the patient was discharged for each hospital visit. For this reason, the adverse health outcomes included in this study are 1) in-hospital mortality and 2) 30-day readmission to UWMC. To identify in-hospital mortalities, the patient detail report included a variable indicating whether or not the patient died during their visit; the discharge date and time for patients with a death code = 1 was used as the mortality date and time. Multiple steps were taken to identify patients readmitted within 30-days. First, patient account numbers that were featured on multiple patient encounters were identified. Of these patients, the date and time of the latest admission was compared with the date and time of the previous discharge; encounters with a discharge to admission time of $\leq$ 30days were identified. For these patients, a readmission code = 1 was given to the encounter associated with the date and time of the previous discharge.

2.2.3 Data Segmentation

This current study used an approach similar to Badawi & Breslow (2012), where readmission and post-discharge death after treatment in the intensive care unit was predicted. A similar cohort assignment approach for model building (training) and model validation (testing) purposes is considered in this current study. For this study, each patient visit was randomly assigned to either a training or testing cohort, where a 2 to 1 assignment ratio was used. Prior to cohort assignment, the patient visits with missing values for the variables of interest were removed from the data set. The cohort flow chart (figure 2.1) details the number of patient visits removed due to missing values, and the number of patient visits assigned to each cohort. Of a total 71959 patient visits, there were 68209 patient visits featuring values for every variable of interest in this study within the study time frame of interest. In order to ensure observation and short stay patients were not included in the study, all patients with a length of stay less than 24hrs were excluded (n=3193); 65016 patient visits remained in the dataset. A total of 43344 patient visits were randomly assigned to the training cohort and 21672 patient visits were assigned to the testing cohort.

2.2.4 Data Analysis

Descriptive Analysis

Descriptive statistics, histograms, and box plots were used to assess distributions of each discrete variables in the dataset, which includes age and length of stay. To ensure the variable values are equally distributed across each cohort dataset, descriptive statistics are summarized and Chi-Squared (χ^2) tests were performed comparing the training and testing datasets.

Binomial Logistic Regression

Based on the dichotomous nature of each adverse health outcome variables, binomial logistic regression modeling was appropriate to assess the association between patient characteristic factors, as featured in equation 2.1.

$$log\left[\frac{\pi}{1-\pi}\right] = \beta_0 + \sum_{j=1}^{n} \beta_j x_{ij} \quad (2.1)$$

where,

$\pi = \Pr(\text{adverse health outcome})$

$\beta_0 = \text{intercept}$

$\beta_j = $ coefficient for the j^{th} patient risk factor

$x_{ij} = $ value of the j^{th} patient risk factor for the i^{th} patient encounter

$i = 1...\text{m}$ patient encounters

$j = 1...\text{n}$ patient risk factors

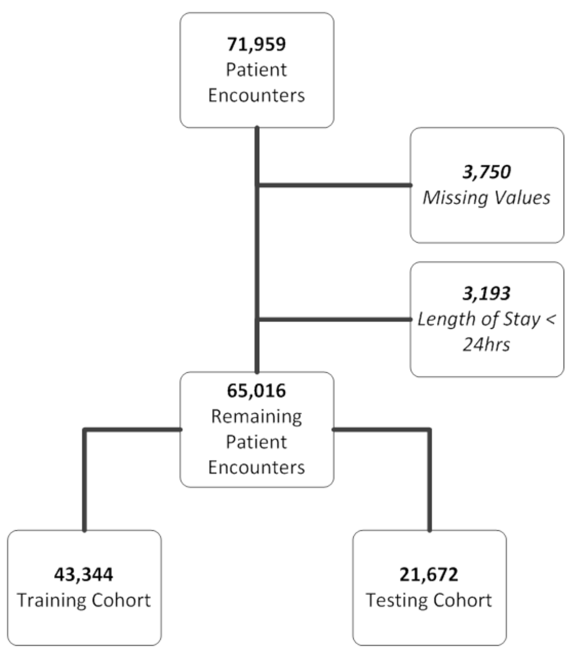


Figure 2.1: Cohort Assignment Flow Chart(a)

The null and alternative hypothesis for RQ1 is as follows:

$$H_0 : \beta_1, \beta_2, ..., \beta_n = 0$$

$$H_1 : \beta_1, \beta_2, ..., \beta_n \neq 0$$

Based on the literature, it is hypothesized that age; health conditions; severity of illness; risk of mortality; admission source; and length of stay are significant risk factors.

The odds ratio (OR), the expected percent change in the odds of the adverse health outcome y_i occurring for every 1-unit increase of a given explanatory variable x_i holding all other explanatory variables fixed, is explained by equation 2.2.

$$OR = e^{\beta_j} \tag{2.2}$$

Binomial Logistic Regression Analytical Method

The following are the 4 assumptions of logistic regression models as defined by Stoltzfus (2011):

1. Independence of errors

2. Linearity in the logit of continuous explanatory variables

3. Absence of influential cases

4. Absence of multicollinearity

Since each patient encounter in the dataset is independent of other patient encounters, the independence of errors assumption is met. There are no continuous patient risk factors featured in this study, so assumption 2 cannot be violated. Assumptions 3 & 4 were addressed as the models were built.

Prior to building the model, the number of cases by nursing unit was assessed to ensure units included in the study were units where adverse health outcomes occurred, especially when studying associations with in-hospital mortality. Next, a χ^2 test was performed to assess the independence of each patient risk factor for each cohort, indicated by a p-value > 0.05. The number of events per variable was also assessed to ensure there were at least 10 events per patient risk factor [85]. Next, Cook's distance plots were used to identify influential cases (Logistic Regression Assumption 3). Any cases with a Cook's distance greater than 1 were removed [86]. A regression was initially performed using the training dataset for each model. A backwards stepwise approach was used to determine the significant variables within each model. The full model included all dummy variables and the discrete variables of age and length of stay. If any of the discrete variables were insignificant, then these variables were replaced by a dummy-variable representation and their p-value will be observed for significance. The dummy variable for Age was Age$\geq$ 65 years old. This value was selected to correspond with other similar observational studies that included Medicare beneficiary populations, who are all 65 years of age and older. The dummy variable for the length of stay was length of stay $\geq$ 7 days, selected since the average length is approximately 7 days for the patient encounters in the dataset.

Once the significant patient risk factors are identified for the model, the variance inflation factor (VIF) was calculated for each significant patient risk factor. The VIFs were used to determine if multicollinearity existed amongst the significant patient risk factors (Logistic Regression Assumption 4), which is identified when the VIF for a variable is greater than 4 [87]. If the VIF for a variable was greater than 4, the variable was removed from the model.

The stopping condition for the backwards stepwise regression occurs when all variables are significant with a p-value < 0.05. The coefficient estimate, standard error, odds ratio (OR) and confidence interval, and the p-value for the significant variables of the final binomial logistic model are presented.

Lasso Logistic Regression

Each model includes 30 potential risk factors. To counter the possibility of overfitting each adverse health outcome model, least absolute shrinkage and selection operator (LASSO) logistic regression shrinking method was used to fit the model by minimizing a a negative version of the binomial log-likelihood function, which includes a penalty. The objective function for the penalized binomial logistic regression is featured in equation 2.3,

$$\min_{(\beta_0,\beta)} -\left[\frac{1}{N}\sum_{i=1}^{N} y_i \cdot (\beta_0 - x_i^T\beta) - \log(1 + e^{(\beta_0 - x_i^T\beta)})\right] + \lambda\sum_{i=1}^{N} \mid \beta_i \mid \tag{2.3}$$

where the penalized portion is explained by the term featured in equation 2.4.

$$\lambda\sum_{i=1}^{N} \mid \beta_i \mid \tag{2.4}$$

Lasso Logistic Regression Analytical Method

The penalty parameters of the LASSO logistic regression (LLR) is λ. To determine λ, a 10-fold cross-validation method was used where the selected λ maximized the area under the receiver operating characteristic curve (AUC). The LLR with the $\alpha = 1$ and selected λ was used to fit the model. As performed with the binomial logistic regression analysis, the discrete variables age and length of stay were added to the model first. Additionally, dummy variable representing the discrete variables were added and assessed for significance. The model includes the variable(s) that are significant indicated by an $OR \neq 1$.

The odds ratio (OR) for the significant variables of the final LLR model are presented. For LLR models, the confidence interval is not included since the standard errors are difficult to calculate for LLR models since the LASSO estimate function is non-differentiable and non-linear [88].

Final Model Selection

Finally, the analytical method—binomial or LASSO logistic regression—resulting in the best performing model was selected as the final model for each adverse health outcome. After all the significant variables were added to the model for the training cohort, the model was validated against the testing cohort. Binary and Lasso regression models were fit to the testing cohort data by including only variables significant for the training cohort. The model performance was measured in terms of discrimination and overall goodness-of-fit.

Discrimination, or concordance, indicates how well the model classifies patients with (true positive) and without (true negative) the adverse health outcome. The AUC is commonly used to measure discrimination where the calculated value varies between 0.5 to 1, where 1 indicates absolute discrimination ([89]; [90]).

Once the model was built and validated where only significant explanatory variables remain in the model, the Hosmer-Lemeshow goodness-of-fit test was performed. Goodness-of-fit compares the predicted to observed model values. The goodness-of-fit test selected for this study was the *le Cessie-van Houwelingen-Copas-Hosmer unweighted sum of squares test for global goodness-of-fit* because of its performance compared against other goodness-of-fit tests for logistic regression models [91].

Similar studies have used AUC and Hosmer-Lemeshow goodness-of-fit tests to assess models predictive performance. An AUC ≥ 0.74 has been categorized as "adequate" discrimination [20]. Similar studies have found a mortality AUC of 0.74 [20] and readmission AUC between 0.62 to 0.75 [82]. Therefore an AUC ≥ 0.62 for readmission and AUC ≥ 0.74 for mortality was used as a benchmark for model discrimination performance.

2.3 Results

Unit Selection

Prior to building the binomial and LASSO logistic regression models, the distribution of patients for each unit was assessed to determine if there are any nursing units to be excluded from the study. A nursing unit was excluded if there were 0 adverse patient health outcome cases in either the training or testing cohort. The 30-day readmission cases for each unit is featured in table 2.1. Nursing units 2SP, 7S, and 8NA had 0 cases in the training cohort dataset, and 7S and 8NA had 0 cases in the testing cohort. For that reason, these units were excluded from the dataset used to model 30-day readmission. The in-hospital mortality cases for each unit is featured in table 2.2. Nursing Units 2NN, 2SP, 4S, 5S, L&D, 6S, 7N, 7S, 8N, 8NA, NBN, and General had 0 cases in the training cohort dataset. These nursing units except 8N and General Units also had 0 in-hospital mortality cases. Therefore, these units were excluded from the dataset used to model in-hospital mortality.

Table 2.1: Total 30-day Readmission Cases by Nursing Unit

Unit	Unit Description	Total Patients	Training Cohort	Training Cohort Cases	%Cases	Testing Cohort	Testing Cohort Cases	%Cases
2NN	Post-Procedure Unit	78	47	6	12.77%	31	3	9.68%
2SP	Post-Procedure Unit	15	8	0	0.00%	7	2	28.57%
4NE	Medical/Surgical Unit	7076	4774	528	11.06%	2302	274	11.90%
4S	Limited Stay Unit	957	647	47	7.26%	310	12	3.87%
4SE	Medical/Surgical Unit	4876	3270	616	18.84%	1606	313	19.49%
5E	Critical Care Unit	1066	700	48	6.86%	366	36	9.84%
5NE	Medical/Surgical Unit	5404	3598	671	18.65%	1806	355	19.66%
5S	Post-Partum Unit	6651	4403	106	2.41%	2248	38	1.69%
5SE	Critical Care Unit	706	450	46	10.22%	256	24	9.38%
L&D	Labor & Delivery Unit	371	234	34	14.53%	137	19	13.87%
6NE	Medicine Unit	5932	3947	663	16.80%	1985	355	17.88%
6S	Baby Unit	933	607	177	29.16%	326	93	28.53%
6SE	Orthopedics Unit	6516	4369	710	16.25%	2147	374	17.42%
7N	Psychiatric Unit	1596	1068	51	4.78%	528	15	2.84%
7NE	Hematology/Oncology Unit	3632	2412	865	35.86%	1220	409	33.52%
7S	Clinical Research Unit	2	2	0	0.00%	0	0	0.00%
7SE	Oncology Unit	5793	3856	747	19.37%	1937	381	19.67%
8N	Rehabilitation Unit	912	591	60	10.15%	321	28	8.72%
8NA	Obstetrics Unit	3	1	0	0.00%	2	0	0.00%
8NE	Hematology/Oncology Unit	2753	1814	565	31.15%	939	305	32.48%
8SA	Medical Oncology Unit	2957	1984	1042	52.52%	973	508	52.21%
NBN	Newborn Unit	5348	3601	28	0.78%	1747	11	0.63%
NICU	Neonatal Care Unit	1272	842	5	0.59%	430	8	1.86%
General	General Unit	167	119	13	10.92%	48	7	14.58%

Table 2.2: Total In-hospital Mortality Cases by Nursing Unit

Unit	**Unit Description**	**All Patients**	**Training Cohort**	**Training Cohort Cases**	**%Cases**	**Testing Cohort**	**Testing Cohort Cases**	**%Cases**
2NN	Post-Procedure Unit	78	47	0	0.00%	31	0	0.00%
2SP	Post-Procedure Unit	15	8	0	0.00%	7	0	0.00%
4NE	Medical/Surgical Unit	7076	4774	15	0.31%	2302	8	0.35%
4S	Limited Stay Unit	957	647	1	0.15%	310	0	0.00%
4SE	Medical/Surgical Unit	4876	3270	17	0.52%	1606	8	0.50%
5E	Critical Care Unit	1066	700	233	33.29%	366	108	29.51%
5NE	Medical/Surgical Unit	5404	3598	29	0.81%	1806	14	0.78%
5S	Post-Partum Unit	6651	4403	0	0.00%	2248	0	0.00%
5SE	Critical Care Unit	706	450	155	34.44%	256	80	31.25%
L&D	Labor & Delivery Unit	371	234	0	0.00%	137	0	0.00%
6NE	Medicine Unit	5932	3947	72	1.82%	1985	36	1.81%
6S	Baby Unit	933	607	0	0.00%	326	0	0.00%
6SE	Orthopedics Unit	6516	4369	37	0.85%	2147	23	1.07%
7N	Psychiatric Unit	1596	1068	0	0.00%	528	0	0.00%
7NE	Hematology/Oncology Unit	3632	2412	41	1.70%	1220	23	1.89%
7S	Clinical Research	2	2	0	0.00%	0	0	0.00%
7SE	Oncology Unit	5793	3856	77	2.00%	1937	37	1.91%
8N	Rehabilitation Unit	912	591	0	0.00%	321	1	0.31%
8NA	Obstetrics Unit	3	1	0	0.00%	2	0	0.00%
8NE	Hematology/Oncology Unit	2753	1814	186	10.25%	939	96	10.22%
8SA	Medical Oncology Unit	2957	1984	38	1.92%	973	29	2.98%
NBN	Newborn Unit	5348	3601	0	0.00%	1747	0	0.00%
NICU	Neonatal Care Unit	1272	842	17	2.02%	430	9	2.09%
General	General Unit	167	119	0	0.00%	48	1	2.08%

2.3.1 30-day Readmission

Descriptive Statistics Summary

After removing aforementioned nursing units, a χ^2 test was performed to assess the independence of each patient risk factor and the cohorts indicated by a p-value > 0.05. Simulated p-value was performed to estimate the p-value for age and length of stay discrete variables. The results of the χ^2 tests are summarized in table 2.3. Of the 30 patient risk factors, Medicare was the only risk factor with a p-value $= 0.01$, indicating that random assignment of patients into each training and testing cohort may not have appropriately distributed Medicare beneficiaries into each cohort. Patient risk factors "hospice care" and "stroke" had fewer than 10 30-day readmission cases, so they were not included in the model. Since the other patient risk factors were appropriately distributed between each cohort, modeling with all patient risk factors was performed with all risk factors.

Next, the age and length of stay distribution for all patients included in the full dataset was observed for each adverse health outcome. Figure 2.2 illustrates the age distribution for patients who did and did not have a 30-day readmission. The patients who did not have a 30-day readmission had a average age of 45.26 years, and the patients who were readmitted within 30-days had an average age of 51.53 years. Based on the box plot, the age distribution for patients who were readmitted within 30days had less variation than those who were not readmitted within the same time frame.

Figure 2.3 illustrates a boxplot and histogram of the length of stay for patients who were and were not readmitted within 30 days. The length of stay for patients who were readmitted was 7.53 days on average compared with the average length of stay of 6.71 days for patients who were not readmitted.

Table 2.3: Descriptive Statistics Summary: 30 Day Readmission

	Training Cohort (n=7028)	Testing Cohort (n=3568)	χ^2 p-value	χ^2 (simulated) p-value
Demographics				
Age, years mean (sd)	51.40(16.67)	51.78(17.01)		0.8101
Race/Ethnicity: Black or African American n(%)	580(8.25)	287(8.04)	0.7388	
Race/Ethnicity: Hispanic n(%)	294(4.18)	159(4.46)	0.5447	
Sex: Male n(%)	3653(51.98)	1884(52.80)	0.4337	
Home County: King County n(%)	3091(43.98)	1541(43.19)	0.4498	
Lack of Housing n(%)	62(0.88)	22(0.62)	0.1799	
Payor Group: Medicare n(%)	2345(33.37)	1279(35.85)	0.0117	
Primary Language: English n(%)	6607(94.01)	3374(94.56)	0.2684	
Primary Language:Spanish OR Chinese n(%)	183(2.60)	88(2.47)	0.7199	
Admission & Discharge Details				
Emergency Department Admit n(%)	1877(26.71)	1012(28.36)	0.0742	
Discharge Status: Home/Self-care n(%)	5961(84.82)	2994(83.91)	0.2345	
Length of Stay (Days) mean(sd)	7.64(9.29)	7.32(8.89)		0.3448
ICU Stay n(%)	1232(17.53)	632(17.71)	0.8360	
Discharge during Summer	1836(26.12)	937(26.26)	0.8978	
Discharge during Winter	1724(24.53)	860(24.10)	0.6454	
Health Condition				
Risk of Mortality n(%)				
Extreme	371(5.28)	208(5.83)	0.2570	
Minor	1808(25.73)	857(24.02)	0.0588	
Severity of Illness n(%)				
Extreme	1100(15.65)	550(15.41)	0.7722	
Minor	722(10.27)	339(9.50)	0.2236	
Procedure n(%)	5820(82.81)	2968(83.18)	0.6498	
Acute Myocardial Infarction n(%)	38(0.54)	22(0.62)	0.7225	
Cancer n(%)	3653(51.98)	1876(52.58)	0.5725	
Chronic Obstructive Pulmonary Disease n(%)	31(0.44)	15(0.42)	>0.999	
Heart Failure n(%)	220(3.13)	115(3.22)	0.8421	
Pneumonia n(%)	70(1.00)	39(1.09)	0.7144	
Diabetes n(%)	1413(20.11)	766(21.47)	0.1062	
Sepsis n(%)	519(7.38)	271(7.60)	0.7257	
Stroke n(%)	7(0.10)	9(0.25)	0.0994	
Palliative Care n(%)	63(0.90)	38(1.07)	0.4603	
Hospice Care n(%)	2(0.03)	1(0.03)	>0.999	

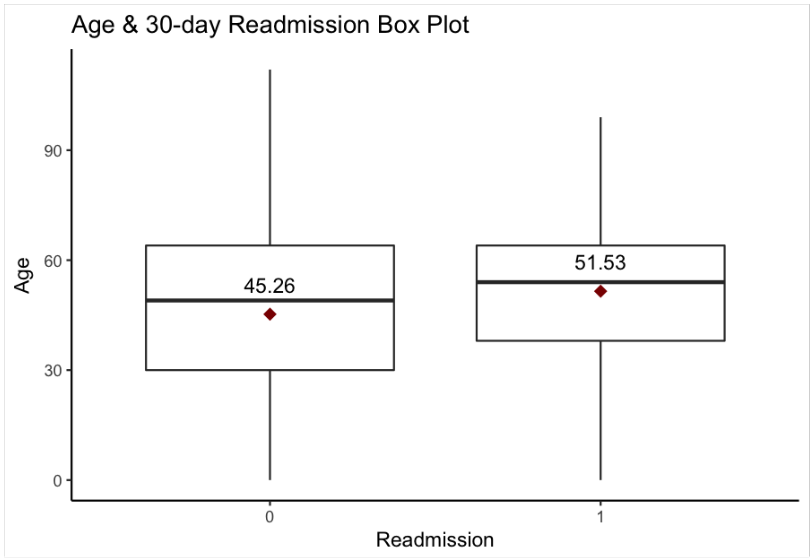


Figure 2.2: Box Plot of Age & 30-day Readmission

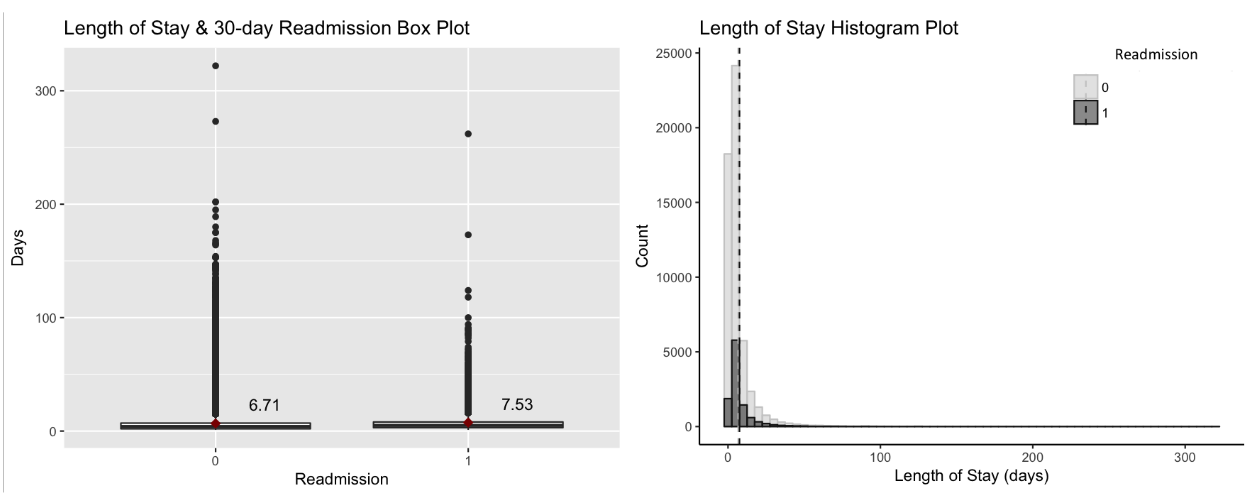


Figure 2.3: Length of Stay & 30-day Readmission Box Plot (left) & Histogram (right)

Binomial Logistic Regression

The factors that may have an impact were examined prior to creating the binomial and LASSO logistic regression models with a Cook's distance plot. Figure 2.4 illustrates the Cook's distances, including the three observations with the highest Cook's distances. Since none of the observations had a Cook's distance ≥ 1 indicating influence, none of the observations were excluded from the dataset.

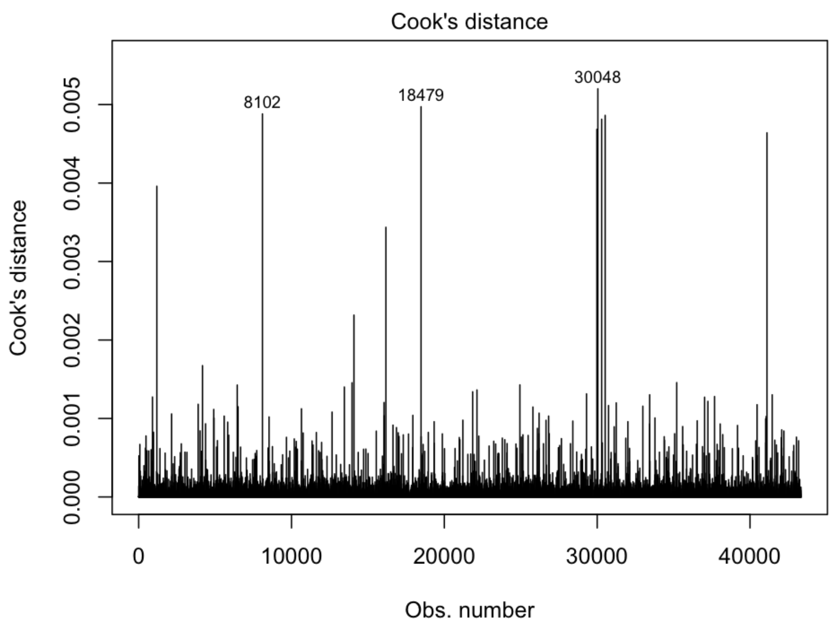


Figure 2.4: Cook's Distance Plot for 30-day Readmission Model

Next, the backwards stepwise approach was performed. At each step, the explanatory variable with the highest p-value was removed from the model and the model was rebuilt until all the variables remaining were significant with p-values≤ 0.05.

Table 2.4 summarizes the model coefficient estimates and odd ratios (OR) for the significant variables. An decreased risk of 30-day readmission was indicated with an OR< 1, and increased risk of 30-day readmission was indicated with an OR> 1. The residual deviance was 34343 in comparison to the null deviance of 38421, indicating the null binomial logistic regression model improved with the addition of the significant patient risk factors.

There were a total of 19 patient risk factors associated with 30-day readmission. There were 8 patient risk factors associated with a decreased risk of 30-day readmission, which were re receiving palliative care; being treated in the ICU; being classified as having a minor risk of mortality; being classified as having a minor severity of illness; being treated for acute myocardial infarction (AMI); being treated for pneumonia; being classified as having an extreme risk of mortality; and being a medicare beneficiary. These results correspond with common knowledge regarding these patient risk factors. Palliative care is provided to those with serious illness; these patients as well as patients classified as having an extreme risk of mortality are more likely to pass away than to be readmitted. Those patients classified as having either minor risk of mortality and/or minor severity of illness should be less likely to be readmitted. As observed in the literature review, efforts have been taken by hospitals to reduce readmission rates for ICU patients due to the high costs of treatment and Medicare beneficiaries due to the reduction in Medicare reimbursement.

The patient risk factors associated with increased risk of 30-day readmission were age; length of stay; having a procedure; being diagnosed with diabetes; speaking English as a primary language; self-identifying as being black/African-American ethnicity/race; being admitted from the ED; being classified as having a extreme severity of illness; being diagnosed with heart failure; being discharged home; and being diagnosed with cancer. Age and length of stay were only slightly associated with an increased risk of 30-day of readmission with an OR=1.0020[95$\% CI : (1.0002, 1.0038)$] and OR=1.0050[95$\% CI : (1.0024, 1.0075)$], respectively. These variables were included in the model since they have been associated with 30-day readmission in similar previous studies discussed in the literature review. Chronic diseases of diabetes and cancer may require frequent hospital visits, and are therefore expected to be associated with increased 30-day readmission risk.

LASSO Logistic Regression

To build the LASSO logistic regression model, a 10-fold cross-validation was used to identify the value of λ that maximized the model discrimination, measured in terms of AUC. Figure 2.5 illustrates the cross-validation curve used to determine the λ parameter value.

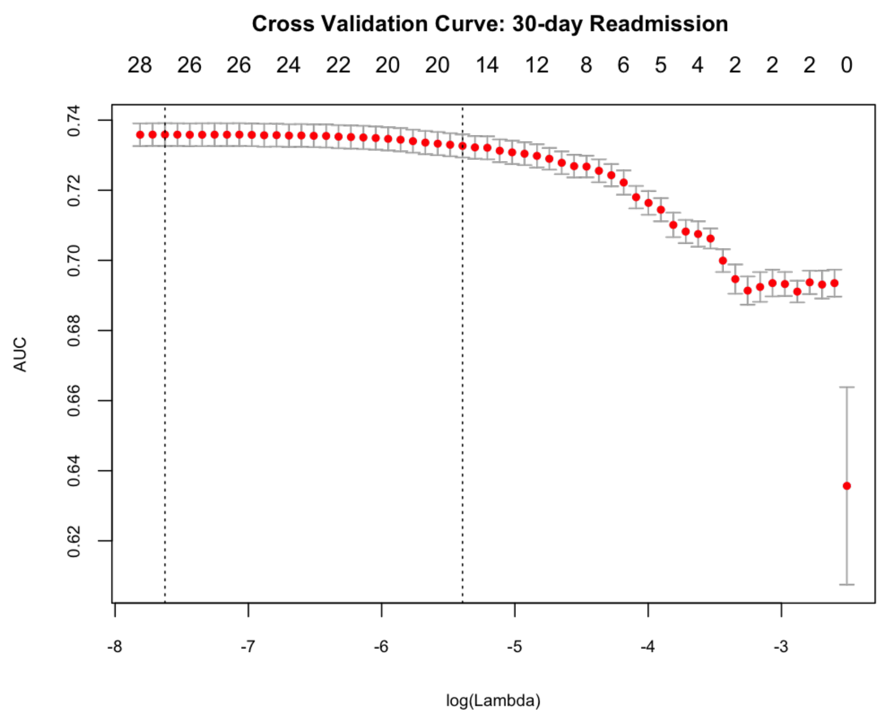


Figure 2.5: Cross Validation Plot for 30-day Readmission

The figure shows the AUC value range for a 10-fold cross validation corresponding to each of the 60 different values of λ. On the y-axis is the AUC; on the lower x-axis are the log(lambda) values, and on the upper x-axis are the number of significant explanatory values of the LASSO regression model corresponding to the λ value that maximizes the AUC for the cross-validation. The leftmost vertical dashed line indicates the minimum λ value that maximizes AUC and the rightmost line indicates the $\lambda + 1se$ value. For this study the

$\lambda + 1se$ was used to select the patient risk factors included in the model since it produces a more conservative model. The $\lambda + 1se$ that maximized AUC was $\lambda + 1se = 0.0045$, which corresponds to 14-20 significant explanatory variables included in the LASSO model. The odds ratio for each significant explanatory variable using the training data and the LLR approach is featured in table 2.5.

There were a total of 14 variables that were significant in the model. There were a total of 5 patient risk factors associated with an increased risk of 30-day readmission. Similar to the binomial logistic regression model, receiving palliative care; being classified with a minor risk of mortality; being classified with an minor risk of severity of illness; and staying in the ICU during the patients visit were all associated with a decreased risk of readmission. Age as a discrete variable was not significant in the LASSO regression model, however the dummy variable of age ≥ 65 years old was significant. Similar to binomial logistic regression results, due to cost reduction and reimbursement programs, these findings are expected. There were a total of 9 patient risk factors associated with increased risk of 30-day readmission, which includes speaking English as their primary language; identifying as black/African-American; being diagnosed with diabetes; having a length of stay ≥ 7 days; being admitted from the emergency department (ED); being classified as having an extreme severity of illness; being diagnosed with heart failure; being discharged home; and being diagnosed/treated for cancer. Similar to binomial logistic regression results, it is assumed that sicker patients as indicated by the extreme severity of illness risk factor, being admitted through the ED and being treated for a chronic disease, increase the patients likelihood of requiring multiple visits to the hospital. Similar to age, length of stay discrete variable was not significant in the LASSO regression model, however the dummy variable of length of stay $\geq$ 7days was significant in the model.

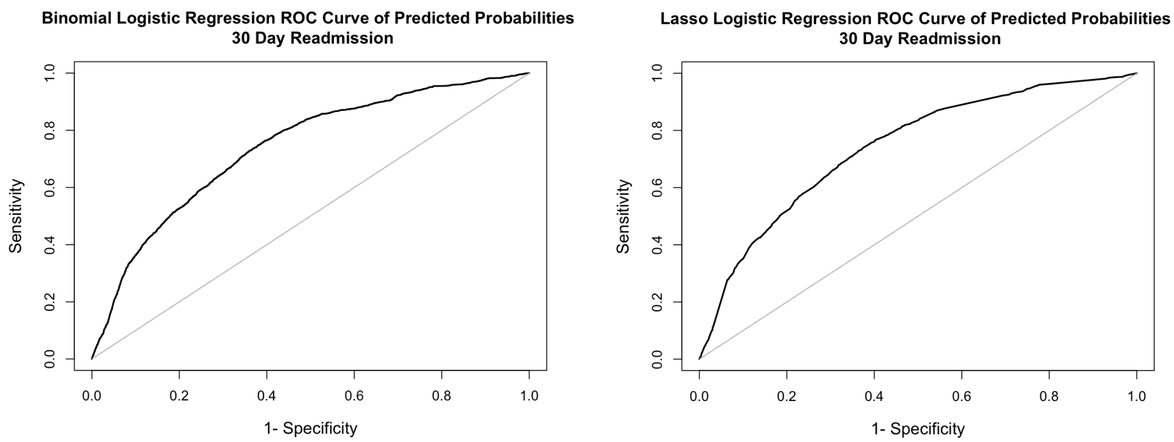
Binomial & LASSO Logistic Regression Variable Selection Comparison

The binomial and LASSO logistic regression modeling methods produced similar results in terms of significant patient risk factors associated with 30-day readmission. Binomial logistic regression had a total of 19 significant patient risk factors, while LASSO logistic regression had a total of 14 significant patient risk factors. For decreased risk of readmission, both models had receiving palliative care, classifications of minor risk of morality and severity of illness, and ICU stay in common. The age discrete variable was slightly associated with an increased risk of readmission in the binomial logistic regression model, while the age dummy variable was associated with a decreased risk of readmission in the LASSO regression model. In addition to these similarities, binomial regression methods also found receiving treatment for AMI and pneumonia; being classified as having an extreme risk of mortality, and being a Medicare beneficiary are associated with 30-day readmission. Both binomial and LASSO logistic regression methods shared several patient risk factors associated with increased risk of 30-day readmission including speaking English as a primary language; self-identifying as black/African-American; being treated for diabetes, heart failure, and cancer; length of stay; admission from the ED; classification of extreme severity of illness; and being discharged home. In addition, binomial logistic regression found patient risk factors of age and receiving a procedure was associated with increased 30-day readmission.

Final 30-day Readmission Logistic Regression Model Selection

The logistic regression model for patient risk factor association with 30-day readmission was selected based on AUC and goodness-of-fit test p-values. Table 2.6 summarizes the performance measures as well as the number of significant patient risk factors for each model.

The AUC and confidence intervals (CI) for both regression models were similar, as featured in table 2.6 and illustrated in figure 2.6. The similar AUC values indicate each model had the same ability to classify true positives and true negatives. With a p-value = 0.8120, the binomial logistic regression had a better goodness-of-fit compared against the LASSO Logistic Regression model. Due to the better performance in terms of goodness-of-fit, the binomial logistic regression model was selected to model the patient risk factor association with 30-day readmission.



(a) (b)

Figure 2.6: AUC Plots for Binomial & LASSO Logistic Regression 30-day Readmission Models

2.3.2 In-hospital Mortality

Descriptive Statistics Summary

A χ^2 test was performed to assess the independence of each patient risk factor and the cohorts with significance assessed at α=0.05. Simulated p-value was performed to estimate the p-value for age and length of stay discrete variables. The results of the χ^2 tests are summarized in table 2.7. All 30 patient risk factors had a p-value $\geq$ 0.05, indicating that random assignment of patients into each training and testing cohort appropriately distributed each patient risk factor into each cohort for in-hospital mortality. Lack of housing, being discharged home, treatment for Chronic Obstructive Pulmonary Disease (COPD), and treatment for stroke each had fewer than 10 cases in each cohort, and were therefore removed from the model.

Next, the age and length of stay distribution for all patients included in the full dataset was observed for in-hospital mortality. Figure 2.7 illustrates the age distribution for patients passed away and survived. The patients who survived had a average age of 53.78 years, and the patients who passed away had an average age of 59.13 years.

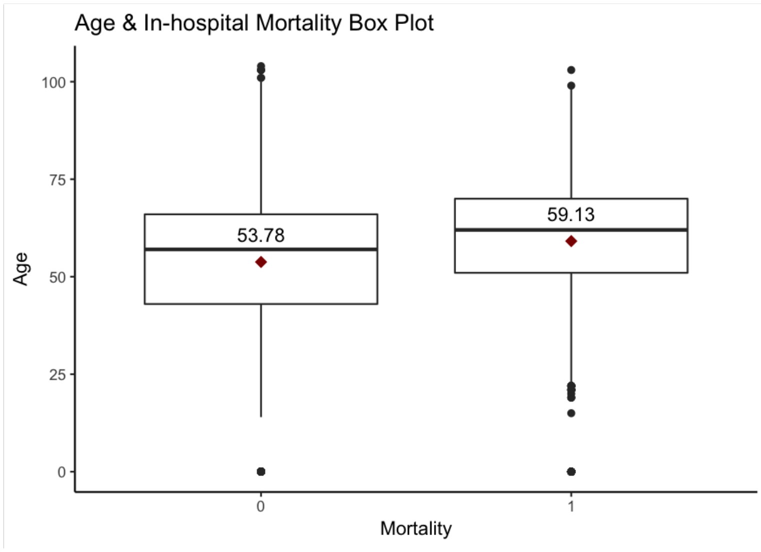


Figure 2.7: Box Plot of Age & In-hospital Mortality

Figure 2.8 illustrates a box plot and histogram of the length of stay for patients who passed away and survived. The mean length of stay for patients who passed away was 14.36 days, compared to the mean length of stay of 7.37 days for patients who did not pass away. The higher mean length of stay for patients who passed away is expected since patients who stay in the hospital for longer amounts of time are typically sicker and sicker patients are more likely to pass away.

Binomial Logistic Regression

Prior to building the binomial and LASSO logistic regression models, potentially influential factors were assessed. To determine if the dataset includes any potentially influential observations, a Cook's distance plot was used to assess Cook's distances for each observation. Figure 2.9 illustrates the Cook's distances, including the three observations with the highest Cook's distances. Since none of the observations had a Cook's distance ≥ 1 indicating

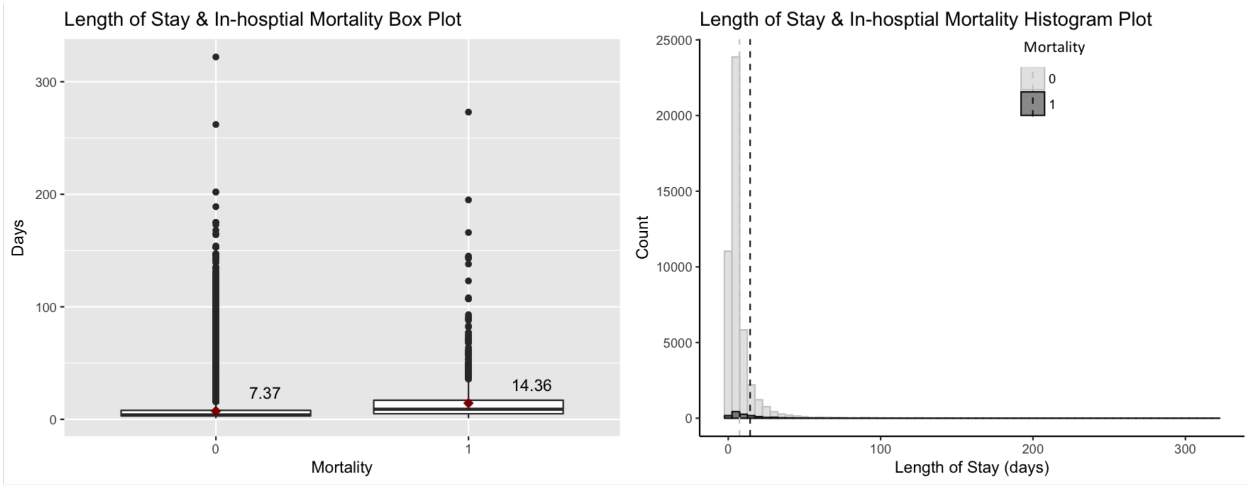


Figure 2.8: Length of Stay & In-hospital Mortality Box Plot & Histogram

influence, none of the observations were excluded from the dataset.

Next, the backwards stepwise approach was performed. At each step, the explanatory variable with the highest p-value was removed from the model and the model was rebuilt until all the variables remaining were significant with p-values$\leq$ 0.05.

Table 2.8 summarizes the model coefficient estimates and odd ratios (OR) for the significant variables. A decreased risk of in-hospital mortality was indicated with an OR$<$ 1, and increased risk of in-hospital mortality was indicated with an OR$>$. The residual deviance was 3514.4 in comparison to the null deviance of 8323.4, indicating the null binomial logistic regression model improved with the addition of the significant patient risk factors.

There were a total of 8 patient risk factors associated with in-hospital mortality. The 2 patient risk factors associated with decreased risk were having a classification of minor risk of mortality and receiving treatment for heart failure. The 6 patient risk factors associate with an increased risk were having a classification extreme severity of illness and risk of mortality; receiving treatment for sepsis and AMI; staying in the ICU; and receiving palliative care. The results are as expected since it is assumed patient classified with risk of mortality and

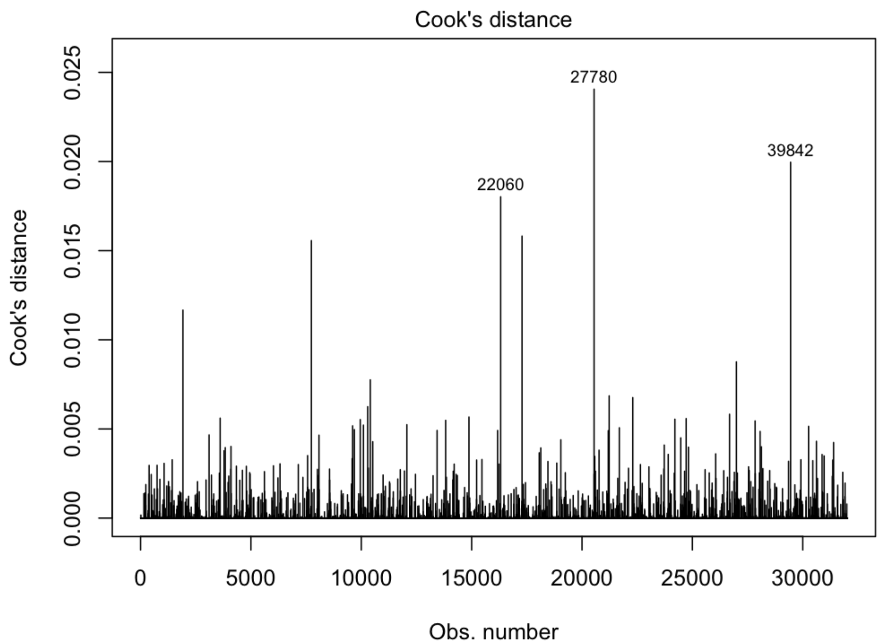


Figure 2.9: Cook's Distance Plot for In-hospital Mortality

severity of illness are more likely to pass away than patients classified as having minor risk of mortality.

LASSO Logistic Regression

To build the LASSO logistic regression model, a 10-fold cross-validation was used to identify the value of $\lambda + 1se$ that maximized the model discrimination, measured in terms of AUC. Figure 2.10 illustrates the cross-validation curve used to determine the λ parameter value.

The $\lambda + 1se$ that maximized AUC was $\lambda = 0.0038$, which corresponds to 5-7 significant explanatory variables included in the LASSO model. The odds ratio for each significant explanatory variable using the training data and the LASSO logistic regression modeling method is featured in table 2.9.

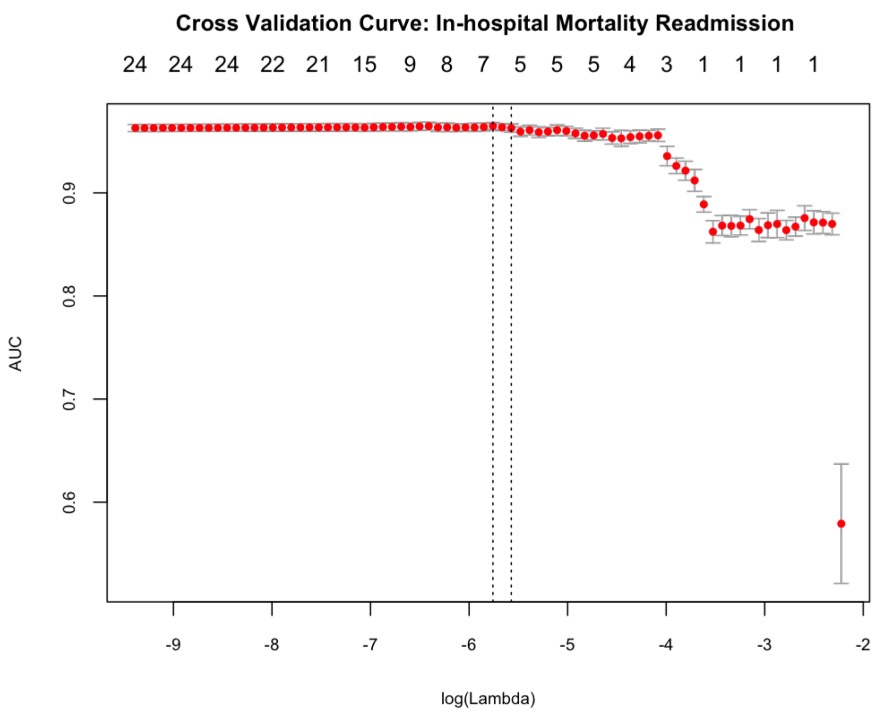


Figure 2.10: Cross-Validation Curve for In-hospital Mortality

There were 5 significant patient risk factors found using LASSO logistic regression, all of which were associated with an increased risk of in-hospital mortality. Being classified as having extreme risk of mortality and severity of illness, receiving treatment for sepsis, staying the ICU during the visit, and receiving palliative care were all associated with an increased risk of mortality.

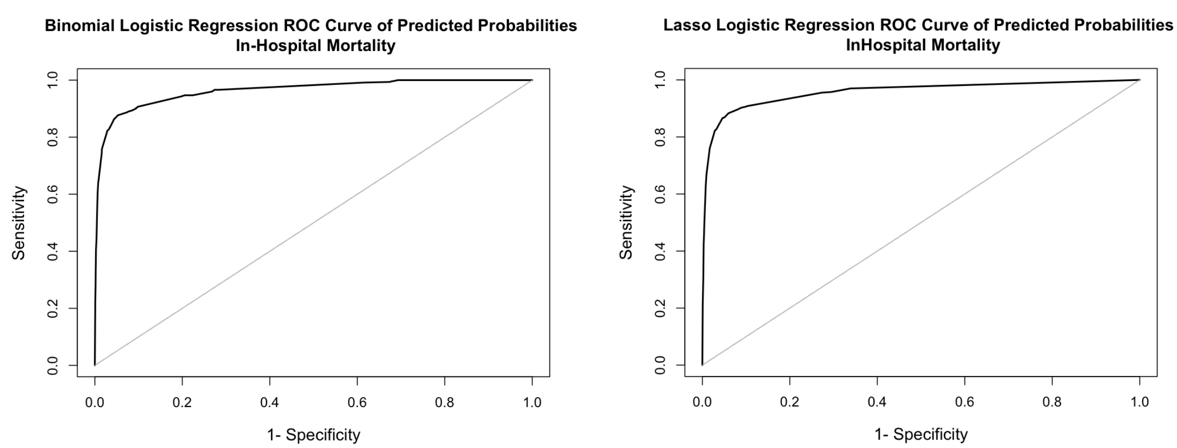
Binomial & LASSO Logistic Regression Variable Selection Comparison

Both the binomial and LASSO logistic regression had similar risk factors associated with increased risk of in-hospital mortality, including being classified as having extreme risk of mortality and severity of illness, receiving treatment for sepsis, staying in the ICU during the visit, and receiving palliative care. Additionally, binomial logistic regression included receiving treatment for AMI, which was associated with an increased risk of mortality, while receiving treatment for heart failure and being classified as having a minor risk of mortality was associated with a decreased risk of mortality.

Final In-hospital Mortality Logistic Regression Model Selection

The logistic regression model for patient risk factor association with in-hospital mortality was selected based on AUC and goodness-of-fit test results. Table 2.10 summarizes the performance measures and the number of significant patient risk factors for each model.

The AUC and confidence intervals (CI) for both regression models were similar as featured in table 2.10 and illustrated in figure 2.11. The similar AUC values indicate each model had the same ability to classify true positives and true negatives. With a p-value = 0.0.0030, the binomial logistic regression had a better goodness-of-fit compared against the LASSO Logistic Regression model, although both had poor fit. Due to the better performance in terms of goodness-of-fit, the binomial logistic regression model was selected to model the patient risk factor association with in-hospital mortality.



(a) (b)

Figure 2.11: AUC Plots for Binomial & LASSO Logistic Regression In-hospital Mortality Models

2.4 Discussion

The binomial and LASSO logistic regression methods showed similar AUC results for both adverse health outcomes in terms of performance measured by AUC and goodness-of-fit. The binomial logistic regression did have slightly better goodness-of-fit. There were trade-offs between AUC and goodness-of-fit performance for each adverse health outcome. Logistic regression models for 30-day readmission included 19 significant patient risk factors, had poorer discrimination, and better goodness-of-fit, while in-hospital mortality was less complex with 8 significant patient risk factors, better discrimination, and poorer goodness-of-fit. Ultimately, binomial logistic regression was selected for the slightly better goodness-of-fit in comparison to LASSO logistic regression methods.

There were few similarities and several differences between the patient risk factors associated with increased and decreased risk of both adverse health outcomes. Patients who were classified with a minor risk of mortality had a decreased risk of both adverse health outcomes, while patients classified with a extreme severity of illness had an increased risk of both adverse health outcomes. Interestingly, minor severity of illness was not significantly associated with decreased risk of in-hospital mortality, but was significantly associated with decreased risk of 30-day readmission. Both age and length of stay were not significantly associated with in-hospital mortality but were associated with 30-day readmission.

The adverse health outcome models described in this chapter can be used for risk-adjustment purposes, as performed in chapters 3, 4, and 5 of this dissertation.

Table 2.4: Patient Risk Factors & 30-day Readmission Binomial Logistic Regression Model

	Coefficient Estimate	**Standard Error**	**Odds Ratio (CI)**	**p-value**	
(Intercept)	*-2.3324*	*0.0889*	*0.10(0.08, 0.12)*	*<0.0005*	*****
Decreased Risk of 30-day Readmission					
Palliative Care	-1.7584	0.1349	0.17(0.13, 0.22)	<0.0005	***
Minor Risk of Mortality	-0.8353	0.0379	0.43(0.40, 0.47)	<0.0005	***
Minor Severity of Illness	-0.6042	0.0470	0.55(0.50, 0.60)	<0.0005	***
AMI	-0.5066	0.1763	0.60(0.42, 0.84)	0.0041	**
ICU Stay	-0.3468	0.0388	0.71(0.66, 0.76)	<0.0005	***
Pneumonia	-0.3237	0.1388	0.72(0.55, 0.94)	0.0197	*
Extreme Risk of Morality	-0.1422	0.0707	0.87(0.75, 1.00)	0.0445	*
Medicare Beneficiary	-0.1265	0.0356	0.88(0.82, 0.94)	<0.0005	***
Increased Risk of 30-day Readmission					
Age	0.0020	0.0009	1.00(1.00, 1.00)	0.0293	*
Length of Stay	0.0050	0.0013	1.00(1.00, 1.01)	<0.0005	***
Procedure	0.1175	0.0381	1.12(1.04, 1.21)	0.0021	**
Diabetes	0.1412	0.0361	1.15(1.07, 1.24)	<0.0005	***
Primary Language: English	0.2040	0.0567	1.23(1.10, 1.37)	<0.0005	***
Race/Ethnicity: Black/African-American	0.2467	0.0510	1.28(1.16, 1.41)	<0.0005	***
Admission from Emergency Department	0.2567	0.0342	1.29(1.21, 1.28)	<0.0005	***
Extreme Severity of Illness	0.3107	0.0465	1.36(1.25, 1.49)	<0.0005	***
Heart Failure	0.3801	0.0824	1.46(1.24, 1.72)	<0.0005	***
Discharge Status: Home/Self-care	0.4491	0.0407	1.57(1.45, 1.70)	<0.0005	***
Cancer	0.9049	0.0318	2.47(2.32, 2.63)	<0.0005	***
Total 30-day Readmission Cases in Training Dataset = 7028					
Null Deviance = 38421					
Residual Deviance = 34343					

Table 2.5: Patient Risk Factors & 30-day Readmission LASSO Logistic Regression Model

	Odds Ratio
(Intercept)	*0.1685*
Decreased Risk of 30-day Readmission	
Palliative Care	0.2693
Minor Risk of Mortality	0.4312
Minor Severity of Illness	0.6081
Age$\geq$ 65	0.7815
ICU Stay	0.8011
Increased Risk of 30-day Readmission	
Primary Language English	1.0317
Race/Ethnicity: Black/African-American	1.0414
Diabetes	1.0748
Length of Stay$\geq$ 7days	1.0972
Admission from Emergency Department	1.1574
Extreme Severity of Illness	1.1606
Heart Failure	1.2390
Discharge Status: Home/Self-care	1.3597
Cancer	2.3659
Total 30-day Readmission Cases = 7028	

Table 2.6: Performance Summary for Binomial & LASSO Logistic Regression 30-day Readmission Models

	Total Significant Variables	**AUC(CI)**	**Goodness-of-Fit p-value**
Binomial Logistic Regression	19	0.74(0.73, 0.75)	0.8120
LASSO Logistic Regression	14	0.74(0.73, 0.75)	<0.0005

Table 2.7: Descriptive Statistics Summary: In-Hospital Mortality

	Training Cohort (n=917)	Testing Cohort (n=471)	χ^2 p-value	χ^2 (simulated) p-value
Demographics				
Age, years mean (sd)	58.77(17.63)	59.82(17.20)		0.9900
Race/Ethnicity: Black or African American n(%)	41(4.47)	25(5.31)	0.5752	
Race/Ethnicity: Hispanic n(%)	31(3.38)	19(4.03)	0.6409	
Sex: Male n(%)	519(56.60)	269(57.11)	0.8996	
Home County: King County n(%)	378(41.22)	211(44.80)	0.2227	
Lack of Housing n(%)	4(0.44)	2(0.42)	>0.999	
Payor Group: Medicare n(%)	442(48.20)	222(47.13)	0.7490	
Primary Language: English n(%)	845(92.15)	441(93.63)	0.3716	
Primary Language:Spanish OR Chinese n(%)	26(2.84)	11(2.34)	0.7103	
Admission & Discharge Details				
Emergency Department Admit n(%)	327(35.66)	174(36.94)	0.6802	
Discharge Status: Home/Self-care n(%)	0	0	NA	
Length of Stay (Days) mean(sd)	14.46(19.37)	14.10(17.22)		0.8361
ICU Stay n(%)	668(72.85)	334(70.91)	0.4853	
ICU Length of Stay for All patients(Days) mean(sd)	6.81(13.27)	6.08(10.42)		0.8001
ICU Length of Stay for ICU patients(Days) mean(sd)	9.36(14.77)	8.60(11.50)		0.7501
Discharge during Summer	247(26.94)	129(27.39)	0.9077	
Discharge during Winter	201(21.92)	124(26.33)	0.0769	
Health Condition				
Risk of Mortality n(%)				
Extreme	420(45.80)	199(42.25)	0.2289	
Minor	20(2.18)	10(2.12)	>0.999	
Severity of Illness n(%)				
Extreme	546(59.54)	284(60.30)	0.8306	
Minor	6(0.65)	5(1.06)	0.6237	
Procedure n(%)	822(89.64)	424(90.02)	0.8979	
Acute Myocardial Infarction n(%)	24(2.62)	11(2.34)	0.8916	
Cancer n(%)	432(47.11)	222(47.13)	>0.999	
Chronic Obstructive Pulmonary Disease n(%)	9(0.98)	3(0.64)	0.7261	
Heart Failure n(%)	45(4.91)	29(6.16)	0.3925	
Pneumonia n(%)	23(2.51)	10(2.12)	0.7950	
Diabetes n(%)	241(26.28)	122(25.90)	0.9302	
Sepsis n(%)	411(44.82)	199(42.25)	0.3919	
Stroke n(%)	7(0.76)	4(0.85)	>0.999	
Palliative Care n(%)	693(75.57)	358(76.01)	0.9098	
Hospice Care n(%)	3(0.33)	1(0.21)	>0.999	

Table 2.8: Binomial Logistic Regression Model for Patient Risk Factors & In-hospital Mortality

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value	
(Intercept)	*-5.7159*	*0.1085*	*0.00(0.00, 0.00)*	*<0.0005*	***
Decreased risk of In-hospital Mortality					
Minor Risk of Mortality	-1.5028	0.2459	0.22(0.13, 0.35)	<0.0005	***
Heart Failure	-0.7789	0.2228	0.46(0.29, 0.71)	<0.0005	***
Increased Risk of In-hospital Mortality					
Extreme Severity of Illness	0.3660	0.1200	1.44(1.14, 1.82)	0.0023	**
Extreme Risk of Mortality	0.6415	0.1302	1.90(1.47, 2.45)	<0.0005	***
Sepsis	0.9776	0.1172	2.66(2.11, 3.34)	<0.0005	***
AMI	1.0021	0.2934	2.72(1.48, 4.70)	0.0006	***
ICU Stay	1.5574	0.1055	4.75(3.87, 5.85)	<0.0005	***
Palliative Care	4.6093	0.1026	100.42(82.31, 123.07)	<0.0005	***
Total In-hospital Mortality Cases in Training Dataset = 917					
Null Deviance = 8323.4					
Residual Deviance = 3514.4					

Table 2.9: LASSO Logistic Regression Model of Patient Risk Factors & In-hospital Mortality

	Odds Ratio
(Intercept)	*0.0051*
Increased Risk of In-hospital Mortality	
Extreme Severity of Illness	1.1591
Extreme Risk of Mortality	2.0157
Sepsis	2.1672
ICU Stay	2.4630
Palliative Care	82.3235
Total In-hospital Mortality Cases in Training Dataset = 917	

Table 2.10: Performance Summary for Binomial & LASSO Logistic Regression In-hospital Mortality Models

	Total Significant Variables	**AUC(CI)**	**Goodness-of-Fit p-value**
Binomial Logistic Regression	8	0.96(0.95, 0.97)	0.0030
LASSO Logistic Regression	5	0.96(0.95, 0.97)	<0.0005

Chapter 3

THE INFLUENCE OF HOSPITAL RESOURCES AND ADVERSE HEALTH OUTCOMES

3.1 Introduction

The second research question (RQ2) examines the resource factors variables that impact in-hospital mortality and 30-day readmission rates. Access to human, bed, and equipment resources in the hospital setting directly affect healthcare delivery timeliness and safety. There is extended boarding time and increased wait time for patients seeking care in the ED when hospital inpatient beds are filled to capacity with admitted patients. Depending on the arrival rate of patients, overcrowding can become an issue very quickly as well.

Hospital resources include nursing staff, hospital beds, and equipment. Ideally, when resources are available, patients arriving to the hospital would be seen by a healthcare provider upon arrival and would not experience delays in care. Similarly, patients discharged during times when resources are available would receive detailed, easy to follow after care and medication education since nursing staff would have more time to spend at their patient's bedside [10]. During weekends, evenings, and night shifts, it is possible that diagnostic equipment and beds are unavailable due to the lack of qualified healthcare providers required to utilize the equipment or beds [14].

The objective of this chapter is to assess the association between potential hospital resource factors and adverse patient health outcomes. In the last chapter, significant patient risk factors associated with 30-day readmission were identified using binomial logistic regression. Each hospital resource variable will be assessed for influence on adverse patient health outcomes independently to assess the crude association, and then the association will be adjusted to account for variations of the hospital resource factors across significant patient risk factors.

Resource factors include variables related to resource levels as well as proxy measures as defined in §1.5. The terms "nurse staffing" and "number of nurses scheduled to work" are used interchangeably throughout this chapter. It is hypothesized increased nurse staffing, beds, and equipment are associated with an decreased likelihood of experiencing adverse health outcomes, while proxy measures for increased nursing workload (i.e. number of admissions and discharges to a nursing unit) and reduced access to diagnostic treatment (i.e. admission during night shift) are associated with increased likelihood of experiencing an adverse health outcome.

3.2 Method

3.2.1 Data Overview

The data came from administrative reports from the University of Washington Medical Center (UWMC), an urban teaching hospital in Seattle, WA. Administrative data included individual patient health outcome, demographics, admission and discharge details, and health condition information. The population included in this study were all patients admitted and discharged from this hospital between January 1st, 2012 to July 30th, 2015. A total of 71959 patient visits were available for this time frame. Missing values and patients with a length of stay less than 24 hours were excluded from the dataset, illustrated in figure 2.1 in chapter 2. A total of 65016 patient visits were available for this time frame.

Staffing Data

Registered nurse staffing data was provided by the UWMC Kronos Scheduling Department. The staffing dataset included data on the number of nurses scheduled to work and to be on vacation by shift and date. Data prior to August 19th, 2013 could not be accessed through the Kronos database, so the dataset included staffing variables from August 19th, 2013 to July 30th, 2015.

Census Data

A hospital midnight census data report for each unit was provided by the Clinical Analytics and Amalga Team at the University of Washington. Midnight census is defined as the number of patients occupying a bed in each nursing unit at midnight. The census data for each unit was compared to the number of licenses beds on each unit; the census for each unit subtracted from the number of licensed beds on the unit was the calculation used to find the number of available beds on the day of admission and discharge.

Daily Admission and Discharge Count Data

Daily admission and discharge count data for each unit was provided by the Epic Team at the University of Washington.

3.2.2 Data Merging and Segmentation

Staffing, census, admission, and discharge count data were merged with the patient detail report. Of the 65016 encounters from the patient detail report, 29493 were removed due to discharges occurring before August 19th, 2013, 4500 were removed due to missing staffing data, 4864 were removed due to missing census data, and 22 were removed due to missing admitting nursing unit information. A total of 26137 patient visits remained in the dataset 3.1.

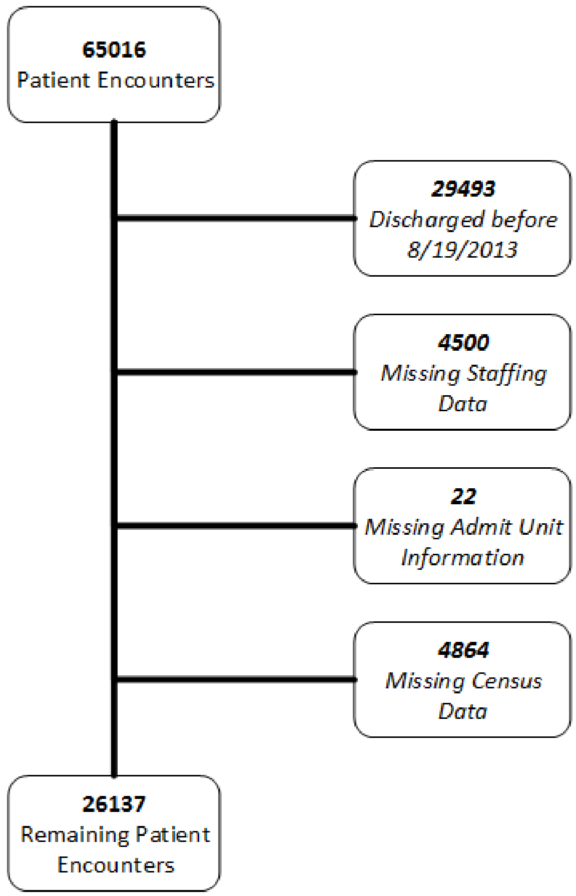


Figure 3.1: Cohort Assignment Flow Chart(b)

3.2.3 Data Analysis

Descriptive Analysis

Descriptive analysis was performed on the discrete variables, which includes age and length of stay, to observe their distributions and identify possible categorization boundaries. Histograms and box plots are performed on each discrete variable.

Binomial Logistic Regression

The binomial logistic regression used in this study builds on the regression model explained in equation 2.1. Based on the dichotomous nature of each adverse health outcome variables, binomial logistic regression modeling was appropriate to assess the association between each individual hospital resource factor, as featured in equation 3.1.

$$log\left[\frac{\pi}{1-\pi}\right] = \beta_0 + \beta_k y_{ik} \tag{3.1}$$

where,

π = Pr(adverse health outcome)

β_0 = intercept

β_k = coefficient for the k^{th} hospital resource factor

y_{ik} = value of the k^{th} hospital resource factor for the i^{th} patient encounter

i = 1...m patient encounters

k = 1...p hospital resource factors

To adjust for variability across patient risk factor values, all patient risk factors significant in chapter 2 will be combined with each individual hospital resource factor, as featured in equation 3.2.

$$log\left[\frac{\pi}{1-\pi}\right] = \beta_0 + \beta_k y_{ik} + \sum_{j=1}^{n} \beta_j x_{ij} \tag{3.2}$$

The null and alternative hypothesis for RQ2 is as follows:

$$H_0 : \beta_1, \beta_2, ..., \beta_k = 0 \tag{3.3}$$

$$H_1 : \beta_1, \beta_2, ..., \beta_k \neq 0$$

Based on the literature, it is hypothesized that age; health conditions; severity of illness; risk of mortality; admission source; and length of stay are significant risk factors.

Binomial Logistic Regression Analytical Method

A regression was performed between each individual hospital resource value and adverse health outcome to find the crude association. Next, the significant patient risk factors found in Chapter 2 is used to adjust the association between each hospital resource variable and adverse health outcome. The odds ratio (OR) and confidence interval for each significant variable of the final model will be presented.

To ensure that the multicollinearity assumption is not violated, the generalized variation inflation factor (VIF) will be assessed for each explanatory variable of the model to identify any variables with a correlation to two or more variables. Of the variables with a VIF>4, the variable with the highest VIF will be removed from the model and the VIF for the remaining explanatory variables. This process will be repeated until all variables remaining have a VIF<4.

3.3 Results

3.3.1 Unit Selection

Prior to building the models, the distribution of patients for each unit was assessed to determine if there are any nursing units to be excluded from the study. A nursing unit was excluded if there were 0 adverse patient health outcome cases in either the training or testing cohort. Since hospital resources were assessed at both the day of admission and day of discharge, both the admitting and discharging nursing units were taken into consideration. The 30-day readmission and in-hospital mortality cases for each admitting and discharging unit is featured in table 3.1. All admitting and discharging nursing units had $\geq$ 10 30-day readmission cases in the dataset. Psychiatry, rehabilitation, ante-partum and mother-baby admitting nursing units had 0 in-hospital mortality cases, and Psychiatry, Rehabilitation, and Post-partum discharging nursing units had 0 in-hospital mortality cases in the dataset. Therefore, these units were excluded from the dataset used to model in-hospital mortality.

Hospital Resources Descriptive Statistics

Hospital resources featured in this exploratory study included resources levels at the time a patient is admitted to and discharged from a hospital unit. Box plots were made to assess the distribution of each hospital resource discrete variable, including number of nurses staffed, number of nurses vacationing, number of beds available, and number of admissions and discharges to the admitting and discharging nursing unit.

Figures 3.2 and 3.3 feature number of nurses staffed for each adverse health outcome on day of admission and day of discharge. For the day of admission, the number of nurses staffed for patients who were readmitted and who passed away during their hospital stay were greater than the number of staff for patients who did not experience adverse health outcomes, as featured in figure 3.2. This was also the case for day of discharge/mortality, as illustrated in figure 3.3. For those patients who were readmitted, not readmitted, and survived,the average number of nurses on staff was between 9-10 on their day of admission and discharge. for those patients who passed away during their stay, there were on average 11-12 nurses on staff at the time of the patient's death.

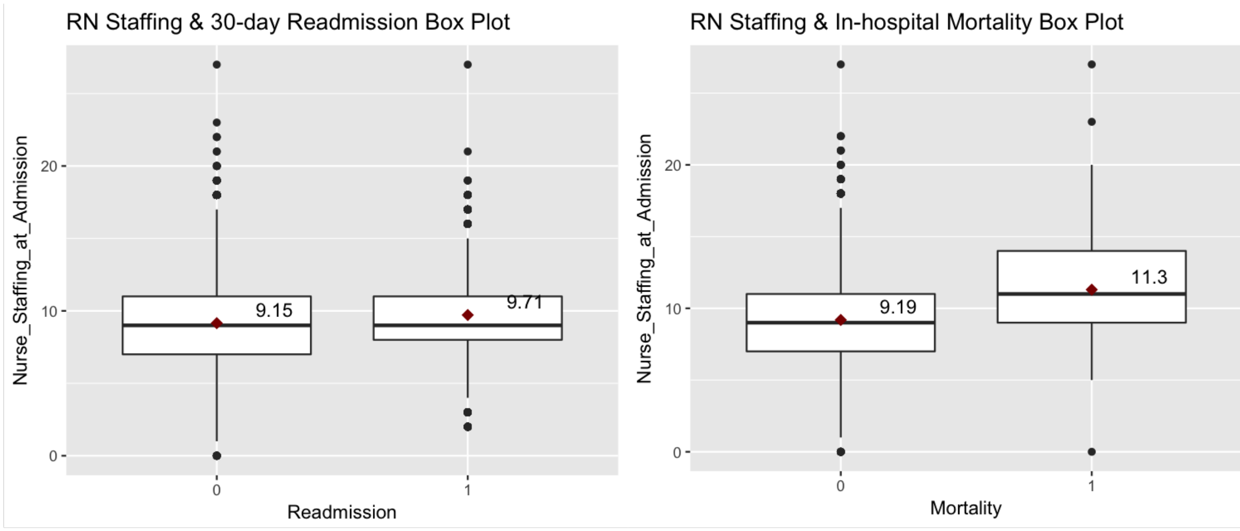


Figure 3.2: Nurses Staffed on Units by Readmission and Mortality Status on Day of Admission

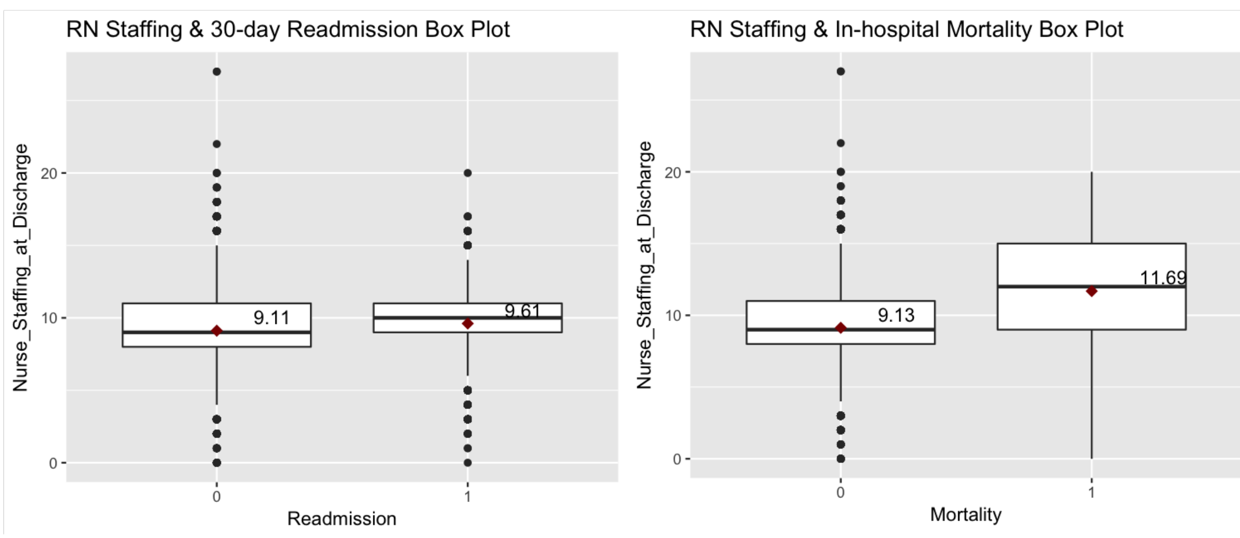


Figure 3.3: Nurses Staffed on Units by Readmission and Mortality Status on Day of discharge

Figures 3.4 and 3.5 feature number of nurses on vacation for each adverse health outcome on day of admission and day of discharge. For the day of admission and discharge, the number of nurses on vacation was between 2-3 nurses for all adverse health outcome statuses.

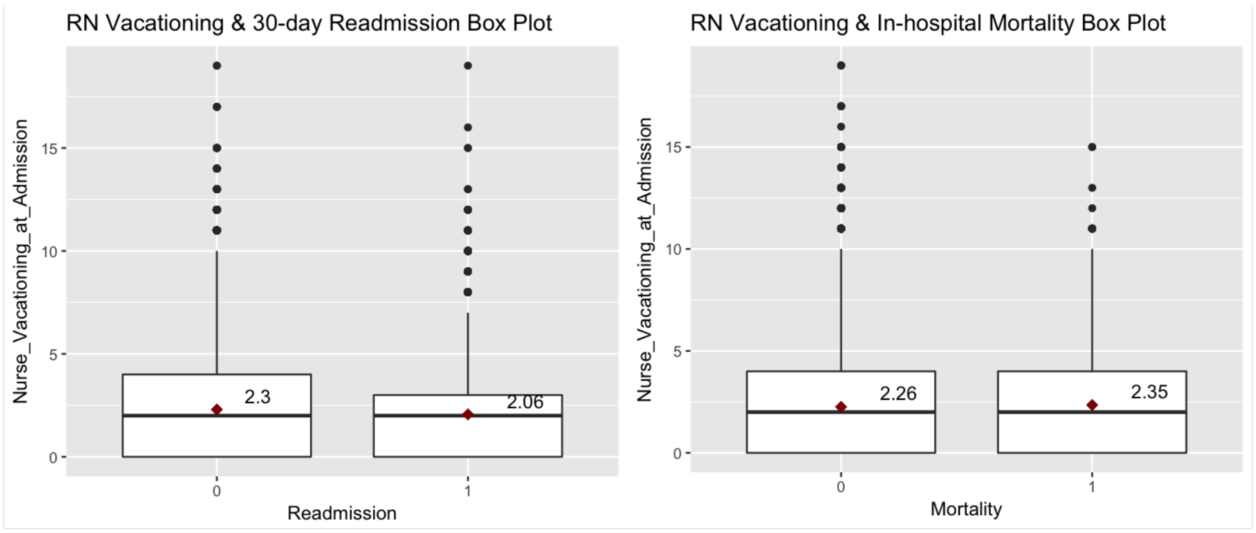


Figure 3.4: Nurses Vacationing on Units by Readmission and Mortality Status on Day of Admission

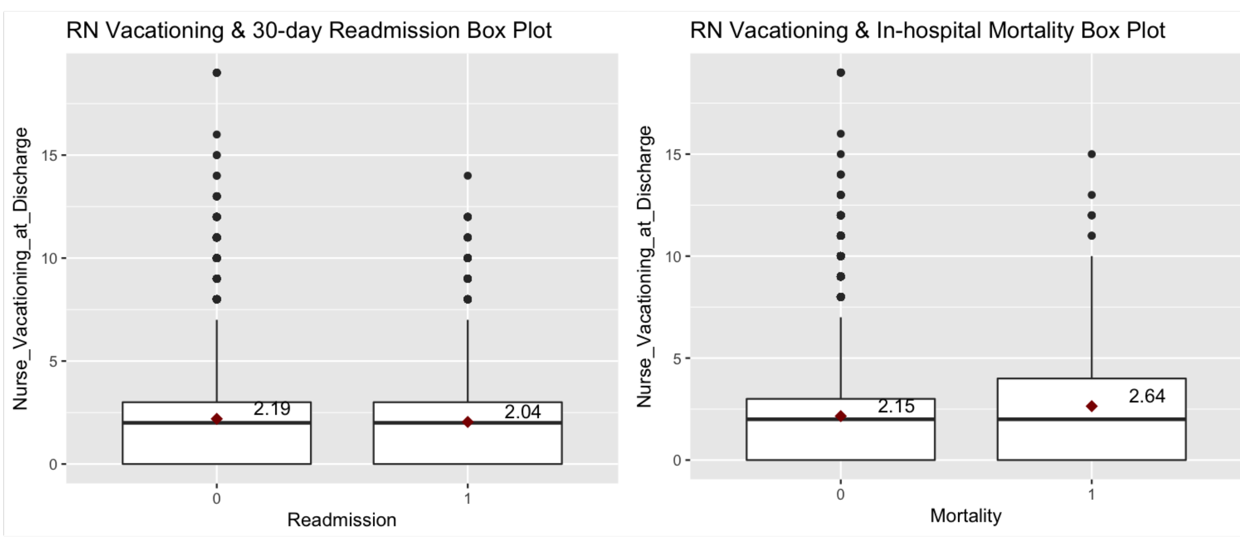


Figure 3.5: Nurses Vacationing on Units by Readmission and Mortality Status on Day of discharge

Figures 3.6 and 3.7 feature number of beds available for each adverse health outcome status on day of admission and day of discharge. For the day of admission and discharge, the average number of beds available was between 3-4 beds on day of admission and between 2-4 on day of discharge for all adverse health outcome statuses.

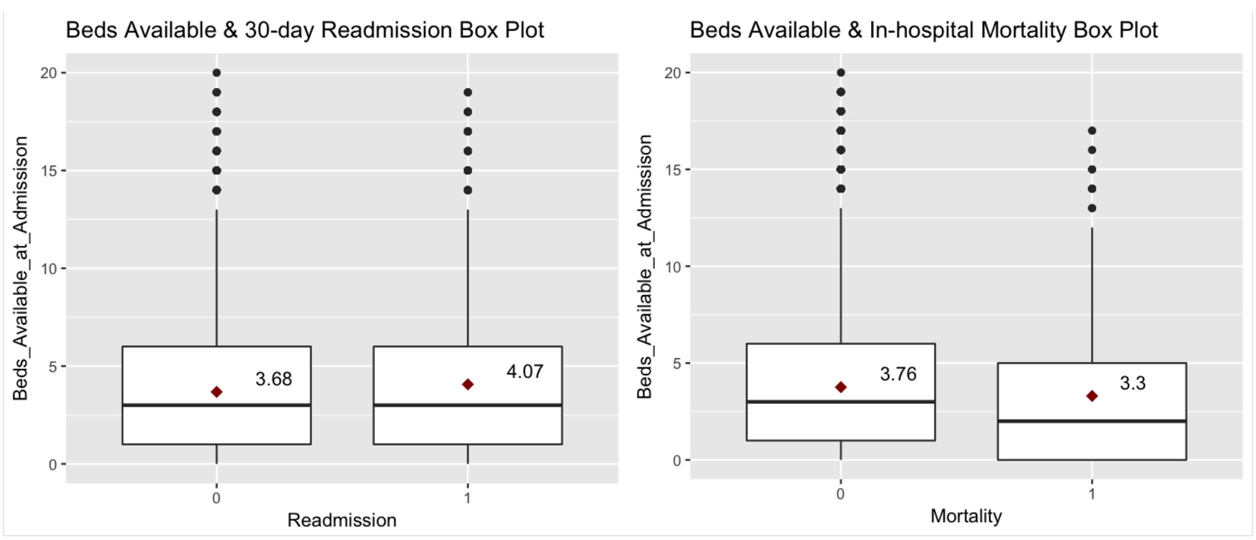


Figure 3.6: Beds Available on Units by Readmission and Mortality Status on Day of Admission

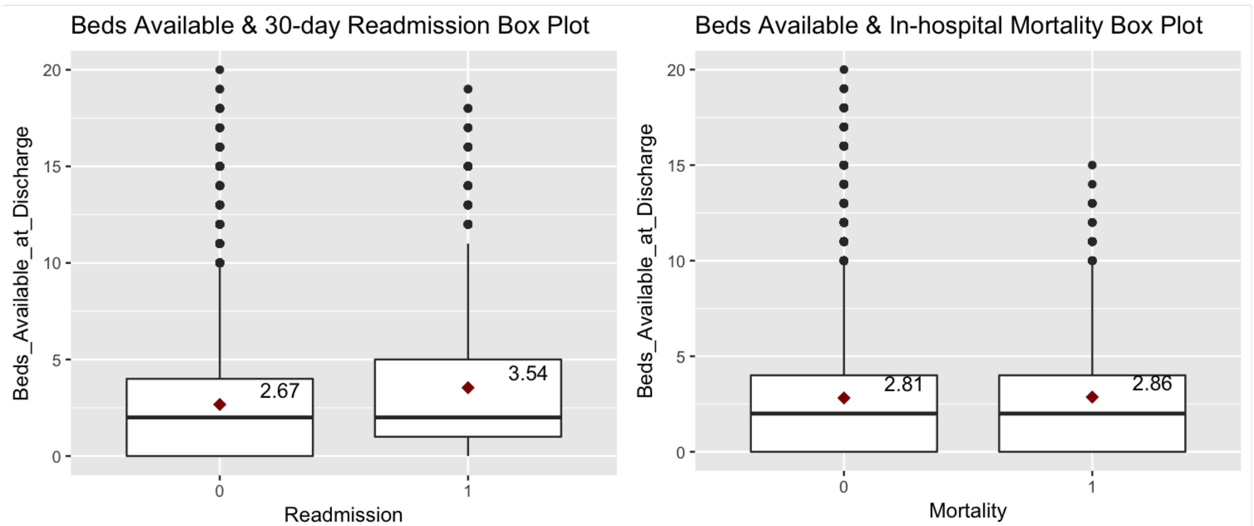


Figure 3.7: Beds Available on Units by Readmission and Mortality Status on Day of discharge

Figures 3.8 and 3.9 feature number of patients admitted to a unit for each adverse health outcome status on day of admission and day of discharge. For the day of admission and discharge, the average number of patients admitted was between 4-5 admissions on day of admission and between 3-4 on day of discharge for all adverse health outcome statuses.

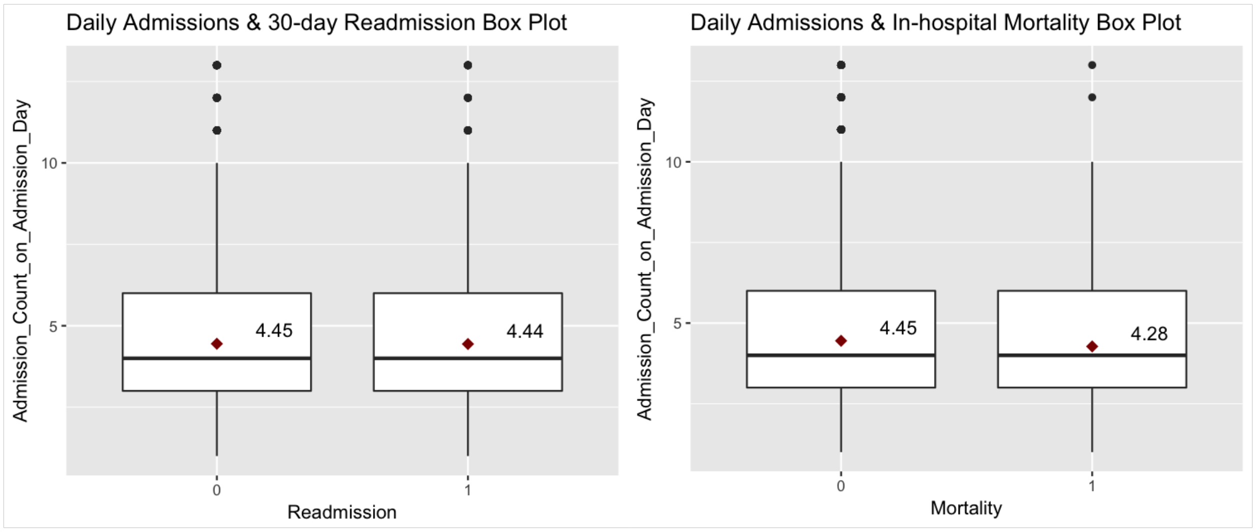


Figure 3.8: Number of Admissions to Units by Readmission and Mortality Status on Day of Admission

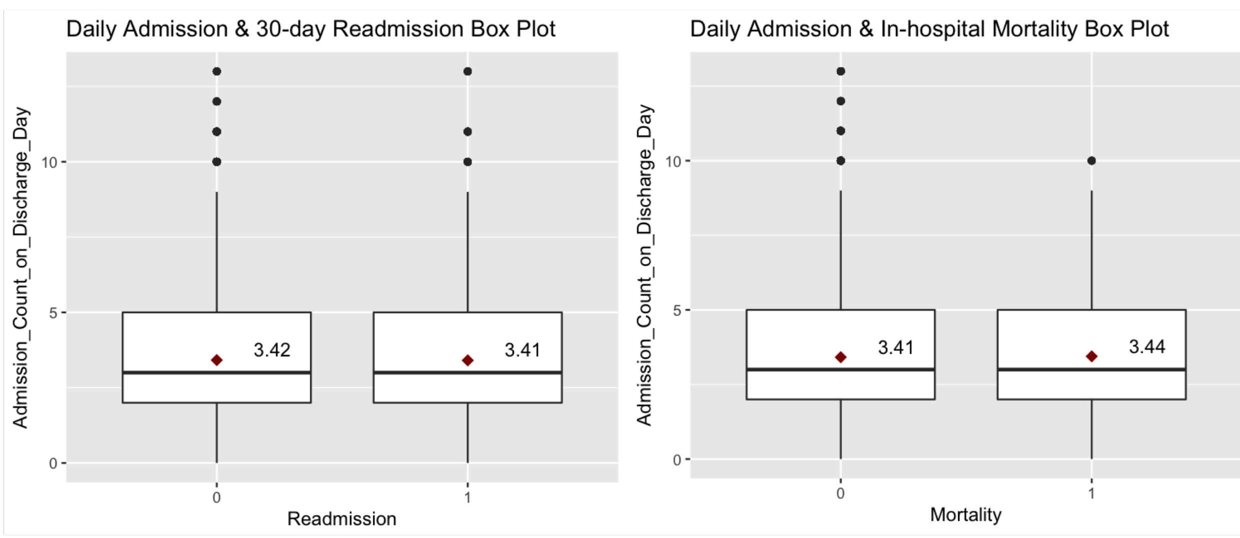


Figure 3.9: Number of Admissions to Units by Readmission and Mortality Status on Day of discharge

Figures 3.10 and 3.11 feature number of patients discharged from a unit for each adverse health outcome status on day of admission and day of discharge. For the day of admission and discharge, the average number of patients discharged was lower for those patients who passed away in comparison to those patients who survived.

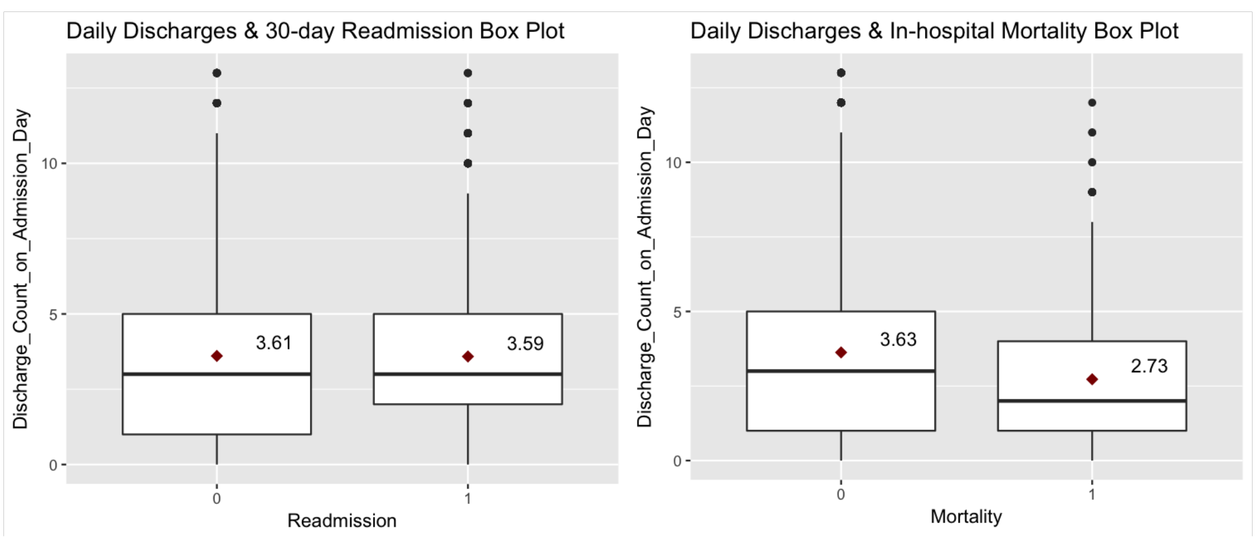


Figure 3.10: Number of Discharges from Units by Readmission and Mortality Status on Day of Admission

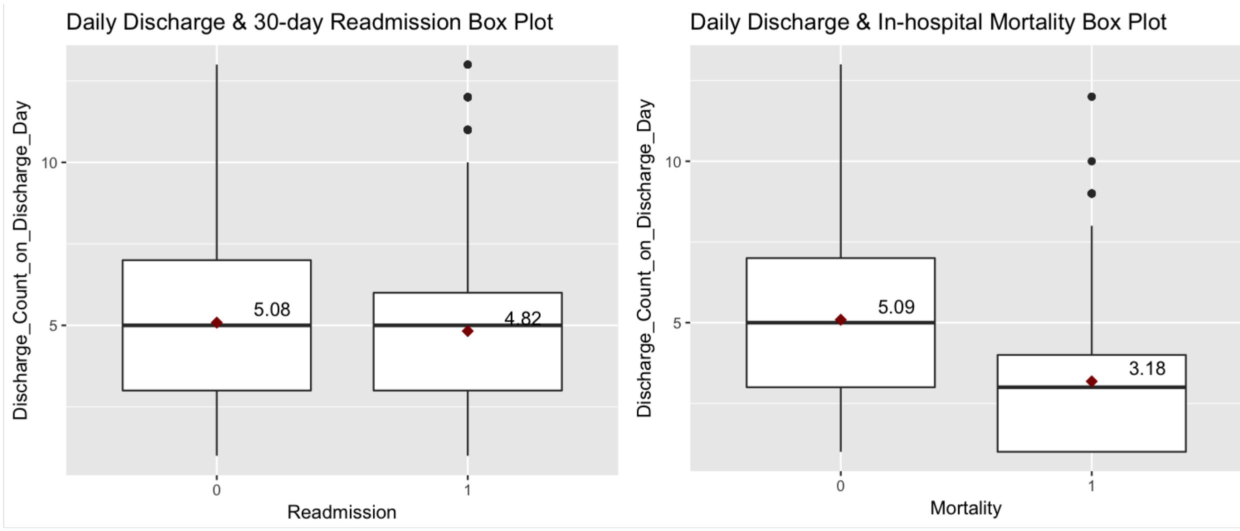


Figure 3.11: Number of Discharges from Units by Readmission and Mortality Status on Day of discharge

Descriptive Statistics Summary

Next, the age and length of stay distributions were assessed for patients who were and were not readmitted within 30-days. Figure 3.12 displays a box plot of readmission status. The average age for those patients readmitted and not readmitted were 53.84 and 53.18 years old, respectively. The distribution of length of stay based on readmission status is featured in figure 3.13. Patients who were and were not readmitted within 30 days appear to have similar length of stay distributions, peaking at approximately 7 days.

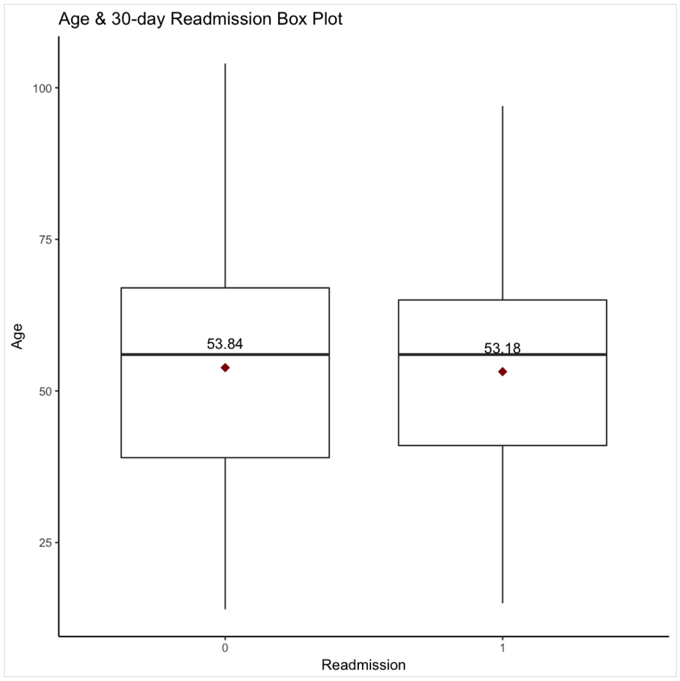


Figure 3.12: Age & 30-day Readmission Box Plots

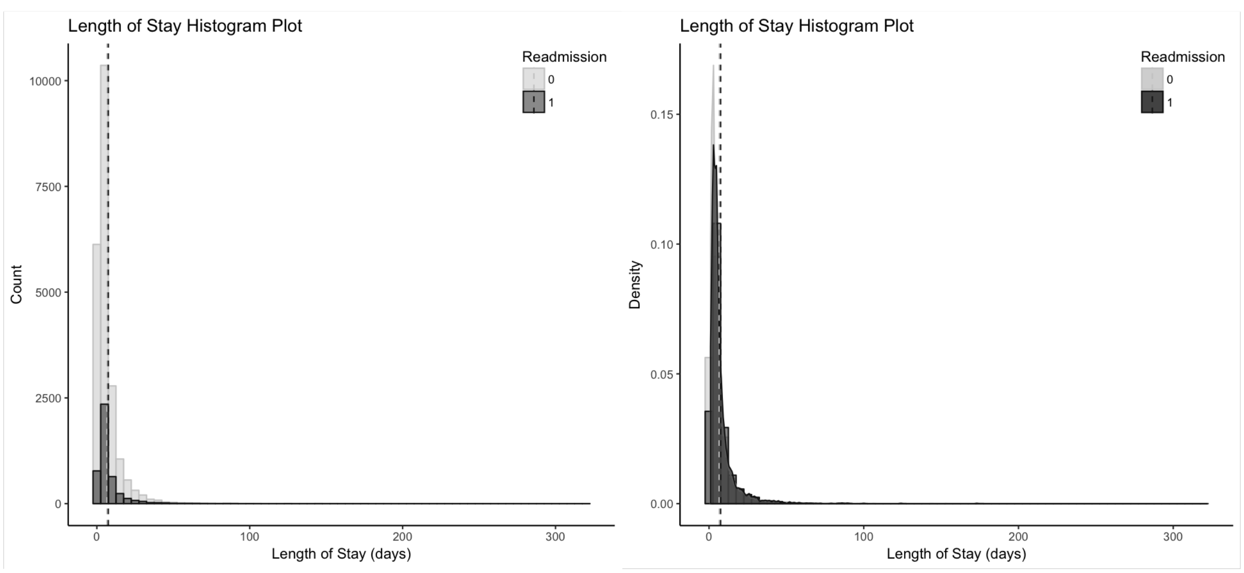


Figure 3.13: Length of Stay & 30-day Readmission Histograms

3.3.2 Hospital Resource Associations with 30-day Readmission

Each hospital resource factors individual influence on 30-day readmission was assessed on the day of the patient's last admission to and day of last discharge from the hospital. Table 3.2 features the odds ratio for each hospital resource variable.

On the day of the last admission to the hospital, the significant hospital resource factors included number of nurses staffed, number of nurses on vacation, number of beds available on the unit, being admitted on the weekend, being admitted during the evening shift, and being admitted during the night shift. The number of nurses staffed, the number of beds available, being admitted during the weekend, and being admitted during the evening shift had an association with increased risk of 30-day readmission. Number of nurses vacationing and being admitted during the night shift had an association with decreased risk of 30-day readmission.

On the day of the last discharge from the hospital, the significant hospital resource variables included number of nurses staffed, number of nurses on vacation, number of beds available, number of discharges from the unit, being discharged during the evening shift, and being discharged during the night shift. Number of nurses staffed, number of beds available, and being discharged during the evening shift were all associated with an increased risk of mortality.

Table 3.3 provides an adjustment for the aforementioned significant hospital resource variables by accounting for the significant patient risk factors. After adjustment, the significant hospital resources on day of last admission were number of nurses staffed, number of nurses on vacation, being discharged during the evening shift and being discharged during the night shift. Both number of beds available and being admitted during the weekend were no long significant after adjusting for patient risk factors. Of the significant risk-adjusted hospital resource factors, number of nurses staffed and being admitted during the evening shift were associated with increased risk of readmission. The number of nurses on vacation and being admitted during the night shift were associated with decreased risk of readmission. For the day of last discharge, number of nurses scheduled to work, number of beds available, number of discharges from the unit, being discharged during the evening shift and being discharged during the night shift were associated with 30-day readmission after adjustment. The number of nurses staffed, number of beds available, and being discharged during the evening shift were associated with an increased risk of readmission. Number of discharges from the unit and discharges during the night shift were associated with decreased of readmission.

3.3.3 Hospital Resource Associations with In-hospital Mortality

Hospital resources related to staffing, bed availability, and time of admission and death are were studied for potential associations with in-hospital mortality. Table 3.4 summarizes the individual associations between hospital resource variables and in-hospital mortality.

For the day of admission, number of nurses scheduled to work, number of admissions to the unit, number of discharges from the unit, being admitted during the weekend, being admitted during the evening shift, and being admitted during the night shift were significantly associated with in-hospital mortality. The number of nurses on staff, being admitted during the weekend, and being admitted during the evening shift were associated with increased risk of in-hospital mortality. Number of admission to the unit and discharges from the unit, and admission during the night shift were associated with decreased risk of mortality. For the day of mortality, the number of nurses scheduled to work, number of nurses scheduled to be on vacation, number of admissions to the unit, number of discharges from the unit, and death during the night shift were associated with in-hospital mortality. The number of nurses scheduled to work, number of nurses scheduled to be on vacation, and death during night shift were associated with increased risk of mortality, while number of admissions to the unit and discharges from the unit were associated with decreased risk of mortality.

Table 3.5 provides an adjustment for the significant hospital resource factors by accounting for significant patient risk factors associated with mortality. After adjustment, the significant hospital resources on day of admission were admissions to the unit and being admitted during the night shift, which both had an association with decreased risk of mortality. For day of mortality, number of nurses scheduled to work, number of nurses scheduled to be on vacation, number of discharges from the unit, and death during the night shift were associated with in-hospital mortality after adjustment. Except for number of discharges from the unit, all other hospital resource factors were associated with increased risk of mortality.

3.4 Discussion

In terms of number of nurses scheduled to work and to be on vacation, the findings were contrary to expectations. It was expected that reduced staffing and increased staff on vacation would be associated with increased risk of readmission, however these findings were opposite. This may be explained by assumptions made for data featured in the staffing report. The assumption of the staffing report is staff actually worked during their scheduled shift, however it is possible the actual staff who worked varied from the number of staff scheduled to work. Similar studies on staffing levels and adverse health outcomes used nursing surveys as opposed to staffing schedules, which would overcome the discrepancy. Additionally, it was not possible to determine the registered nurses assigned to direct patient care versus assigned to administrative duties. It is possible for nursing units with higher readmission rates to also have higher number of registered nurses performing administrative duties, such as supervising and case management. Finally, the education level of the nurses providing direct patient care was not captured in this study. Similar studies have included the education and experience level of the registered nurses providing care [92].

The association observed between hospital resource factors and adverse health outcomes may vary from unit-to-unit. Additionally there may be other factors that explain the unit-to-unit variation. The next chapter will explore associations between select hospital resource factors for select units, and if demand:supply ratio factors explain the variation.

Table 3.1: Patient Volume by Admitting & Discharging Unit

Admitting Unit	**Unit Description**	**Total Patients**	**30-day Readmission n(%)**	**In-hospital Mortality n(%)**
4NE	Medical/Surgical Unit	2758	308(11.17)	13(0.47)
4SE	Medical/Surgical Unit	1838	347(18.88)	19(1.03)
5E	Critical Care Unit	2669	332(12.44)	145(5.43)
5NE	Medical/Surgical Unit	1470	341(23.20)	32(2.18)
5SE	Critical Care Unit	2040	272(13.33)	117(5.74)
6NE	Medicine Unit	2631	436(16.57)	100(3.80)
6SE	Orthopaedics Unit	3266	573(17.54)	37(1.13)
7N	Psychiatry Unit	876	45(5.14)	0(0)
7NE	Hematology/Oncology Unit	2196	663(30.19)	61(2.78)
7SE	Oncology Unit	2643	467(17.67)	65(2.46)
8N	Rehabilitation Unit	507	51(10.06)	0(0)
8NE	Hematology/Oncology Unit	1520	479(31.51)	93(6.12)
ANTE-P	Ante-partum Unit	313	15(4.79)	0(0)
MBU	Mother-Baby Unit	1410	28(1.99)	0(0)
Discharging Unit	**Unit Description**	**Total Patients**	**30-day Readmission n(%)**	**In-hospital Mortality n(%)**
4NE	Medical/Surgical Unit	3763	410(10.90)	13(0.35)
4SE	Medical/Surgical Unit	2537	470(18.53)	18(0.71)
5E	Critical Care Unit	542	36(6.64)	171(31.55)
5NE	Medical/Surgical Unit	2865	551(19.23)	23(0.80)
5S	Post-partum Unit	1715	45(2.62)	0(0)
5SE	Critical Care Unit	398	32(8.04)	136(34.17)
6NE	Medicine Unit	3217	540(16.79)	59(1.83)
6SE	Orthopaedics Unit	3453	580(16.80)	46(1.33)
7N	Psychiatry Unit	876	45(5.14)	0(0)
7NE	Hematology/Oncology Unit	2040	634(31.08)	34(1.67)
7SE	Oncology Unit	2792	502(17.98)	63(2.26)
8N	Rehabilitation Unit	507	51(10.06)	0(0)
8NE	Hematology/Oncology Unit	1432	461(32.19)	119(8.31)

Table 3.2: Hospital Resources Associated with 30-day Readmission (Crude)

Resources Variables on Day of Previous Admission	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing on Admission Date & Shift	0.0423	0.0059	1.04(1.03, 1.06)	<0.0005	***
RN Unit Vacationing on Admission Date & Shift	-0.0447	0.0087	0.96(0.94, 0.97)	<0.0005	***
Unit Bed Availability on Day of Admission	0.0258	0.0053	1.03(1.02, 1.04)	<0.0005	***
Admissions to the Unit on Day of Admission	-0.0056	0.0092	0.99(0.98, 1.01)	0.5380	
Discharges from the Unit on Day of Admission	-0.0039	0.0078	1.00(0.98, 1.01)	0.6130	
Admitted during Weekend	0.1367	0.0536	1.15(1.03, 1.27)	0.0108	*
Admitted during Evening Shift	0.3263	0.0421	1.39(1.28, 1.50)	<0.0005	***
Admitted during Night Shift	-0.5855	0.0480	0.56(0.51, 0.61)	<0.0005	***
Resources Variables on Day of Previous Discharge	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing on Discharge Date & Shift	0.0657	0.0080	1.07(1.05, 1.08)	<0.0005	***
RN Unit Vacationing on Discharge Date & Shift	-0.0359	0.0091	0.96(0.95, 0.98)	<0.0005	***
Unit Bed Availability on Day of Discharge	0.0757	0.0057	1.08(1.07, 1.09)	<0.0005	***
Admissions to the Unit on Day of Discharge	-0.0088	0.0091	0.99(0.97, 1.01)	0.3340	
Discharges from the Unit on Day of Discharge	-0.0492	0.0088	0.95(0.94, 0.97)	<0.0005	***
Discharged during Weekend	-0.0117	0.0476	0.99(0.90, 1.08)	0.8060	
Discharged during Evening Shift	0.3199	0.0409	1.38(1.27, 1.49)	<0.0005	***
Discharged during Night Shift	-0.8590	0.2695	0.42(0.24, 0.69)	0.00143	**

Table 3.3: Hospital Resources Associated with 30-day Readmission (Adjusted)

Resources Variables on Day of Previous Admission	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing on Admission Date & Shift	0.0880	0.0087	1.09(1.07, 1.11)	<0.0005	***
RN Unit Vacationing on Admission Date & Shift	-0.0228	0.0093	0.98(0.96, 1.00)	0.0138	*
Unit Bed Availability on Day of Admission	0.0098	0.0057	1.01(1.00, 1.02)	0.0872	.
Admitted during Weekend	0.0736	0.0565	1.08(0.96, 1.20)	0.1929	
Admitted during Evening Shift	0.1877	0.0454	1.21(1.10, 1.32)	<0.0005	***
Admitted during Night Shift	-0.4603	0.0502	0.63(0.57, 0.70)	<0.0005	***
Resources Variables on Day of Previous Discharge	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing on Discharge Date & Shift	0.0636	0.0093	1.07(1.05, 1.09)	<0.0005	***
RN Unit Vacationing on Discharge Date & Shift	-0.0142	0.0097	0.99(0.97, 1.00)	0.1421	
Unit Bed Availability on Day of Discharge	0.0444	0.0062	1.05(1.03, 1.06)	<0.0005	***
Discharges from the Unit on Day of Discharge	-0.0383	0.0093	0.96(0.94, 0.98)	<0.0005	***
Discharged during Evening Shift	0.2385	0.0427	1.27(1.17, 1.38)	<0.0005	***
Discharged during Night Shift	-0.6010	0.2818	0.55(0.30, 0.92)	0.0330	*

Table 3.4: Hospital Resources Associated with In-hospital Mortality (Crude)

Resources Variables on Day of Admission	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing on Admission Date & Shift	0.1456	0.0146	1.16(1.12, 1.19)	<0.0005	***
RN Unit Vacationing on Admission Date & Shift	-0.0149	0.0191	0.99(0.95, 1.02)	0.4360	
Unit Bed Availability on Day of Admission	-0.0013	0.0130	1.00(0.97, 1.02)	0.9190	
Admissions to the Unit on Day of Admission	-0.1107	0.0230	0.90(0.86, 0.95)	<0.0005	***
Discharges from the Unit on Day of Admission	-0.1691	0.0206	0.84(0.81, 0.88)	<0.0005	***
Admitted during Weekend	0.5892	0.1094	1.80(1.45, 2.23)	<0.0005	***
Admitted during Evening Shift	0.8841	0.0954	2.42(2.01, 2.92)	<0.0005	***
Admitted during Night Shift	-0.4377	0.1104	0.65(0.52, 0.80)	<0.0005	***
Resources Variables on Day of Death	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing at Time of Death	0.4002	0.0199	1.49(1.44, 1.55)	<0.0005	***
RN Unit Vacationing at Time of Death	0.0481	0.0186	1.05(1.01, 1.09)	0.0099	**
Unit Bed Availability at Time of Death	-0.0196	0.0150	0.98(0.95, 1.01)	0.1920	
Admissions to the Unit on Day of Death	-0.0564	0.0216	0.95(0.91, 0.99)	0.0091	**
Discharges from the Unit on Day of Death	-0.4859	0.0276	0.62(0.58, 0.65)	<0.0005	***
Death during Weekend	0.1559	0.1055	1.17(0.95, 1.43)	0.1400	
Death during Evening Shift	0.0211	0.0952	1.02(0.85, 1.23)	0.8250	
Death during Night Shift	4.2394	0.1632	69.37(50.52, 95.90)	<0.0005	***

Table 3.5: Hospital Resources Associated with In-hospital Mortality (Adjusted)

Resources Variables on Day of Admission	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing on Admission Date & Shift	0.0244	0.0273	1.02(0.97, 1.08)	0.3724	
Admissions to the Unit on Day of Admission	-0.0947	0.0350	0.91(0.85, 0.97)	0.0068	**
Discharges from the Unit on Day of Admission	0.0040	0.0323	1.00(0.94, 1.07)	0.9006	
Admitted during Weekend	0.1332	0.1728	1.14(0.81, 1.60)	0.4410	
Admitted during Evening Shift	0.1913	0.1469	1.21(0.91, 1.61)	0.1930	
Admitted during Night Shift	-0.4086	0.1669	0.66(0.47, 0.92)	0.0144	*
Resources Variables on Day of Death	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**Pr(>$\|z\|$)**	
RN Unit Staffing at Time of Death	0.2701	0.0301	1.31(1.24, 1.39)	<0.0005	***
RN Unit Vacationing at Time of Death	0.0588	0.0275	1.06(1.00, 1.12)	0.0355	*
Admissions to the Unit on Day of Death	-0.0394	0.0336	0.96(0.90, 1.03)	0.2399	
Discharges from the Unit on Day of Death	-0.3372	0.0360	0.71(0.66, 0.77)	<0.0005	***
Death during Night Shift	4.4128	0.2873	82.50(46.83, 144.63)	<0.0005	***

Chapter 4

THE UNIT-TO-UNIT VARIATION OF HOSPITAL RESOURCE INFLUENCE ON ADVERSE HEALTH OUTCOMES

4.1 Introduction

The third research question (RQ3) examines the association between resource factors and the risk-adjusted 30-day readmission and in-hospital mortality (as defined in RQ2) and whether there are differences in association between nursing units. If differences are observed, the study aims to assess whether or not the differences are due to the demand and supply of various resource and service measures at the nursing unit level.

In this study, demand for resources and services is measured by census, which is defined as the number of patients occupying a bed in a nursing unit. It is possible for nursing units that offer different levels of resources and services (supply) to have a similar number of patients occupying a bed (demand). For this reason, both the demand and supply will be considered in this study. The demand:supply measures included in this study are defined at the end of §1.5.

The level of resources offered by a nursing unit can be measured by the number of nursing staff and beds. Based on the available data, nursing staff (i.e. the number of nurses scheduled to work) is a measure available for nursing units at each shift. The number of beds offered by a nursing unit is fixed. Service mix variables include the number of services offered and the number of procedures performed [84]. The available dataset used for this research does not provide data on the number of procedures performed at the patient level, however service line information is provided in the report. The University Health System Consortium, a consortium of academic health system in the US of which UWMC is a member, has defined a set of services lines as a means to standardize groups of services across their different health systems. Within UWMC, a service is defined as the primary specialty service a patient requires during their hospital stay. A patient is classified under a service based on their medical specialty needs and the medical team providing care. In this study, service mix is the total number of unique services that provided care to patients admitted on a nursing unit.

Although supply and demand ratios in terms of patient to nurse staffing and bed occupancy ratios have been previously considered in predicting adverse health outcomes, the supply and demand of hospital services has not been explored as extensively. Service-mix is defined as the scope and range of services provided [84]. The scope and range of specialty areas, also known as service lines, can be used to measure service-mix. Demand for these services can be measured as the number of patients within a given unit who are treated under a service line offered by a given unit. Including both supply and demand measures have been included in studies in order to account for the heterogeneity amongst different hospitals [84]. Including both supply and demand at the unit level in a study accounts for the both the supply of resources available to patients and the demand of those resources in terms of resource utilization.

If there is a difference in resource and adverse health outcomes between the nursing units, the difference in the association between resource factors and patient health outcomes between units may be due to the variety of services and resources offered from unit to unit.

4.2 Method

4.2.1 Data Overview

The dataset described in chapter 3 will also be used for the analyses in this chapter. Similarly, the units without adverse health outcome cases were excluded from further analyses.

4.2.2 Data Analysis

Summarized data (counts per admitting unit), box plots and histograms were created to examine the distribution and skewness of the data. This summarized data helped identify a subset of units for further exploration. From the data, four admitting units were selected given the high number of adverse health outcome cases and the variety of services provided. The four selected units include intensive/critical care, medical/surgical care, orthopedic care, and hematology/oncology care.

Next, two hospital resource factors, one for the day of admission and one for the day of discharge, were selected for each adverse health outcome. Before performing any inferential analysis, the number of events for each significant patient risk factor by adverse health outcome and unit was examined. Patient risk factors with fewer than 10 cases were removed from each unit.

4.2.3 Binomial Logistic Regression Models for Each Unit

The risk-adjusted association between each selected hospital resource factor was examined for each of the four selected nursing units. To determine if there are differences in associations between hospital resource factors and adverse health outcomes from unit-to-unit, a logistic regression model was developed for each unit and compared to the results of chapter 3. Each unit's model included selected hospital resource factors discussed in chapter 3 and the significant patient risk factors discussed in chapter 2. Various demand:supply ratio variables will be added to the adjusted association between hospital resource factors and adverse health outcome models for each unit to explore potential changes in direction of association or signification.

4.3 Results

4.3.1 Admitting & Discharging Unit Selection

As noted earlier, the nursing units included were selected by identifying units with the highest number of cases that specialize in different types of treatment (e.g. medical/surgical, intensive/critical, etc.). The number and percent of cases for each unit and adverse health outcome are shown in Table 4.1. Based on the above criteria, the units selected include: critical care unit (5E), medical/surgical unit (5NE), orthopedics unit (6SE), and hematology/oncology unit (8NE).

4.3.2 30-Day Readmission

Descriptive Statistics

Box plots and histograms was created for each ratio distribution. The average census:staff ratio at both admission and discharge was similar, ranging from 3-4 patients per nursing staff. The ratio was slightly lower for patients who were readmitted, indicating that there were slightly more nurses per patients scheduled to work during shifts when readmitted patients were originally admitted to and discharged from the nursing units.

Table 4.1: Patient Volume by Admitting & Discharging Unit

Admitting Unit	**Unit Description**	**Total Patients**	**30-day Readmission n(%)**	**In-hospital Mortality n(%)**
4NE	Medical/Surgical Unit	2758	308(11.17)	13(0.47)
4SE	Medical/Surgical Unit	1838	347(18.88)	19(1.03)
5E	Critical Care Unit	2669	332(12.44)	145(5.43)
5NE	Medical/Surgical Unit	1470	341(23.20)	32(2.18)
5SE	Critical Care Unit	2040	272(13.33)	117(5.74)
6NE	Medicine Unit	2631	436(16.57)	100(3.80)
6SE	Orthopaedics Unit	3266	573(17.54)	37(1.13)
7N	Psychiatry Unit	876	45(5.14)	0(0)
7NE	Hematology/Oncology Unit	2196	663(30.19)	61(2.78)
7SE	Oncology Unit	2643	467(17.67)	65(2.46)
8N	Rehabilitation Unit	507	51(10.06)	0(0)
8NE	Hematology/Oncology Unit	1520	479(31.51)	93(6.12)
ANTE-P	Ante-partum Unit	313	15(4.79)	0(0)
MBU	Mother-Baby Unit	1410	28(1.99)	0(0)
Discharging Unit	**Unit Description**	**Total Patients**	**30-day Readmission n(%)**	**In-hospital Mortality n(%)**
4NE	Medical/Surgical Unit	3763	410(10.90)	13(0.35)
4SE	Medical/Surgical Unit	2537	470(18.53)	18(0.71)
5E	Critical Care Unit	542	36(6.64)	171(31.55)
5NE	Medical/Surgical Unit	2865	551(19.23)	23(0.80)
5S	Post-partum Unit	1715	45(2.62)	0(0)
5SE	Critical Care Unit	398	32(8.04)	136(34.17)
6NE	Medicine Unit	3217	540(16.79)	59(1.83)
6SE	Orthopaedics Unit	3453	580(16.80)	46(1.33)
7N	Psychiatry Unit	876	45(5.14)	0(0)
7NE	Hematology/Oncology Unit	2040	634(31.08)	34(1.67)
7SE	Oncology Unit	2792	502(17.98)	63(2.26)
8N	Rehabilitation Unit	507	51(10.06)	0(0)
8NE	Hematology/Oncology Unit	1432	461(32.19)	119(8.31)

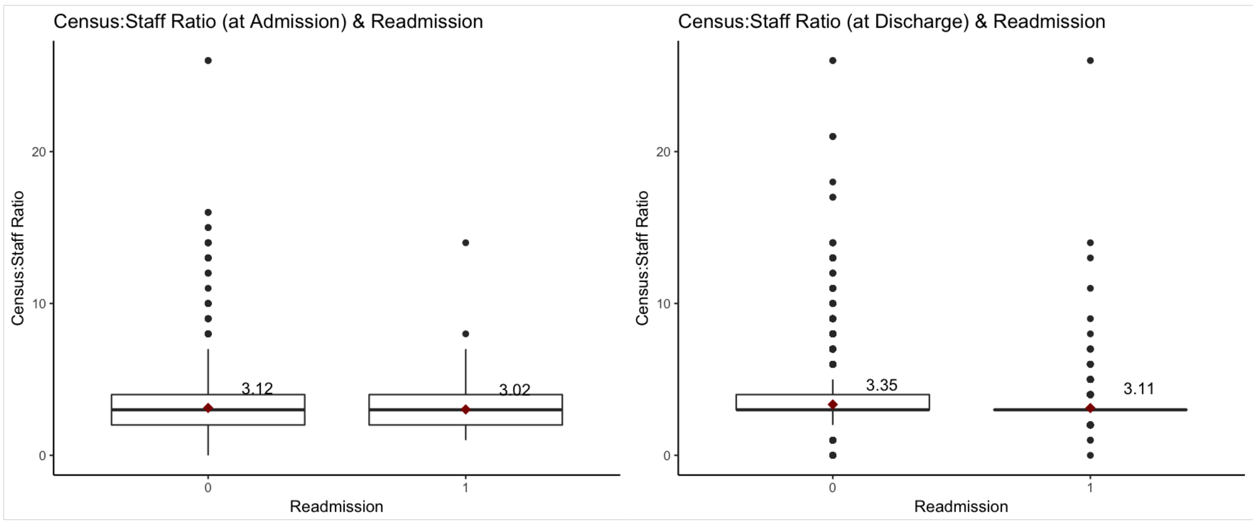


Figure 4.1: Box Plot of Census:Staffing Ratio for 30-day Readmission

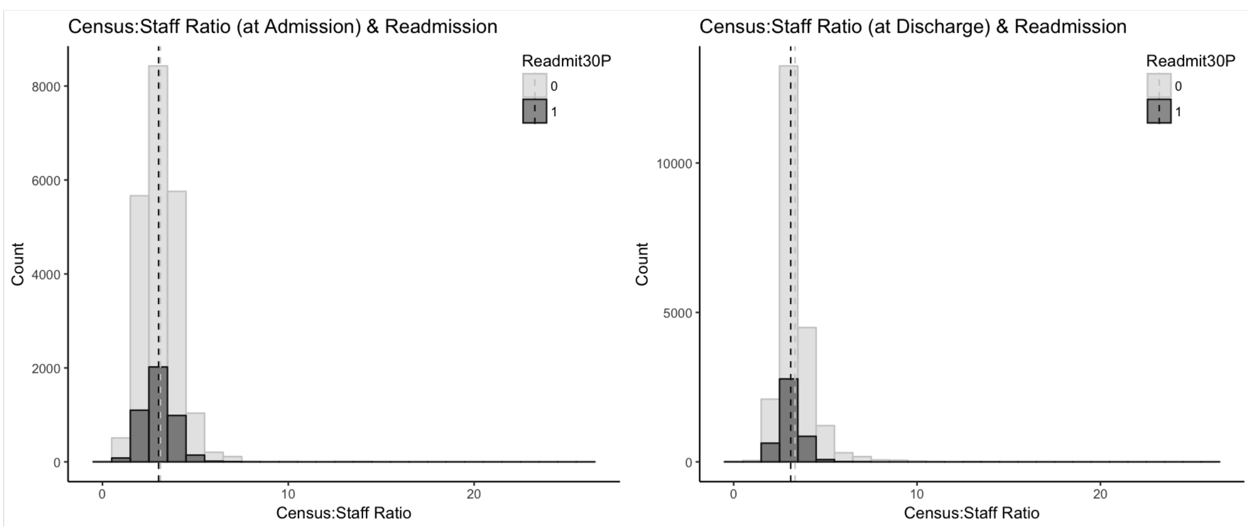


Figure 4.2: Histogram of Census:Staffing Ratio for 30-day Readmission

The average census:service ratio ranged between 0.72 to 1.15 for day of admission and day of discharge. On day of admission, the average census:service ratio was 0.96 for patients who were not readmitted, compared to 0.72 for patients who were readmitted within 30-days.

Similarly, the average census:service ratio was 1.15 on the day of admission for patients who were not readmitted, compared to 0.77 of the day of discharge for those readmitted. The Census:Service ratio for patients who were readmitted was less than for the ratio for patients who were not readmitted, which could indicate that patients who are readmitted may be more commonly admitted to and discharged from units that offer more services and provide more complex care.

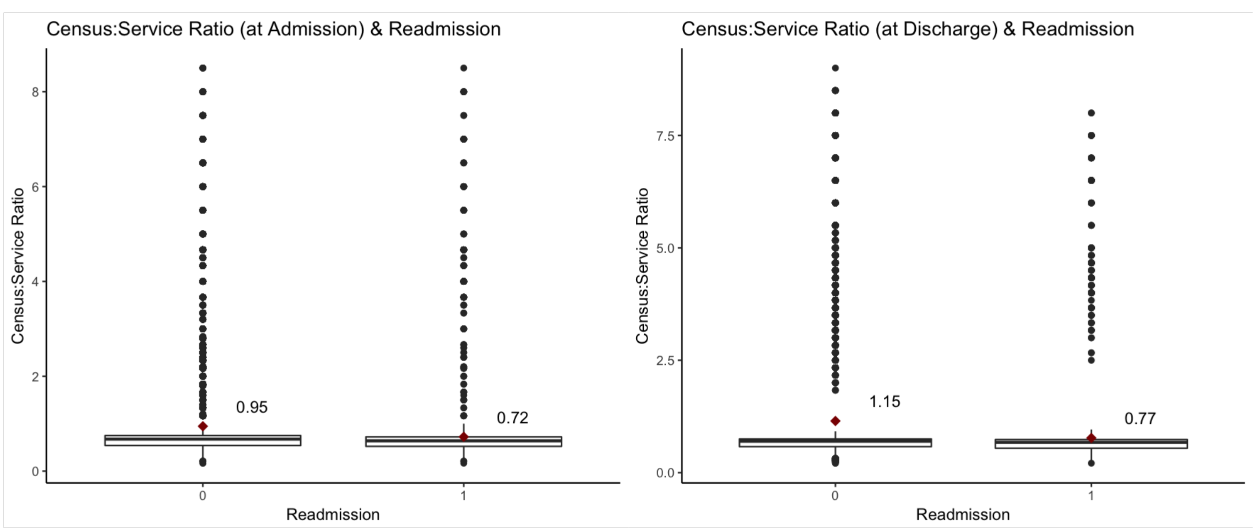


Figure 4.3: Box Plot of Census:Service Ratio for 30-day Readmission

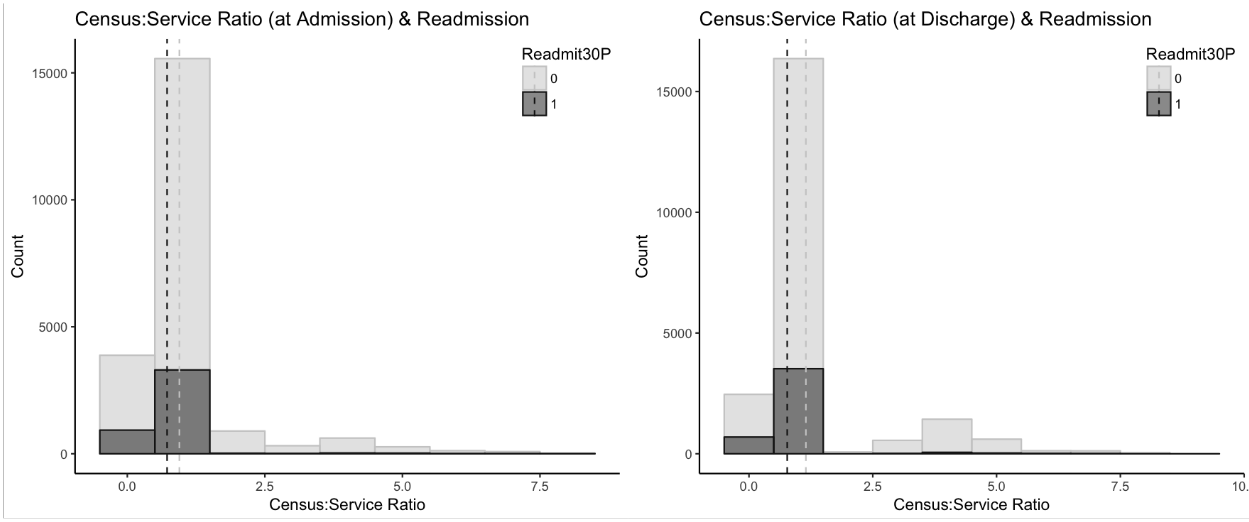


Figure 4.4: Histogram of Census:Service Ratio for 30-day Readmission

The average census:bed ratio on the day of admission and discharge ranged between 0.86 to 0.94 for patients who were and were not readmitted. Patients who were readmitted experienced slightly lower census:bed ratio on both the day admission and discharge.

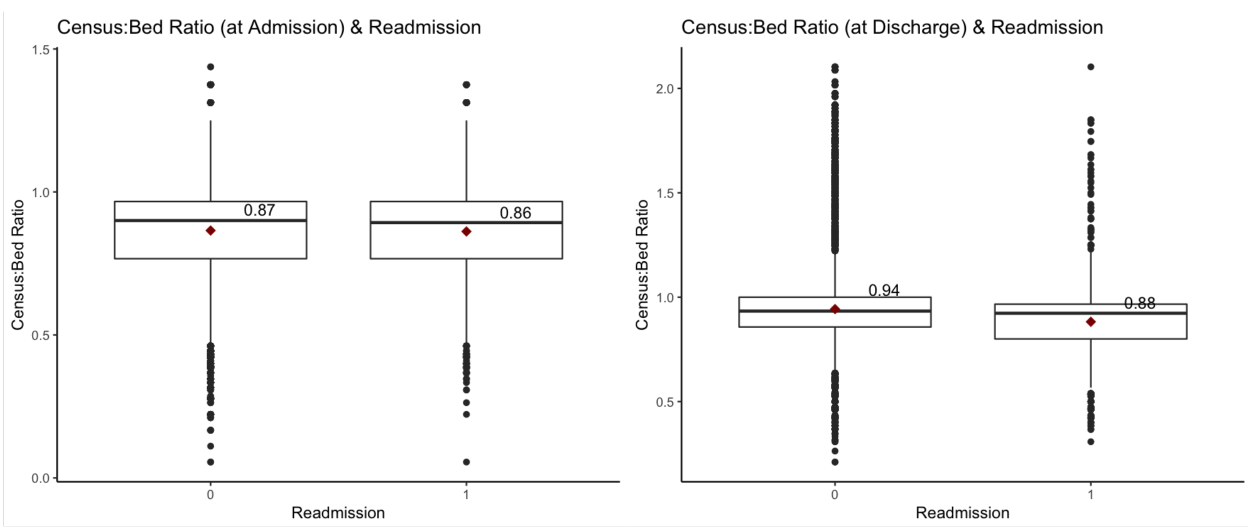


Figure 4.5: Box Plot of Census:Bed Ratio for 30-day Readmission

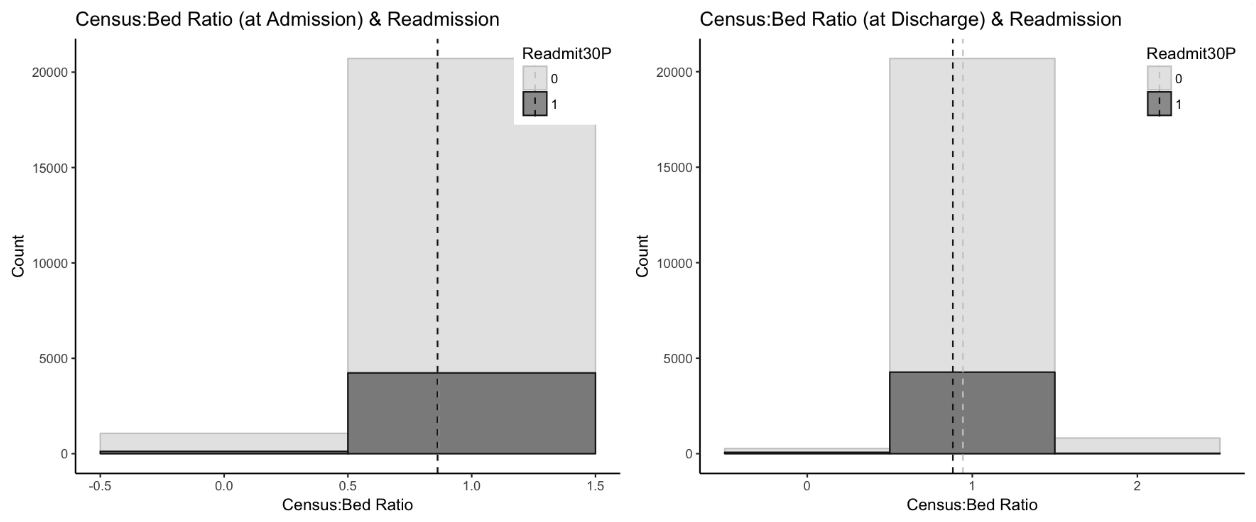


Figure 4.6: Histogram of Census:Bed Ratio for 30-day Readmission

The number of 30-day readmission cases for each significant patient risk factor found in chapter 2 was assessed by nursing unit. Tables 4.2 and 4.3 feature the number of cases for each admitting and discharging unit. For both admitting and discharging units, health conditions including acute myocardial infarction (AMI), heart failure, pneumonia, as well as palliative care variables with less than 10 30-day readmission cases were removed from risk-adjustment models. For critical care (5E) discharging unit, race/ethnicity: Black/African-American, extreme and minor risk of mortality, cancer, and diabetes had fewer than 10 cases and were therefore excluded from risk adjusted models.

Table 4.2: Significant Patient Risk Factors associated with 30-day Readmission by Unit (Admitting Unit)

Patient Risk Factors	**5E**	**5NE**	**6SE**	**8NE**
Race/Ethnicity: Black	22(6.63)	45(13.20)	28(4.89)	17(3.55)
Primary Language: English	317(95.48)	330(96.77)	544(94.94)	463(96.66)
Payor Group: Medicare	143(43.07)	160(46.92)	167(29.14)	119(24.84)
Admission from Emergency Department	119(35.84)	104(30.50)	203(35.43)	33(6.89)
Discharge Status: Home/Self-Care	246(74.10)	293(85.92)	474(82.72)	445(92.90)
Extreme Risk of Mortality	76(22.89)	10(2.93)	18(3.14)	17(3.55)
Minor Risk of Mortality	70(21.08)	28(8.21)	124(21.64)	96(20.04)
Extreme Severity of Illness	95(28.61)	37(10.85)	58(10.12)	120(25.05)
Minor Severity of Illness	33(9.94)	13(3.81)	56(9.77)	58(12.11)
Procedure	311(93.67)	248(72.73)	470(82.02)	415(86.64)
AMI	0(0)	3(0.88)	0(0)	0(0)
Cancer	112(33.73)	23(6.74)	328(57.24)	417(87.06)
Heart Failure	6(1.81)	90(26.39)	3(0.52)	0(0)
Pneumonia	2(0.60)	2(0.59)	1(0.17)	15(3.13)
Diabetes	88(26.51)	129(37.83)	87(15.18)	62(12.94)
Palliative Care	3(0.90)	3(0.88)	4(0.70)	2(0.42)

Table 4.3: Significant Patient Risk Factors associated with 30-day Readmission by Unit (Day of Discharge)

Discharging Unit	**5E**	**5NE**	**6SE**	**8NE**
Race/Ethnicity: Black	3(8.33)	65(11.80)	32(5.52)	16(3.47)
Primary Language: English	35(97.22)	532(96.55)	554(95.52)	446(96.75)
Payor Group: Medicare	17(47.22)	240(43.56)	174(30.00)	114(24.73)
Admission from Emergency Department	15(41.67)	135(26.32)	213(36.72)	22(4.77)
Discharge Status: Home/Self-Care	27(75.00)	461(83.67)	478(82.41)	435(94.36)
Extreme Risk of Mortality	7(19.44)	40(7.26)	17(2.93)	12(2.60)
Minor Risk of Mortality	9(25.00)	52(9.44)	125(21.55)	90(19.52)
Extreme Severity of Illness	9(25.00)	110(19.96)	54(9.31)	118(25.60)
Minor Severity of Illness	5(13.89)	36(6.53)	53(9.14)	55(11.93)
Procedure	33(91.67)	450(81.67)	474(81.72)	399(86.55)
AMI	0(0)	8(1.45)	0(0)	0(0)
Cancer	9(25.00)	26(4.72)	327(56.34)	404(87.64)
Heart Failure	0(0)	137(24.86)	4(0.69)	0(0)
Pneumonia	1(2.78)	2(0.36)	1(0.17)	14(3.04)
Diabetes	4(11.11)	187(33.94)	88(15.17)	59(12.80)
Palliative Care	0(0)	2(0.36)	4(0.69)	2(0.43)

Hospital Resource Factor Associations by Unit

The hospital resource factors selected for this study were staffing on day of admission, admission count on day of admission, staffing on day of discharge/mortality, and admission count on day of discharge/mortality. These resources were selected for the various levels of significance found in chapter 3. Staffing on day of admission was associated with increased risk of 30-day readmission (adjusted) and was not associated with in-hospital mortality (adjusted), while number of admissions to the unit was associated with decreased risk of in-hospital mortality (adjusted) and was not associated with 30-day readmission (crude). Staffing on day of discharge/mortality was associated with increased risk of readmission and mortality, while admission count on day of discharge/mortality was not significantly associated readmission (crude) and was not associated with mortality (adjusted).

After units were selected, the association between hospital resources and 30-day readmission was assessed for all hospital units as featured in chapter 3 and each selected unit. Table 4.4 summarizes the hospital resource variables and readmission associations by unit. The number of nurses scheduled to work was only significant for the orthopedic unit and had an association with increased risk of mortality. Notably, the number of nurses scheduled on day of admission was associated with decreased risk of mortality as indicated by the coefficient estimate, however the association was not significant with a p-value= 0.1329. This variable was not significant for the selected medical/surgical (5NE) and hematology/oncology (8NE) admitting units. Similar to the results found for the entire hospital, the admission count on day of admission was not significant across each unit. Critical care unit (5E), medical/-surgical unit (5NE), and hematology/oncology unit (8NE) had a non-significant association with increased risk of readmission. For number of nurses scheduled to work on day of discharge, each discharging unit had a non-significant association with decreased risk of 30-day readmission, although all hospital nurses scheduled on day of discharge was significant and associated with increased risk of mortality. Admission count on day of discharge for critical care, medical/surgical, and hematology/oncology discharging units had a non-significant association with decreased readmission; for the orthopedics discharging unit, admission count had a non-significant association with increased risk of readmission.

Table 4.4: Hospital Resource Factors & 30-day Readmission by Selected Units

Units	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value	
Staffing on Day of Admission & 30-day Readmission					
All Units	0.088	0.0087	1.09(1.07, 1.11)	<0.0005	***
5E	-0.0534	0.0355	0.95(0.88, 1.02)	0.1329	
5NE	0.0452	0.0539	1.05(0.94, 1.16)	0.4014	
6SE	0.1682	0.0381	1.18(1.10, 1.28)	<0.0005	***
8NE	0.0177	0.0273	1.02(0.97, 1.07)	0.5165	
Admission Count on Day of Admission & 30-Day Readmission					
All Units	-0.0012	0.0096	1.00(0.98, 1.02)	0.9002	
5E	0.0367	0.0286	1.04(0.98, 1.10)	0.2004	
5NE	0.0125	0.0384	1.10(0.94, 1.09)	0.7452	
6SE	-0.0192	0.0209	0.98(0.94, 1.02)	0.3569	
8NE	0.0489	0.0382	1.05(0.97, 1.13)	0.2009	
Staffing on Day of Discharge & 30-day Readmission					
All Units	0.0657	0.0080	1.07(1.05, 1.08)	<0.0005	***
5E	-0.1482	0.1151	0.86(0.69, 1.08)	0.1980	
5NE	-0.0261	0.0526	0.97(0.88, 1.08)	0.6202	
6SE	-0.0244	0.0391	0.97(0.91, 1.06)	0.5325	
8NE	-0.0169	0.0301	0.98(0.93, 1.04)	0.5749	
Admission Count on Day of Discharge & 30-Day Readmission					
All Units	-0.0088	0.0091	0.99(0.97, 1.01)	0.3349	
5E	-0.0440	0.0812	0.96(0.81, 1.12)	0.5876	
5NE	-0.0060	0.0309	0.99(0.94, 1.06)	0.8448	
6SE	0.0168	0.0192	1.02(0.98, 1.06)	0.3825	
8NE	-0.0342	0.0382	0.97(0.90, 1.04)	0.3711	

Hospital Resource & Demand:Supply Variable Associations

Tables 4.5, 4.6, 4.7, and 4.8 feature each hospital resource variable adjusted for patient risk factors as well as demand:supply measures. In table 4.5, the level of significance and direction of the significance did not change with the addition of demand:supply ratio variables for the critical care unit. Similarly, in table 4.6, the level of significance and direction of the significance did not change with the addition of demand:supply ratio variables for the medical/surgical unit. For the orthopedics unit featured in 4.7, the number of scheduled staff on day of admission had a significant association with increased risk of readmission with and without the addition of demand:supply ratio variables. All other variables in 4.7 did not have an association with readmission. Similar to the critical care and medical/surgical units, table 4.8 shows the level of significance and direction of the significance did not change with the addition of demand:supply ratio variables for the hematology/oncology unit.

Table 4.5: Hospital Resource & Demand:Supply Variables Associated with 30-day Readmission in the Critical Care Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value
Staffing on Day of Previous Admission for Critical Unit (5E) & 30-day Readmission				
Staffing on Day of Previous Admission	-0.0534	0.0355	0.95(0.88, 1.02)	0.1329
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.0363	0.0394	0.96(0.89, 1.04)	0.3580
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.0545	0.0356	0.95(0.88, 1.02)	0.1252
Staffing and Census:Service Ratio on Day of Previous Admission	-0.0363	0.0394	0.96(0.89, 1.04)	0.3580
Admission Count on Day of Previous Admission for Critical Unit (5E) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0367	0.0286	1.04(0.98, 1.10)	0.2004
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0275	0.0294	1.03(0.97, 1.09)	0.3485
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0363	0.0297	1.04(0.98, 1.10)	0.2212
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0275	0.0294	1.03(0.97, 1.09)	0.3485
Staffing on Day of Previous Discharge for Critical Unit (5E) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.1482	0.1151	0.86(0.69, 1.08)	0.1980
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0995	0.1336	0.90(0.69, 1.17)	0.4565
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.1425	0.1165	0.87(0.69, 1.09)	0.2213
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0995	0.1336	0.91(0.69, 1.17)	0.4565
Admission Count on Day of Previous Discharge for Critical Unit (5E) & 30-day Readmission				
Admission Count on Day of Previous Discharge	-0.0440	0.0812	0.96(0.81, 1.12)	0.5876
Admission Count and Census:Beds Ratio on Day of Previous Discharge	-0.0459	0.0801	0.96(0.81, 1.12)	0.5663
Admission Count and Census:Staff Ratio on Day of Previous Discharge	-0.0365	0.0819	0.96(0.82, 1.13)	0.6557
Admission Count and Census:Service Ratio on Day of Previous Discharge	-0.0459	0.0801	0.96(0.81, 1.12)	0.5663

Table 4.6: Hospital Resource & Demand:Supply Variables Associated with 30-day Readmission in the Medical/Surgical Unit

	Coefficient Estimate	**Standard Error**	**Odds Ratio (CI)**	**p-value**
Staffing on Day of Previous Admission for Medical/Surgical Unit (5NE) & 30-day Readmission				
Staffing on Day of Previous Admission	0.0452	0.0539	1.05(0.94, 1.16)	0.4014
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0348	0.0587	1.04(0.92, 1.16)	0.5533
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0403	0.0637	1.04(0.92, 1.18)	0.5270
Staffing and Census:Service Ratio on Day of Previous Admission	0.0348	0.0587	1.04(0.92, 1.16)	0.5533
Admission Count on Day of Previous Admission for Critical Unit (5NE) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0125	0.0384	1.10(0.94, 1.09)	0.7452
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0198	0.0393	1.02(0.94, 1.10)	0.6151
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0099	0.0387	1.01(0.94, 1.09)	0.7988
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0198	0.0393	1.02(0.94, 1.10)	0.6151
Staffing on Day of Previous Discharge for Medical/Surgical Unit (5NE) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.0261	0.0526	0.97(0.88, 1.08)	0.6202
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0360	0.0588	0.96(0.86, 1.08)	0.5408
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0306	0.0566	0.97(0.87, 1.08)	0.5891
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0360	0.0588	0.96(0.86, 1.08)	0.5408
Admission Count on Day of Previous Discharge for Medical/Surgical Unit (5NE) & 30-day Readmission				
Admission Count on Day of Previous Discharge	-0.0060	0.0309	0.99(0.94, 1.06)	0.8448
Admission Count and Census:Beds Ratio on Day of Previous Discharge	-0.0055	0.0313	0.99(0.93, 1.06)	0.8595
Admission Count and Census:Staff Ratio on Day of Previous Discharge	-0.0061	0.0310	0.99(0.93, 1.06)	0.8431
Admission Count and Census:Service Ratio on Day of Previous Discharge	-0.0055	0.0313	0.99(0.93, 1.06)	0.8595

Table 4.7: Hospital Resource & Demand:Supply Variables Associated with 30-day Readmission in the Orthopedic Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value	
Staffing on Day of Previous Admission for Orthopedics Unit (6SE) & 30-day Readmission					
Staffing on Day of Previous Admission	0.1682	0.0381	1.18(1.10, 1.28)	<0.0005	***
Staffing and Census:Beds Ratio on Day of Previous Admission	0.1796	0.0403	1.20(1.11, 1.30)	<0.0005	***
Staffing and Census:Staff Ratio on Day of Previous Admission	0.1645	0.0453	1.18(1.08, 1.29)	<0.0005	***
Staffing and Census:Service Ratio on Day of Previous Admission	0.1796	0.0403	1.20(1.11, 1.30)	<0.0005	***
Admission Count on Day of Previous Admission for Orthopedics Unit (6SE) & 30-day Readmission					
Admission Count on Day of Previous Admission	-0.0192	0.0209	0.98(0.94, 1.02)	0.3569	
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.0179	0.0211	0.98(0.94, 1.02)	0.3982	
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.0286	0.0213	0.97(0.93, 1.01)	0.1787	
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.0179	0.0211	0.98(0.94, 1.02)	0.3982	
Staffing on Day of Previous Discharge for Orthopedics Unit (6SE) & 30-day Readmission					
Staffing on Day of Previous Discharge	-0.0244	0.0391	0.97(0.91, 1.06)	0.5325	
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0147	0.0415	0.99(0.91, 1.07)	0.7240	
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0186	0.0418	0.98(0.91, 1.06)	0.6563	
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0147	0.0415	0.99(0.91, 1.07)	0.7240	
Admission Count on Day of Previous Discharge for Orthopedics Unit (6SE) & 30-day Readmission					
Admission Count on Day of Previous Discharge	0.0168	0.0192	1.02(0.98, 1.06)	0.3825	
Admission Count and Census:Beds Ratio on Day of Previous Discharge	0.0149	0.0193	1.02(0.98, 1.05)	0.4397	
Admission Count and Census:Staff Ratio on Day of Previous Discharge	0.0189	0.0194	1.02(0.98, 1.06)	0.3298	
Admission Count and Census:Service Ratio on Day of Previous Discharge	0.0149	0.0193	1.02(0.98, 1.05)	0.4397	

Table 4.8: Hospital Resource & Demand:Supply Variables Associated with 30-day Readmission in the Hematology/Oncology Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value
Staffing on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Staffing on Day of Previous Admission	0.0177	0.0273	1.02(0.97, 1.07)	0.5165
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0189	0.0280	1.02(0.97, 1.08)	0.4991
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0234	0.0416	1.02(0.94, 1.11)	0.5734
Staffing and Census:Service Ratio on Day of Previous Admission	0.0189	0.0280	1.02(0.97, 1.08)	0.4991
Admission Count on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0489	0.0382	1.05(0.97, 1.13)	0.2009
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0518	0.0395	1.05(0.97, 1.14)	0.1901
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0480	0.0383	1.05(0.97, 1.13)	0.2100
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0518	0.0395	1.05(0.97, 1.14)	0.1901
Staffing on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.0169	0.0301	0.98(0.93, 1.04)	0.5749
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0147	0.0315	0.99(0.93, 1.05)	0.6407
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0116	0.0450	0.99(0.90, 1.08)	0.7961
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0147	0.0315	0.99(0.93, 1.05)	0.6407
Admission Count on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Admission Count on Day of Previous Discharge	-0.0342	0.0382	0.97(0.90, 1.04)	0.3711
Admission Count and Census:Beds Ratio on Day of Previous Discharge	-0.0382	0.0388	0.96(0.89, 1.04)	0.3260
Admission Count and Census:Staff Ratio on Day of Previous Discharge	-0.0333	0.0382	0.97(0.90, 1.04)	0.3843
Admission Count and Census:Service Ratio on Day of Previous Discharge	-0.0382	0.0388	0.96(0.89, 1.04)	0.3260

4.3.3 In-hospital Mortality

Descriptive Statistics

The distribution of each demand:supply ratio measure was assessed using box plots and histograms. Note ”at discharge” box plots and histograms indicate ratio levels at the time of mortality. The average census:staff ratio on days of admission and day of mortality ranged from 2.6 to 3.33. Average census:staff ratio was less for patients who passed away during their hospital stay compared to those who survived. This may indicate there are more staff on nursing units that treat a higher volume of patients classified as having an extreme risk of mortality and/or severity of illness, which is commonly the case in the intensive/critical care units.

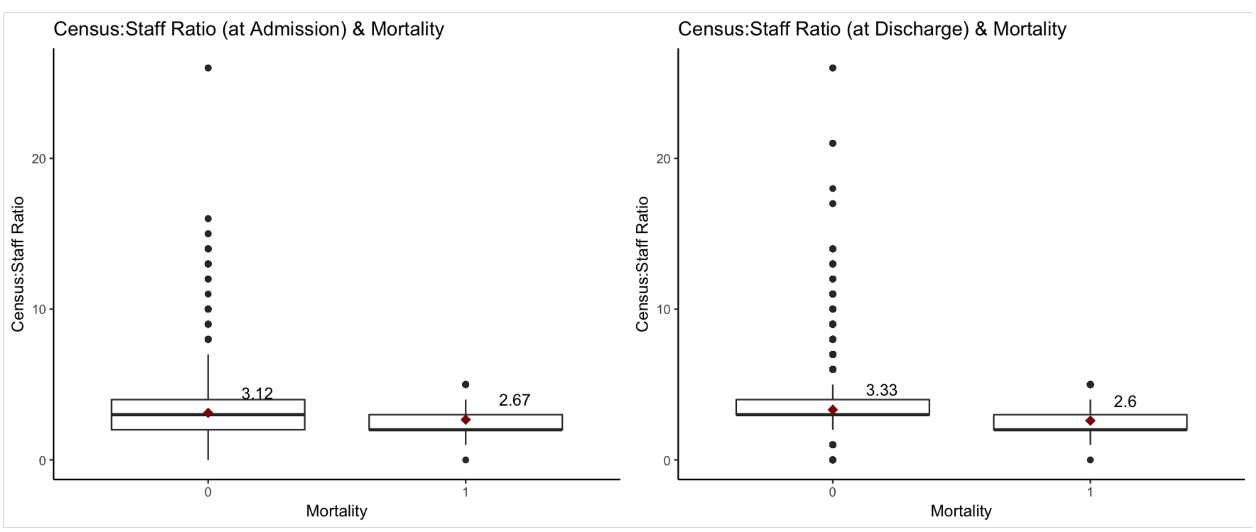


Figure 4.7: Box Plot of Census:Staffing Ratio for In-hospital Mortality

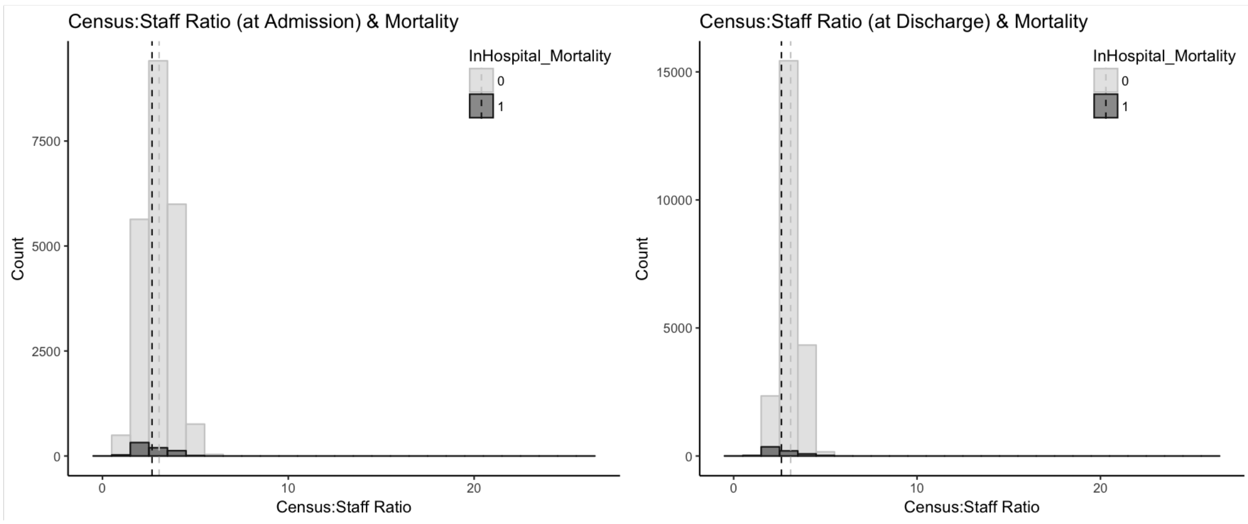


Figure 4.8: Histogram of Census:Staffing Ratio for In-hospital Mortality

The average census:service ratio ranged from 0.62 to 1.1 on day of admission and day of mortality. The average census:service ratio on day of admission and day mortality for those patients who passed away during their hospital stay was the same and less than the ratio for those patients who survived. This may indicate that most in-hospital mortalities occur on nursing units that offer a several different services.

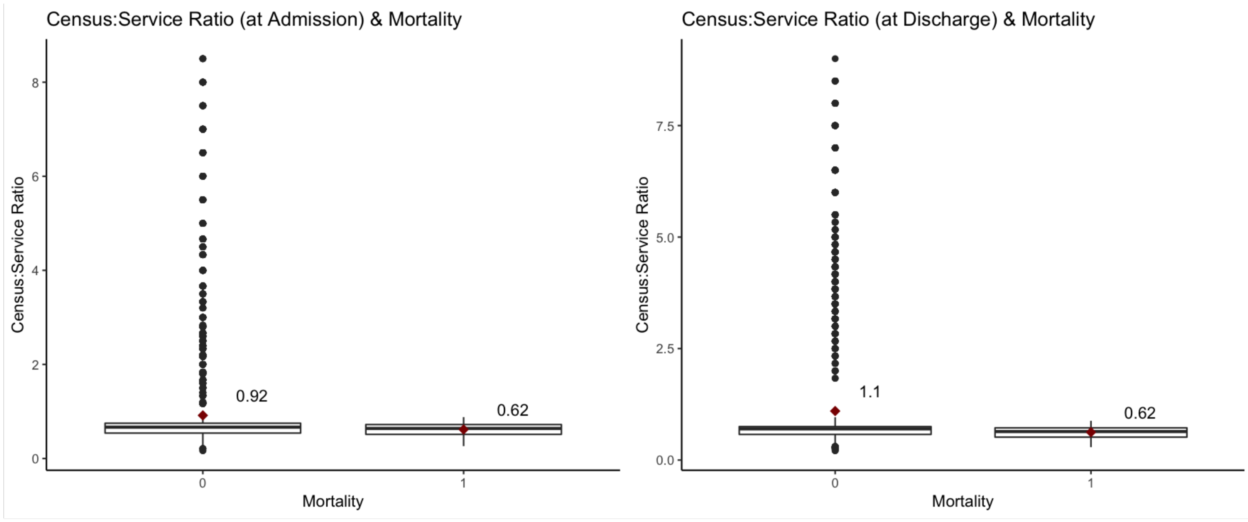


Figure 4.9: Box Plot of Census:Service Ratio for In-hospital Mortality

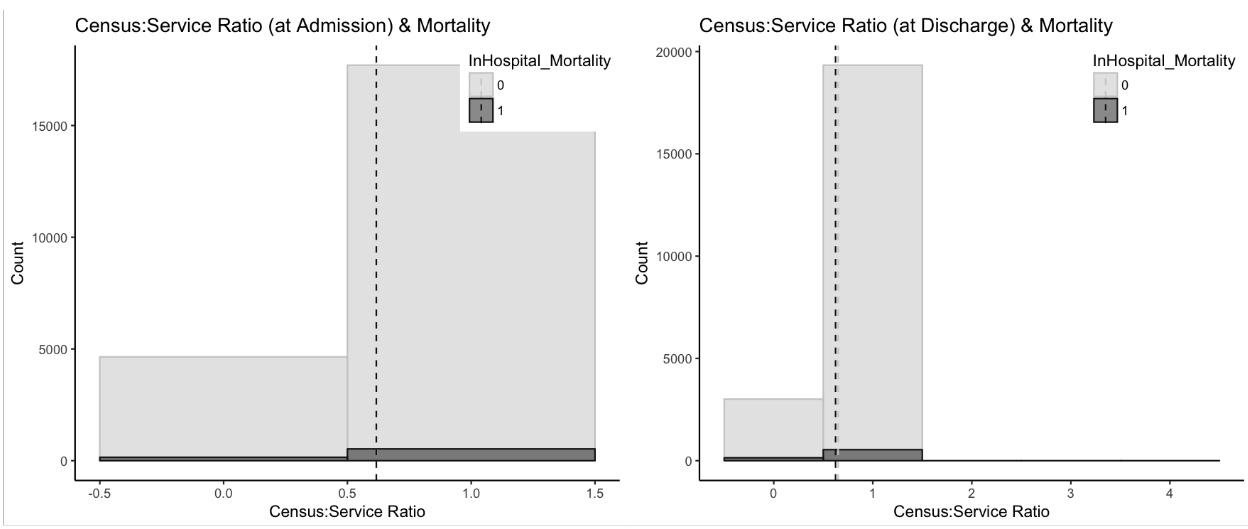


Figure 4.10: Histogram of Census:Service Ratio for In-hospital Mortality

The average census:bed ratio ranged from 0.86 to 0.93 on day of admission and mortality for patients who did and did not survive. This ratio was slightly higher for patients who passed away on their day of admission. The census:bed ratio on day of mortality was similar for patients who did and did not survive.

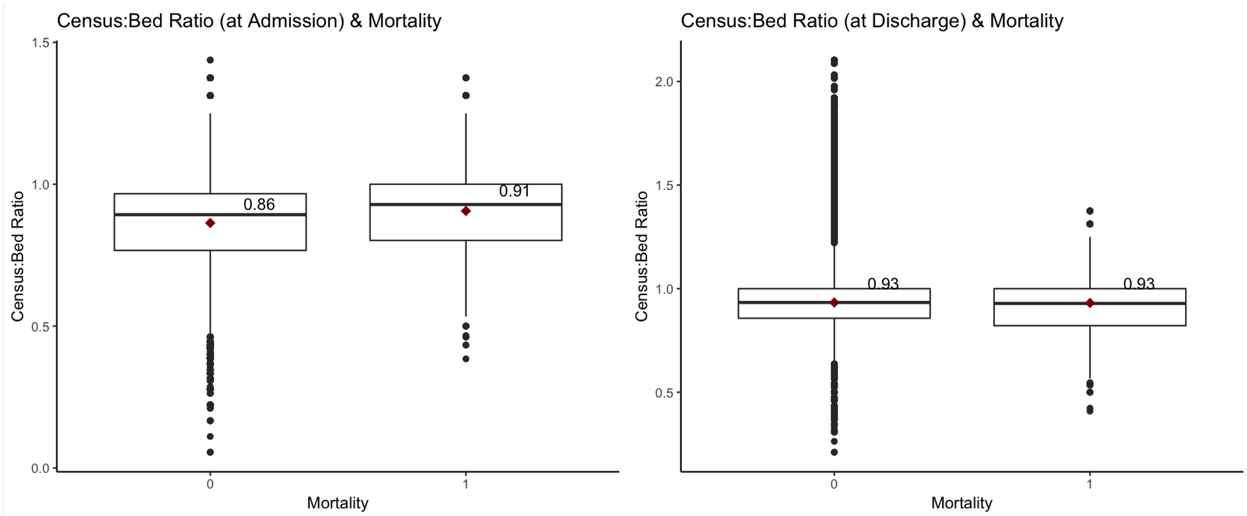


Figure 4.11: Box Plot of Census:Bed Ratio for In-hospital Mortality

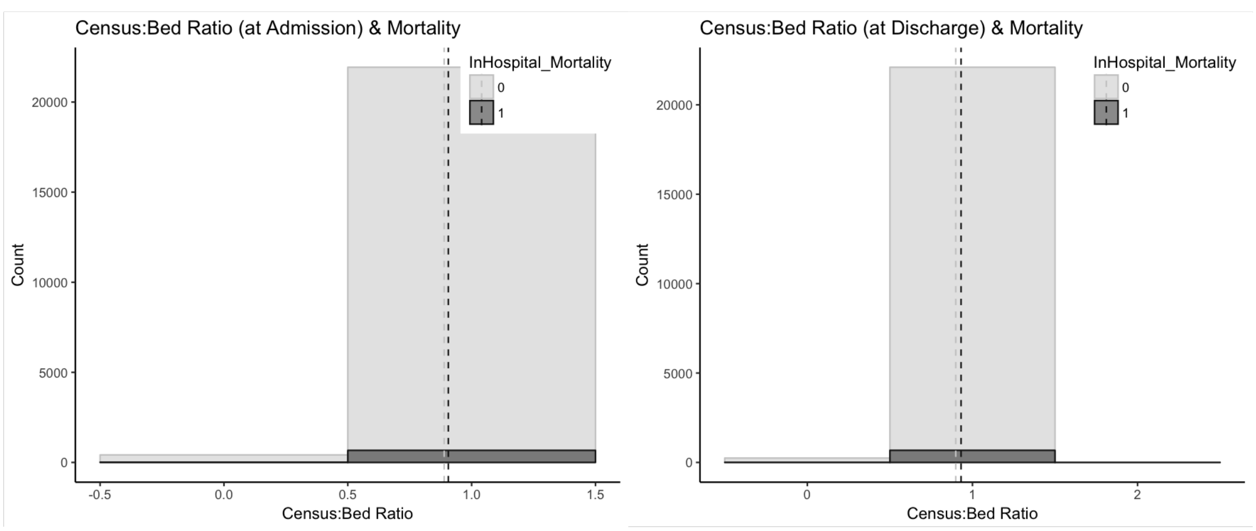


Figure 4.12: Histogram of Census:Bed Ratio for In-hospital Mortality

The number of in-hospital mortality cases for each significant patient risk factor found in chapter 2 was assessed by nursing unit. Table 4.9 features the number of cases for each admitting and discharging unit. For both admitting and discharging unit, risk of mortality and severity of illness classifications as well as treatment for health conditions including acute myocardial infarction (AMI), heart failure, and sepsis with less than 10 morality cases were removed from risk-adjustment models.

Table 4.9: Significant Patient Risk Factors associated with In-hospital Mortality by Unit

Unit of Admission	**5E**	**5NE**	**6SE**	**8NE**
Extreme Risk of Mortality	94(64.83)	4(12.50)	15(40.54)	55(59.14)
Minor Risk of Mortality	4(2.76)	2(6.25)	0(0)	2(2.15)
Extreme Severity of Illness	101(69.66)	15(46.88)	23(62.16)	73(78.49)
AMI	0(0)	1(3.13)	0(0)	0(0)
Heart Failure	1(0.69)	12(37.50)	0(0)	1(1.08)
Sepsis	80(55.17)	15(46.88)	15(40.54)	64(68.82)
Palliative Care	111(76.55)	23(71.88)	30(81.08)	79(84.95)
Unit of Death	**5E**	**5NE**	**6SE**	**8NE**
Extreme Risk of Mortality	117(68.42)	5(21.74)	22(47.83)	60(50.42)
Minor Risk of Mortality	3(1.75)	0(0)	1(2.17)	2(1.68)
Extreme Severity of Illness	121(70.76)	12(52.17)	30(65.22)	86(72.27)
AMI	1(0.58)	1(4.35)	1(2.17)	0(0)
Heart Failure	1(0.58)	5(21.74)	0(0)	1(0.84)
Sepsis	114(66.67	6(26.09)	19(41.30)	84(70.59)
Palliative Care	135(78.95)	17(73.91)	39(84.78)	105(88.24)

Hospital Resource Factor Associations by Unit

Hospital resource factor associations with in-hospital mortality were assessed for each unit and compared to the entire-hospital associations found in chapter 3. The number of nurses scheduled to work on the day of admission was only significantly associated with mortality for the orthopedic units; this hospital resource factor was associated with a decreased risk of mortality. The admission count on day of admission was only significantly associated with mortality for the critical care unit; the variable was associated with a decreased risk of mortality. Notably, the number of nurses scheduled to work on the day of mortality, which was significantly associated with increased risk of mortality for all nursing units, was significantly associated with decrease risk of mortality for the medical/surgical and hematology/oncology units. The admission count on the day of mortality, which was not significantly associated with mortality, had a significant association with decreased risk of mortality for the medical/surgical unit.

Table 4.10: Hospital Resource Factors & In-hospital Mortality by Selected Units

Units	**Coefficient Estimate**	**Standard Error**	**Odds Ratio (CI)**	**p-value**	
Staffing on Day of Admission & In-hospital Mortality					
All Units	0.0244	0.0237	1.02(0.97, 1.08)	0.3274	
5E	0.0524	0.0789	1.05(0.90, 1.23)	0.5066	
5NE	-0.0883	0.2134	0.92(0.61, 1.41)	0.6790	
6SE	-0.2888	0.1394	0.75(0.57, 0.98)	0.0382	*
8NE	0.0581	0.0948	1.06(0.88, 1.28)	0.5399	
Admission Count on Day of Admission & In-hospital Mortality					
All Units	-0.0947	0.0350	0.91(0.85, 0.97)	0.0068	**
5E	-0.1455	0.0655	0.86(0.76, 0.98)	0.0263	*
5NE	-0.2018	0.1712	0.82(0.57, 1.12)	0.2385	
6SE	-0.1878	0.1019	0.83(0.67, 1.01)	0.0654	.
8NE	-0.1643	0.1253	0.85(0.66, 1.08)	0.1900	
Staffing on Day of Mortality & In-hospital Mortality					
All Units	0.2701	0.0301	1.31(1.24, 1.39)	<0.0005	***
5E	-0.0643	0.1199	0.94(0.74, 1.19)	0.5920	
5NE	-0.6960	0.2496	0.50(0.31, 0.84)	0.0053	**
6SE	-0.1272	0.1510	0.88(0.67, 1.19)	0.3997	
8NE	-0.3313	0.0836	0.72(0.61, 0.85)	0.0001	***
Admission Count on Day of Mortality & In-hospital Mortality					
All Units	-0.0394	0.0335	0.96(0.90, 1.03)	0.2399	
5E	-0.0372	0.0966	0.96(0.79, 1.16)	0.7000	
5NE	-0.7533	0.2607	0.47(0.27, 0.76)	0.0039	**
6SE	0.0032	0.0900	1.00(0.84, 1.20)	0.9713	
8NE	-0.1107	0.1217	0.90(0.70, 1.13)	0.3632	

Hospital Resource & Demand:Supply Variable Associations

Tables 4.11, 4.12, 4.13, and 4.14 feature each hospital resource variable adjusted for patient risk factors as well as demand:supply ratio variables. In table 4.11, the significance and direction of the significance did not change with the addition of demand:supply ratio variables for the critical care unit. Similarly, in table 4.12, the significance did not change with the addition of demand:supply ratio variables for the medical/surgical unit, however the direction of association changed with the addition of the census:staff ratio variable from decreased risk to increased risk of mortality. This association was not significant. For the orthopedics unit featured in 4.13, the significance did not change with the addition of demand:supply ratio variables. The direction of association changed with the addition of the census:staff ratio variables for admission count on day of mortality, however the association was not significant. Similar to the critical care unit, table 4.14 shows the level of significance and direction of the significance did not change with the addition of demand:supply ratio variables for the hematology/oncology unit.

Table 4.11: Hospital Resource & Demand:Supply Variables Associated with In-hospital Mortality in the Critical Care Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value	
Staffing on Day of Admission for Critical Unit (5E) & In-hospital Mortality					
Staffing on Day of Admission	0.0524	0.0789	1.05(0.90, 1.23)	0.5066	
Staffing and Census:Beds Ratio on Day of Admission	0.0649	0.0871	1.07(0.90, 1.27)	0.4561	
Staffing and Census:Staff Ratio on Day of Admission	0.0537	0.0791	1.06(0.91, 1.23)	0.4967	
Staffing and Census:Service Ratio on Day of Admission	0.0649	0.0871	1.07(0.90, 1.27)	0.4561	
Admission Count on Day of Admission for Critical Unit (5E) & In-hospital Mortality					
Admission Count on Day of Admission	-0.1455	0.0655	0.86(0.76, 0.98)	0.0263	*
Admission Count and Census:Beds Ratio on Day of Admission	-0.1482	0.0659	0.86(0.76, 0.98)	0.0246	*
Admission Count and Census:Staff Ratio on Day of Admission	-0.1487	0.0670	0.86(0.75, 0.98)	0.0264	*
Admission Count and Census:Service Ratio on Day of Admission	-0.1482	0.0659	0.86(0.76, 0.98)	0.0246	*
Staffing on Day of Mortality for Critical Unit (5E) & In-hospital Mortality					
Staffing on Day of Mortality	-0.0643	0.1199	0.94(0.74, 1.19)	0.5920	
Staffing and Census:Beds Ratio on Day of Mortality	-0.1274	0.1443	0.88(0.66, 1.17)	0.3772	
Staffing and Census:Staff Ratio on Day of Mortality	-0.0697	0.1219	0.93(0.73, 1.18)	0.5670	
Staffing and Census:Service Ratio on Day of Mortality	-0.1274	0.1443	0.88(0.66, 1.17)	0.3772	
Admission Count on Day of Mortality for Critical Unit (5E) & In-hospital Mortality					
Admission Count on Day of Mortality	-0.0372	0.0966	0.96(0.79, 1.16)	0.7000	
Admission Count and Census:Beds Ratio on Day of Mortality	-0.0337	0.0974	0.97(0.79, 1.17)	0.7296	
Admission Count and Census:Staff Ratio on Day of Mortality	-0.0396	0.0973	0.96(0.79, 1.16)	0.6839	
Admission Count and Census:Service Ratio on Day of Mortality	-0.0337	0.0974	0.97(0.80, 1.17)	0.7296	

Table 4.12: Hospital Resource & Demand:Supply Variables Associated with In-hospital Mortality in the Medical/Surgical Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value	
Staffing on Day of Admission for Medical/Surgical Unit (5NE) & In-hospital Mortality					
Staffing on Day of Admission	-0.0883	0.2134	0.92(0.61, 1.41)	0.6790	
Staffing and Census:Beds Ratio on Day of Admission	-0.2800	0.2284	0.76(0.48, 1.19)	0.2202	
Staffing and Census:Staff Ratio on Day of Admission	0.2366	0.2940	1.27(0.72, 2.28)	0.4210	
Staffing and Census:Service Ratio on Day of Admission	-0.2800	0.2284	0.76(0.48, 1.19)	0.2202	
Admission Count on Day of Admission for Critical Unit (5NE) & In-hospital Mortality					
Admission Count on Day of Admission	-0.2018	0.1712	0.82(0.57, 1.12)	0.2385	
Admission Count and Census:Beds Ratio on Day of Admission	-0.1736	0.1709	0.84(0.58, 1.15)	0.3099	
Admission Count and Census:Staff Ratio on Day of Admission	-0.1662	0.1710	0.85(0.59, 1.16)	0.3308	
Admission Count and Census:Service Ratio on Day of Admission	-0.1736	0.1709	0.84(0.58, 1.15)	0.3099	
Staffing on Day of Mortality for Medical/Surgical Unit (5NE) & In-hospital Mortality					
Staffing on Day of Mortality	-0.6960	0.2496	0.50(0.31, 0.84)	0.0053	**
Staffing and Census:Beds Ratio on Day of Mortality	-0.6748	0.2987	0.51(0.28, 0.92)	0.0239	*
Staffing and Census:Staff Ratio on Day of Mortality	-0.7286	0.2784	0.48(0.29, 0.88)	0.0089	**
Staffing and Census:Service Ratio on Day of Mortality	-0.6748	0.2987	0.51(0.28, 0.92)	0.0239	*
Admission Count on Day of Mortality for Medical/Surgical Unit (5NE) & In-hospital Mortality					
Admission Count on Day of Mortality	-0.7533	0.2607	0.47(0.27, 0.76)	0.0039	**
Admission Count and Census:Beds Ratio on Day of Mortality	-0.8174	0.2701	0.44(0.25, 0.72)	0.0025	**
Admission Count and Census:Staff Ratio on Day of Mortality	-0.7430	0.2738	0.44(0.26, 0.78)	0.0067	**
Admission Count and Census:Service Ratio on Day of Mortality	-0.8174	0.2701	0.44(0.25, 0.72)	0.0025	**

Table 4.13: Hospital Resource & Demand:Supply Variables Associated with In-hospital Mortality in the Orthopedic Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value	
Staffing on Day of Admission for Orthopedics Unit (6SE) & In-hospital Mortality					
Staffing on Day of Admission	-0.2888	0.1394	0.75(0.57, 0.98)	0.0382	*
Staffing and Census:Beds Ratio on Day of Admission	-0.3761	0.1365	0.67(0.53, 0.90)	0.0059	**
Staffing and Census:Staff Ratio on Day of Admission	-0.2830	0.1443	0.75(0.57, 1.00)	0.0499	*
Staffing and Census:Service Ratio on Day of Admission	-0.3761	0.1365	0.69(0.53, 0.90)	0.0059	**
Admission Count on Day of Admission for Orthopedics Unit (6SE) & In-hospital Mortality					
Admission Count on Day of Admission	-0.1878	0.1019	0.83(0.67, 1.01)	0.0654	.
Admission Count and Census:Beds Ratio on Day of Admission	-0.1337	0.1065	0.87(0.71, 1.07)	0.2094	
Admission Count and Census:Staff Ratio on Day of Admission	-0.1832	0.1026	0.83(0.68, 1.01)	0.0740	.
Admission Count and Census:Service Ratio on Day of Admission	-0.1337	0.1065	0.87(0.71, 1.07)	0.2094	
Staffing on Day of Mortality for Orthopedics Unit (6SE) & In-hospital Mortality					
Staffing on Day of Mortality	-0.1272	0.1510	0.88(0.67, 1.19)	0.3997	
Staffing and Census:Beds Ratio on Day of Mortality	-0.1095	0.1596	0.90(0.67, 1.23)	0.4927	
Staffing and Census:Staff Ratio on Day of Mortality	-0.1474	0.1578	0.86(0.66, 1.19)	0.3503	
Staffing and Census:Service Ratio on Day of Mortality	-0.1095	0.1596	0.90(0.67, 1.23)	0.4927	
Admission Count on Day of Mortality for Orthopedics Unit (6SE) & In-hospital Mortality					
Admission Count on Day of Mortality	0.0032	0.0900	1.00(0.84, 1.20)	0.9713	
Admission Count and Census:Beds Ratio on Day of Mortality	-0.0029	0.0905	1.00(0.83, 1.19)	0.9748	
Admission Count and Census:Staff Ratio on Day of Mortality	0.0033	0.0908	1.00(0.84, 1.20)	0.9712	
Admission Count and Census:Service Ratio on Day of Mortality	-0.0029	0.0905	1.00(0.83, 1.19)	0.9748	

Table 4.14: Hospital Resource & Demand:Supply Variables Associated with In-hospital Mortality in the Hematology/Oncology Unit

	Coefficient Estimate	Standard Error	Odds Ratio (CI)	p-value
Staffing on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Staffing on Day of Previous Admission	0.0177	0.0273	1.02(0.97, 1.07)	0.5165
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0189	0.0280	1.02(0.97, 1.08)	0.4991
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0234	0.0416	1.02(0.94, 1.11)	0.5734
Staffing and Census:Service Ratio on Day of Previous Admission	0.0189	0.0280	1.02(0.97, 1.08)	0.4991
Admission Count on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0489	0.0382	1.05(0.97, 1.13)	0.2009
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0518	0.0395	1.05(0.97, 1.14)	0.1901
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0480	0.0383	1.05(0.97, 1.13)	0.2100
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0518	0.0395	1.05(0.97, 1.14)	0.1901
Staffing on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.0169	0.0301	0.98(0.93, 1.04)	0.5749
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0147	0.0315	0.99(0.93, 1.05)	0.6407
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0116	0.0450	0.99(0.90, 1.08)	0.7961
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0147	0.0315	0.99(0.93, 1.05)	0.6407
Admission Count on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Admission Count on Day of Previous Discharge	-0.0342	0.0382	0.97(0.90, 1.04)	0.3711
Admission Count and Census:Beds Ratio on Day of Previous Discharge	-0.0382	0.0388	0.96(0.89, 1.04)	0.3260
Admission Count and Census:Staff Ratio on Day of Previous Discharge	-0.0333	0.0382	0.97(0.90, 1.04)	0.3843
Admission Count and Census:Service Ratio on Day of Previous Discharge	-0.0382	0.0388	0.96(0.89, 1.04)	0.3260

4.4 Discussion

This chapter addresses RQ3 by assessing whether the hospital resource and adverse health outcome association varies between nursing units. It also explores whether the unit to unit variability can be explained by the demand per supply measures.

For hospital resource variables associated with 30-day readmission, the association did not vary significantly from unit-to-unit. It should be noted that the expected association between number of nurses scheduled to work on day of admission for the selected critical care unit and on day of discharge for all selected units and decreased risk of readmission was observed, although these associations were not significant. Similarly, the expected association between admission count on day of admission (for critical care, medical/surgical, and hematology/oncology units) and on day of discharge (for the selected orthopedic unit) with increased risk of readmission was observed, although the association were not significant as well.

For hospital resource variables associated with in-hospital mortality, there was more unit-to-unit variation in comparison with 30-day readmission. The number of nurses scheduled to work on the day of admission had a significant association with decreased mortality for the orthopedic unit. Further, the number of nurses scheduled to work on the day of mortality was associated with increased risk of mortality for the entire hospital, however this staffing measure was associated with decreased risk of mortality for the medical/surgical and hematology/oncology units selected. The findings of the exploratory study described in this chapter suggest the associations between hospital resource and risk-adjusted adverse health outcomes should be studied at the unit-level.

Chapter 5

THE UNIT-TO-UNIT VARIATION OF HOSPITAL RESOURCE INFLUENCE ON ADVERSE HEALTH OUTCOMES STRATIFIED BY PREVALENT HEALTH CONDITIONS

5.1 Introduction

The interactions between health conditions featured in the dataset, including diabetes, cancer, and sepsis, were not included in the analysis described in previous chapters of this dissertation. Patient populations with specific health conditions, such as acute myocardial infarction ([26]; [62]; [75]) and pneumonia ([76]), were included in similar studies to assess associations between hospital resource factors and adverse health outcomes. The study featured in this chapter will assess the associations between selected hospital resource factors and adverse health outcomes for the most prevalent health conditions and compare the findings to the overall model findings from Chapter 4. Since findings in the previous chapters suggest associations be assessed at the nursing unit level, the methodology followed in this chapter is similar to the methodology first introduced in Chapter 4.

5.2 Methods

5.2.1 Data Overview

First, the three health conditions with the highest prevalence were identified. Prevalence is calculated as the number of patients with the health condition divided by the total number of patients admitted and discharged between August 19th, 2013 to July 30th, 2015. Individual datasets were created for each prevalent health condition.

5.2.2 Data Analysis

Hospital Resources & Risk-Adjusted Adverse Health Outcomes by Nursing Unit

For each health condition, the total number of patients treated on each unit as well as the number of adverse health outcome cases were assessed for the admitting and discharging units; three nursing units were selected based on the volume of patients treated for the given health condition. The patient risk factors and hospital resources factors were assessed, and factors with ≥10 cases for each admitting and discharging unit selected were included in the model. Similar to Chapter 4, two hospital resource factors—nurse staffing and admission volume at time of admission and discharge/mortality—were selected as the hospital resource factors included in this study. A logistic regression model was fit for each nursing unit and health condition to evaluate associations between the two selected hospital resource factors and adverse health outcomes. Next, each demand and supply measure was added to the model to assess changes in association between hospital resource factors and adverse health outcomes when unit-level demand:supply measures are considered.

5.3 Results

5.3.1 Health Conditions by Prevalence

Table 5.1 shows the health conditions in order of their prevalence for patients treated at the University of Washington Medical Center (UWMC) between August 19th, 2013 to July 30th, 2015. The three most prevalent health conditions were cancer (prevalence=29.33%), diabetes (prevalence=16.54%), and sepsis (prevalence=5.65%).

5.3.2 30-day Readmission

The following describes the findings for cancer, diabetes and sepsis patients who experienced a 30-day readmission.

Table 5.1: Health Condition Prevalence

Health Condition	**n**	**Prevalence**
Cancer	19066	29.33%
Diabetes	10756	16.54%
Sepsis	3673	5.65%
Heart Failure	1457	2.24%
Acute Myocardial Infarction	563	0.87%
Pneumonia	563	0.87%
Chronic Obstructive Pulmonary Disease	267	0.41%
Stroke	174	0.27%
Total	***65016***	

Cancer Patients

When all nursing units that provided treatment for cancer patients were considered, staffing at the time of the cancer patient's admission was significantly associated with increased risk of 30-day readmission, which corresponds to findings for the overall model. Admission volume at the time of the patient's discharge was significantly associated with decreased risk of 30-day readmission. Analysis was conducted on those units that had the highest number of cases for cancer patients, which were critical care (5E), orthopedics (6SE), and hematology/oncology (8NE) units. Note these units are the not same subsets as the units included in the overall model described in Chapter 4. Hematology/Oncology unit is observed in all models described in this chapter, but orthopedics and critical are not. Table 5.2 summarizes the findings. At the unit level, staffing at the time of admission is associated with increased risk of readmission for patients treated within the orthopedics unit.

Tables 5.3 to 5.5 show critical care, orthopedics, and hematology/oncology, respectively. For all three models, the associations between staffing and admission volume while accounting for the ratio of demand:supply measures are included. For cancer patients treated in the orthopedics department, census:bed and census:staff ratios accounts for unit-level complexity for the staffing on day of admission association with increased readmission, as depicted in table 5.4. This result varies slightly from the overall model, where all three demand:supply measures accounted for unit-level complexity. There were no other significant associations, and this is consistent with the overall model.

Table 5.2: Hospital Resource Factors & 30-day Readmission for Cancer Patients

Units	**Coefficient Estimate**	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**	
Staffing on Admission Date & Shift					
All Units	0.0967	0.0124	1.10(1.08, 1.13)	0.0000	***
5E	-0.0620	0.0676	0.94(0.82, 1.07)	0.3591	
6SE	0.2775	0.0622	1.32(1.17, 1.49)	0.0000	***
8NE	0.0060	0.0286	1.01(0.95, 1.06)	0.8345	
Admission Count on Admission Date & Shift					
All Units	-0.0050	0.0132	0.99(0.97, 1.02)	0.7028	
5E	0.0476	0.0522	1.05(0.95, 1.16)	0.3615	
6SE	0.0024	0.0319	1.00(0.94, 1.07)	0.9406	
8NE	0.0336	0.0411	1.03(0.95, 1.12)	0.4137	
Staffing on Discharge Date & Shift					
All Units	0.0141	0.0117	1.01(0.99, 1.04)	0.2262	
5E	-0.2100	0.2586	0.81(0.49, 1.37)	0.4170	
6SE	-0.0592	0.0689	0.94(0.82, 1.08)	0.3907	
8NE	-0.0161	0.0320	0.98(0.92, 1.05)	0.6151	
Admission Volume on Discharge Date & Shift					
All Units	-0.0259	0.0116	0.97(0.95, 1.00)	0.0257	*
5E	0.0482	0.1845	1.05(0.71, 1.50)	0.7941	
6SE	-0.0008	0.0295	1.00(0.94, 1.06)	0.9776	
8NE	-0.0345	0.0411	0.97(0.89, 1.05)	0.4011	

Table 5.3: Demand:Supply Variables associated with 30-day Readmission for Cancer Patients treated in Critical Care Unit

	Coefficient Estimate	Standard Errors	Odds Ratio (CI)	**Pr**($>\|z\|$)
Staffing on Day of Previous Admission for Critical Care Unit (5E) & 30-day Readmission				
Staffing on Day of Previous Admission	-0.0620	0.0676	0.94(0.82, 1.07)	0.3591
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.0076	0.0727	0.99(0.86, 1.15)	0.9163
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.0664	0.0677	1.03(0.93, 1.15)	0.3270
Staffing and Census:Service Ratio on Day of Previous Admission	-0.0076	0.0727	0.99(0.86, 1.15)	0.9163
Admission Count on Day of Previous Admission for Critical Care Unit (5E) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0476	0.0522	1.05(0.95, 1.16)	0.3615
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0213	0.0533	1.02(0.92, 1.13)	0.6903
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0302	0.0536	1.03(0.93, 1.14)	0.5733
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0213	0.0533	1.02(0.92, 1.13)	0.6903
Staffing on Day of Previous Discharge for Critical Care Unit (5E) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.2100	0.2586	0.81(0.49, 1.37)	0.4170
Staffing and Census:Beds Ratio on Day of Previous Discharge	0.0927	0.3263	1.10(0.58, 2.11)	0.7763
Staffing and Census:Staff Ratio on Day of Previous Discharge	N/A	N/A	N/A	N/A
Staffing and Census:Service Ratio on Day of Previous Discharge	0.0927	0.3263	1.10(0.58, 2.11)	0.7763
Admission Volume on Day of Previous Discharge for Critical Care Unit (5E) & 30-day Readmission				
Admission Volume on Day of Previous Discharge	0.0482	0.1845	1.05(0.71, 1.50)	0.7941
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	0.0951	0.1861	1.10(0.75, 1.59)	0.6093
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	N/A	N/A	N/A	N/A
Admission Volume and Census:Service Ratio on Day of Previous Discharge	0.0951	0.1861	1.10(0.75, 1.59)	0.6093

Table 5.4: Demand:Supply Variables associated with 30-day Readmission for Cancer Patients treated in Orthopedics Unit

	Coefficient Estimate	Standard Errors	Odds Ratio (CI)	Pr(> $\|z\|$)	
Staffing on Day of Previous Admission for Orthopedics Unit (6SE) & 30-day Readmission					
Staffing on Day of Previous Admission	0.2775	0.0622	1.32(1.17, 1.49)	<0.0005	***
Staffing and Census:Beds Ratio on Day of Previous Admission	0.1271	0.0495	1.14(1.03, 1.25)	0.0103	*
Staffing and Census:Staff Ratio on Day of Previous Admission	0.2394	0.0736	1.27(1.11, 1.47)	0.0011	**
Staffing and Census:Service Ratio on Day of Previous Admission	0.0698	0.0441	1.07(0.98, 1.17)	0.1141	
Admission Count on Day of Previous Admission for Orthopedics Unit (6SE) & 30-day Readmission					
Admission Count on Day of Previous Admission	0.0024	0.0319	1.00(0.94, 1.07)	0.9406	
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.0024	0.0320	1.00(0.94, 1.06)	0.9402	
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.0189	0.0327	0.98(0.92, 1.05)	0.5623	
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0048	0.0318	1.00(0.94, 1.07)	0.8805	
Staffing on Day of Previous Discharge for Orthopedics Unit (6SE) & 30-day Readmission					
Staffing on Day of Previous Discharge	-0.0592	0.0689	0.94(0.82, 1.08)	0.3907	
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0643	0.0745	0.94(0.81, 1.08)	0.3879	
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.1120	0.0807	0.89(0.76, 1.04)	0.1650	
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0643	0.0745	0.94(0.81, 1.08)	0.3879	
Admission Volume on Day of Previous Discharge for Orthopedics Unit (6SE) & 30-day Readmission					
Admission Volume on Day of Previous Discharge	-0.0008	0.0295	1.00(0.94, 1.06)	0.9776	
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.0015	0.0299	1.00(0.94, 1.06)	0.9590	
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	-0.0057	0.0301	0.99(0.94, 1.05)	0.8502	
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.0015	0.0299	1.00(0.94, 1.06)	0.9590	

Table 5.5: Demand:Supply Variables associated with 30-day Readmission for Cancer Patients treated in Hematology/Oncology Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr($>|z|$)**
Staffing on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Staffing on Day of Previous Admission	0.0060	0.0286	1.01(0.95, 1.06)	0.8345
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0088	0.0296	1.01(0.95, 1.07)	0.7654
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0081	0.0443	1.01(0.92, 1.10)	0.8547
Staffing and Census:Service Ratio on Day of Previous Admission	0.0097	0.0298	1.01(0.95, 1.07)	0.7450
Admission Count on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0336	0.0411	1.03(0.95, 1.12)	0.4137
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0259	0.0423	1.03(0.94, 1.11)	0.5395
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0285	0.0412	1.03(0.95, 1.12)	0.4888
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0252	0.0426	1.03(0.94, 1.11)	0.5538
Staffing on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.0161	0.0320	0.98(0.92, 1.05)	0.6151
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0089	0.0335	0.99(0.93, 1.06)	0.7911
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0393	0.0489	0.96(0.87, 1.06)	0.4208
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0089	0.0335	0.99(0.93, 1.06)	0.7911
Admission Volume on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission				
Admission Volume on Day of Previous Discharge	-0.0345	0.0411	0.97(0.89, 1.05)	0.4011
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.0426	0.0419	0.96(0.88, 1.04)	0.3090
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	0.0346	0.0412	0.97(0.89, 1.05)	0.4002
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.0426	0.0419	0.96(0.88, 1.04)	0.3090

Diabetes Patients

For all nursing units that provided treatment for diabetes patients, staffing at the time of the patient's admission and discharge were significantly associated with increased risk of 30-day readmission, which corresponds with the overall model. Further analysis was conducted on those units that included the highest number of cases, which include critical care (5E), medicine (6NE), and hematology/oncology (8NE). Table 5.6 summarizes the findings. At the unit level, the selected hospital resource variables were not significant.

Tables 5.7 to 5.9 show critical care, medicine, and hematology/oncology respectively. For diabetes patients treated in the hematology/oncology unit, census:bed and census:service ratios account for unit-level complexity when studying the association between admission volume on the day of discharge and readmission, as depicted in table 5.9. This varies from the overall model, which did not find a significant association between admission volume at the day of discharge and readmission when demand:supply measures were included. There were no other significant associations, and this is consistent with the overall model.

Table 5.6: Hospital Resource Factors & 30-day Readmission for Diabetes Patients

Units	**Coefficient Estimate**	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**	
RN Unit Staffing on Admission Date & Shift					
All Units	0.0640	0.0151	1.07(1.04, 1.10)	0.0000	***
5E	0.0327	0.0840	1.03(0.88, 1.22)	0.6970	
6NE	-0.0774	0.0810	0.93(0.79, 1.09)	0.3389	
8NE	0.0102	0.0722	1.01(0.88, 1.17)	0.8880	
Admission Volume on Admission Date & Shift					
All Units	-0.0069	0.0168	0.99(0.96, 1.02)	0.6791	
5E	0.0806	0.0632	1.08(0.96, 1.23)	0.2020	
6NE	-0.0231	0.0519	0.98(0.88, 1.08)	0.6558	
8NE	-0.0777	0.1038	0.93(0.75, 1.13)	0.4540	
RN Unit Staffing on Discharge Date & Shift					
All Units	0.0461	0.0170	1.05(1.01, 1.08)	0.0067	**
5E	0.0315	0.0933	1.03(0.86, 1.24)	0.7354	
6NE	0.0356	0.0986	1.04(0.86, 1.26)	0.7182	
8NE	-0.0219	0.0830	0.98(0.83, 1.16)	0.7918	
Admission Volume on Discharge Date & Shift					
All Units	-0.0003	0.0168	1.00(0.97, 1.03)	0.9872	
5E	-0.0004	0.0520	1.00(0.90, 1.11)	0.9931	
6NE	-0.0287	0.0468	0.97(0.89, 1.06)	0.5395	
8NE	-0.1950	0.1084	0.82(0.66, 1.01)	0.0721	.

Table 5.7: Demand:Supply Variables associated with 30-day Readmission for Diabetes Patients treated in Critical Care Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**
Staffing on Day of Previous Admission for Critical Care Unit (5E) & 30-day Readmission				
Staffing on Day of Previous Admission	0.0327	0.0840	1.03(0.88, 1.22)	0.6970
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0480	0.0909	1.05(0.88, 1.25)	0.5974
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0444	0.1022	1.05(0.86, 1.28)	0.6639
Staffing and Census:Service Ratio on Day of Previous Admission	0.0480	0.0909	1.05(0.88, 1.25)	0.5974
Admission Count on Day of Previous Admission for Critical Care Unit (5E) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0806	0.0632	1.08(0.96, 1.23)	0.20197
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0804	0.0643	1.08(0.95, 1.23)	0.2106
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0814	0.0636	1.08(0.96, 1.23)	0.2009
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0804	0.0643	1.08(0.95, 1.23)	0.2106
Staffing on Day of Previous Discharge for Critical Care Unit (5E) & 30-day Readmission				
Staffing on Day of Previous Discharge	0.0315	0.0933	1.03(0.86, 1.24)	0.735419
Staffing and Census:Beds Ratio on Day of Previous Discharge	0.0503	0.1013	1.05(0.86, 1.28)	0.6198
Staffing and Census:Staff Ratio on Day of Previous Discharge	0.0172	0.1035	1.02(0.83, 1.25)	0.8684
Staffing and Census:Service Ratio on Day of Previous Discharge	0.0503	0.1013	1.05(0.86, 1.28)	0.6198
Admission Volume on Day of Previous Discharge for Critical Care Unit (5E) & 30-day Readmission				
Admission Volume on Day of Previous Discharge	-0.0004	0.0520	1.00(0.90, 1.11)	0.993106
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.0033	0.0528	1.00(0.90, 1.10)	0.9503
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	-0.0034	0.0524	1.00(0.90, 1.10)	0.9489
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.0033	0.0528	1.00(0.90, 1.10)	0.9503

Table 5.8: Demand:Supply Variables associated with 30-day Readmission for Diabetes Patients treated in Medicine Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr($>|z|$)**
Staffing on Day of Previous Admission for Medicine Unit (6NE) & 30-day Readmission				
Staffing on Day of Previous Admission	-0.0774	0.0810	0.93(0.79, 1.09)	0.3389
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.0757	0.0812	0.93(0.79, 1.09)	0.3512
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.1979	0.1222	0.82(0.65, 1.04)	0.1053
Staffing and Census:Service Ratio on Day of Previous Admission	-0.0757	0.0812	0.93(0.79, 1.09)	0.3512
Admission Count on Day of Previous Admission for Medicine Unit (6NE) & 30-day Readmission				
Admission Count on Day of Previous Admission	-0.0231	0.0519	0.98(0.88, 1.08)	0.6558
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.0298	0.0537	0.97(0.87, 1.08)	0.5796
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.0244	0.0523	0.98(0.88, 1.08)	0.6411
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.0298	0.0537	0.97(0.87, 1.08)	0.5796
Staffing on Day of Previous Discharge for Medicine Unit (6NE) & 30-day Readmission				
Staffing on Day of Previous Discharge	0.0356	0.0986	1.04(0.86, 1.26)	0.7182
Staffing and Census:Beds Ratio on Day of Previous Discharge	0.0282	0.0996	1.03(0.85, 1.25)	0.7769
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0438	0.1176	0.96(0.76, 1.20)	0.7096
Staffing and Census:Service Ratio on Day of Previous Discharge	0.0282	0.0996	1.03(0.85, 1.25)	0.7769
Admission Volume on Day of Previous Discharge for Medicine Unit (6NE) & 30-day Readmission				
Admission Volume on Day of Previous Discharge	-0.0287	0.0468	0.97(0.89, 1.06)	0.5395
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.0246	0.0476	0.98(0.89, 1.07)	0.6063
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	-0.0296	0.0472	0.97(0.88, 1.06)	0.5306
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.0246	0.0476	0.98(0.89, 1.07)	0.6063

Table 5.9: Demand:Supply Variables associated with 30-day Readmission for Diabetes Patients treated in Hematology/Oncology Unit

	Coefficient Estimate	Standard Errors	Odds Ratio (CI)	Pr(> $\lvert z \rvert$)	
Staffing on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Staffing on Day of Previous Admission	0.0102	0.0722	1.01(0.88, 1.17)	0.8880	
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0180	0.0735	1.02(0.88, 1.18)	0.8060	
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0547	0.1159	0.95(0.75, 1.19)	0.6369	
Staffing and Census:Service Ratio on Day of Previous Admission	-1.5126	2.3502	1.02(0.88, 1.18)	0.5200	
Admission Count on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Admission Count on Day of Previous Admission	-0.0777	0.1038	0.93(0.75, 1.13)	0.4540	
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.0900	0.1053	0.91(0.74, 1.12)	0.3930	
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.0820	0.1040	0.92(0.75, 1.13)	0.4300	
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.0900	0.1053	0.91(0.74, 1.12)	0.3930	
Staffing on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Staffing on Day of Previous Discharge	-0.0219	0.0830	0.98(0.83, 1.16)	0.7918	
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0080	0.0860	0.99(0.84, 1.18)	0.9257	
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.1602	0.1355	0.85(0.65, 1.11)	0.2370	
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0080	0.0860	0.99(0.84, 1.18)	0.9257	
Admission Volume on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Admission Volume on Day of Previous Discharge	-0.1950	0.1084	0.82(0.66, 1.01)	0.0721	.
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.2188	0.1111	0.80(0.64, 0.99)	0.0489	*
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	-0.1978	0.1085	0.82(0.66, 1.01)	0.0682	.
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.2188	0.1111	0.80(0.64, 0.99)	0.0489	*

Sepsis Patients

For all nursing units that provided treatment for sepsis patients, staffing at the time of the patient's discharge was significantly associated with decreased risk of 30-day readmission, which is opposite from the overall model that found staffing at discharge to be associated with increased risk of 30-day readmission. Additionally, admission volume on day of admission had a significant association with increased risk of 30-day readmission. Further analysis was conducted on medicine (6NE), oncology (7SE), and hematology/oncology (8NE). Table 5.10 summarizes the findings. At the unit level, staffing at time of admission had an association with decreased risk of readmission for patients treated within the medicine unit; admission volume on day of admission had an association with increased risk of readmission for patients treated withing the hematology/oncology unit; and admission volume on day of discharge had an association with decreased risk of mortality for patients treated within the hematology/oncology unit. These associations were not observed in the overall model.

Tables 5.11 to 5.13 show results for medicine, oncology, and hematology/oncology units respectively. For sepsis patients treated in the medicine unit, census:bed and census:service ratios account for unit-level complexity when assessing the association between staffing at time of admission and readmission, as depicted in table 5.11. For sepsis patients treated within the hematology/oncology unit as featured in table 5.13, census:staff ratio account for unit level complexity when assessing the association between admission volume on day of admission and readmission. All three demand:supply ratio measures account for complexity when assessing the association between admission volume on day discharge and adverse health outcome. These associations were not observed in the overall model.

Table 5.10: Hospital Resource Factors & 30-day Readmission for Sepsis Patients

Units	**Coefficient Estimate**	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**	
RN Unit Staffing on Admission Date & Shift					
All Units	-0.0329	0.0213	0.97(0.93, 1.01)	0.1227	
6NE	-0.2976	0.1277	0.74(0.58, 0.95)	0.0198	*
7SE	-0.0041	0.1172	1.00(0.79, 1.25)	0.9720	
8NE	-0.1368	0.0965	0.87(0.72, 1.05)	0.1565	
Admission Volume on Admission Date & Shift					
All Units	0.0620	0.0279	1.06(1.01, 1.12)	0.0260	*
6NE	-0.0242	0.0848	0.98(0.82, 1.15)	0.7756	
7SE	0.0099	0.0770	1.01(0.87, 1.17)	0.8978	
8NE	0.2551	0.1276	1.29(1.01, 1.67)	0.0457	*
RN Unit Staffing on Discharge Date & Shift					
All Units	-0.0888	0.0290	0.91(0.86, 0.97)	0.0022	**
6NE	-0.0914	0.1479	0.91(0.68, 1.22)	0.5365	
7SE	-0.0215	0.1129	0.98(0.78, 1.22)	0.8489	
8NE	-0.0323	0.1004	0.97(0.79, 1.18)	0.7477	
Admission Volume on Discharge Date & Shift					
All Units	-0.0133	0.0285	0.99(0.93, 1.04)	0.6416	
6NE	-0.0166	0.0734	0.98(0.85, 1.14)	0.8211	
7SE	0.0470	0.0724	1.05(0.91, 1.21)	0.5164	
8NE	-0.4311	0.1573	0.65(0.47, 0.87)	0.0061	**

Table 5.11: Demand:Supply Variables associated with 30-day Readmission for Sepsis Patients treated in Medicine Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr($>\|z\|$)**	
Staffing on Day of Previous Admission for Medicine Unit (6NE) & 30-day Readmission					
Staffing on Day of Previous Admission	-0.2976	0.1277	0.74(0.58, 0.95)	0.0198	*
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.3435	0.1327	0.71(0.54, 0.92)	0.0097	**
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.0457	0.1910	0.96(0.66, 1.40)	0.8109	
Staffing and Census:Service Ratio on Day of Previous Admission	-0.3435	0.1327	0.71(0.54, 0.92)	0.0097	**
Admission Count on Day of Previous Admission for Medicine Unit (6NE) & 30-day Readmission					
Admission Count on Day of Previous Admission	-0.0242	0.0848	0.98(0.82, 1.15)	0.7756	
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.0056	0.0878	0.99(0.83, 1.18)	0.9491	
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0175	0.0869	1.02(0.86(1.20)	0.8409	
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.0056	0.0878	0.99(0.83, 1.18)	0.9491	
Staffing on Day of Previous Discharge for Medicine Unit (6NE) & 30-day Readmission					
Staffing on Day of Previous Discharge	-0.0914	0.1479	0.91(0.68, 1.22)	0.5365	
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.1107	0.1489	0.90(0.67, 1.20)	0.4570	
Staffing and Census:Staff Ratio on Day of Previous Discharge	0.1461	0.2273	1.16(0.75, 1.83)	0.5204	
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.1107	0.1489	0.90(0.67, 1.20)	0.4570	
Admission Volume on Day of Previous Discharge for Medicine Unit (6NE) & 30-day Readmission					
Admission Volume on Day of Previous Discharge	-0.0166	0.0734	0.98(0.85, 1.14)	0.8211	
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.0005	0.0739	1.00(0.86, 1.15)	0.9942	
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	-0.0078	0.0738	0.99(0.86, 1.15)	0.9157	
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.0005	0.0739	1.00(0.86, 1.15)	0.9942	

Table 5.12: Demand:Supply Variables associated with 30-day Readmission for Sepsis Patients treated in Oncology Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr($>\|z\|$)**
Staffing on Day of Previous Admission for Oncology Unit (7SE) & 30-day Readmission				
Staffing on Day of Previous Admission	-0.0041	0.1172	1.00(0.79, 1.25)	0.9720
Staffing and Census:Beds Ratio on Day of Previous Admission	0.1027	0.1720	1.11(0.79, 1.56)	0.5506
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.0044	0.1198	1.00(0.79, 1.26)	0.9707
Staffing and Census:Service Ratio on Day of Previous Admission	0.1027	0.1720	1.11(0.79, 1.56)	0.5506
Admission Count on Day of Previous Admission for Oncology Unit (7SE) & 30-day Readmission				
Admission Count on Day of Previous Admission	0.0099	0.0770	1.01(0.87, 1.17)	0.8978
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.0138	0.0770	1.01(0.87, 1.18)	0.8576
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0102	0.0782	1.01(0.86, 1.18)	0.8967
Admission Count and Census:Service Ratio on Day of Previous Admission	0.0138	0.0770	1.01(0.87, 1.18)	0.8576
Staffing on Day of Previous Discharge for Oncology Unit (7SE) & 30-day Readmission				
Staffing on Day of Previous Discharge	-0.0215	0.1129	0.98(0.78, 1.22)	0.8489
Staffing and Census:Beds Ratio on Day of Previous Discharge	0.0747	0.2086	1.08(0.71, 1.62)	0.7204
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0215	0.1129	0.98(0.78, 1.22)	0.8487
Staffing and Census:Service Ratio on Day of Previous Discharge	0.0747	0.2086	1.08(0.71, 1.62)	0.7204
Admission Volume on Day of Previous Discharge for Oncology Unit (7SE) & 30-day Readmission				
Admission Volume on Day of Previous Discharge	0.0470	0.0724	1.05(0.91, 1.21)	0.5164
Discharge Count and Census:Beds Ratio on Day of Admission Volume	0.0549	0.0735	1.06(0.91, 1.22)	0.4549
Discharge Count and Census:Staff Ratio on Day of Admission Volume	0.0471	0.0724	1.05(0.91, 1.21)	0.5155
Admission Volume and Census:Service Ratio on Day of Previous Discharge	0.0549	0.0735	1.06(0.91, 1.22)	0.4549

Table 5.13: Demand:Supply Variables associated with 30-day Readmission for Sepsis Patients treated in Hematology/Oncology Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\lvert z \rvert$)**	
Staffing on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Staffing on Day of Previous Admission	-0.1368	0.0965	0.87(0.72, 1.05)	0.1565	
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.1083	0.1010	0.90(0.74, 1.10)	0.2834	
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.1769	0.1473	0.84(0.62, 1.12)	0.2298	
Staffing and Census:Service Ratio on Day of Previous Admission	-0.1083	0.1010	0.90(0.74, 1.10)	0.2834	
Admission Count on Day of Previous Admission for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Admission Count on Day of Previous Admission	0.2551	0.1276	1.29(1.01, 1.67)	0.0457	*
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.2331	0.1285	1.26(0.98, 1.63)	0.0696	.
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.2574	0.1281	1.29(1.01, 1.67)	0.0444	*
Admission Count and Census:Service Ratio on Day of Previous Admission	0.2331	0.1285	1.26(0.98, 1.63)	0.0696	.
Staffing on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Staffing on Day of Previous Discharge	-0.0323	0.1004	0.97(0.79, 1.18)	0.7477	
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.0287	0.1087	0.97(0.78, 1.21)	0.7920	
Staffing and Census:Staff Ratio on Day of Previous Discharge	0.0663	0.1535	1.07(0.79, 1.45)	0.6658	
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.0287	0.1087	0.97(0.78, 1.21)	0.7920	
Admission Volume on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & 30-day Readmission					
Admission Volume on Day of Previous Discharge	-0.4311	0.1573	0.65(0.47, 0.87)	0.0061	**
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	-0.4699	0.1640	0.63(0.44, 0.85)	0.0042	**
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	-0.4269	0.1587	0.65(0.47, 0.88)	0.0072	**
Admission Volume and Census:Service Ratio on Day of Previous Discharge	-0.4699	0.1640	0.63(0.44, 0.85)	0.0042	**

5.3.3 In-hospital Mortality

The following describes the findings for cancer, diabetes, and sepsis patients who passed away during their hospital visit.

Cancer Patients

For all nursing units that provided treatment for cancer patients, staffing on the day of mortality was associated with increased risk of in-hospital mortality, which corresponds with the overall model. Further analysis was conducted on those units that included the highest number of cases, which include critical care (5E), orthopedics (6SE), and hematology/oncology (8NE). Table 5.14 summarizes the findings. At the unit level, staffing on day of mortality had an association with decreased risk of mortality for the hematology/oncology unit, which also corresponds with the overall model.

Tables 5.15 to 5.17 show critical care, orthopedics, and hematology/oncology respectively. For cancer patients treated in the hematology/oncology unit, census:bed and census:service ratios account for unit-level complexity when studying the association between staffing at the time of mortality and in-hospital mortality, as depicted in table 5.17. This varies from the overall model, which did not find a significant association between staffing and mortality when demand:supply measures were included. There were no other significant associations, and this is consistent with the overall model.

Table 5.14: Hospital Resource Factors & In-hospital Mortality for Cancer Patients

Units	**Coefficient Estimate**	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**	
RN Unit Staffing on Admission Date & Shift					
All Units	0.0465	0.0410	1.05(0.97, 1.14)	0.2564	
5E	0.2613	0.1578	1.30(0.96, 1.79)	0.0978	.
6SE	-0.2422	0.2157	0.78(0.53, 1.23)	0.2610	
8NE	0.0017	0.0961	1.00(0.83, 1.22)	0.9863	
Admission Count on Admission Date & Shift					
All Units	-0.0446	0.0483	0.96(0.87, 1.05)	0.3550	
5E	-0.0662	0.1174	0.94(0.74, 1.18)	0.5727	
6SE	-0.0271	0.1266	0.97(0.75, 1.24)	0.8310	
8NE	-0.1220	0.1307	0.89(0.68, 1.14)	0.3506	
RN Unit Staffing on Discharge Date & Shift					
All Units	0.2550	0.0406	1.29(1.19, 1.40)	0.0000	***
5E	0.0489	0.2573	1.05(0.63, 1.76)	0.8493	
6SE	-0.0645	0.2991	0.94(0.55, 1.74)	0.8294	
8NE	-0.3205	0.0904	0.73(0.61, 0.87)	0.0004	***
Admission Count on Discharge Date & Shift					
All Units	-0.0313	0.0498	0.97(0.88, 1.07)	0.5299	
5E	0.1347	0.1868	1.14(0.79, 1.68)	0.4708	
6SE	0.0974	0.1360	1.10(0.84, 1.45)	0.4740	
8NE	-0.1189	0.1326	0.89(0.68, 1.14)	0.3698	

Table 5.15: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Cancer Patients treated in Critical Care Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(>** $\lvert z \rvert$**)**
Staffing on Day of Previous Admission for Critical Care Unit (5E) & In-Hospital Mortality				
Staffing on Day of Previous Admission	0.2613	0.1578	1.30(0.96, 1.79)	0.0978
Staffing and Census:Beds Ratio on Day of Previous Admission	0.1389	0.1750	1.15(0.82, 1.63)	0.4276
Staffing and Census:Staff Ratio on Day of Previous Admission	0.2846	0.1600	1.33(0.98, 1.84)	0.0752
Staffing and Census:Service Ratio on Day of Previous Admission	0.1389	0.1750	1.15(0.82, 1.63)	0.4276
Admission Count on Day of Previous Admission for Critical Care Unit (5E) & In-Hospital Mortality				
Admission Count on Day of Previous Admission	-0.0662	0.1174	0.94(0.74, 1.18)	0.5727
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.0163	0.1186	0.98(0.78, 1.24)	0.8906
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.0327	0.1229	0.97(0.76, 1.23)	0.7900
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.0163	0.1186	0.98(0.78, 1.24)	0.8906
Staffing on Day of Previous Discharge for Critical Care Unit (5E) & In-Hospital Mortality				
Staffing on Day of Previous Discharge	0.0489	0.2573	1.05(0.63, 1.76)	0.8493
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.2897	0.3843	0.75(0.34, 1.58)	0.4510
Staffing and Census:Staff Ratio on Day of Previous Discharge	N/A	N/A	N/A	N/A
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.2897	0.3843	0.75(0.34, 1.58)	0.4510
Admission Volume on Day of Previous Discharge for Critical Care Unit (5E) & In-Hospital Mortality				
Admission Volume on Day of Previous Discharge	0.1347	0.1868	1.14(0.79, 1.68)	0.4708
Admission Volume and Census:Beds Ratio on Day of Previous Discharge	0.1428	0.1935	1.15(0.79, 1.72)	0.4603
Admission Volume and Census:Staff Ratio on Day of Previous Discharge	N/A	N/A	N/A	N/A
Admission Volume and Census:Service Ratio on Day of Previous Discharge	0.1428	0.1935	1.15(0.79, 1.72)	0.4603

Table 5.16: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Cancer Patients treated in Orthopedics Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr($>|z|$)**
Staffing on Day of Admission for Orthopedics Unit (6SE) & In-Hospital Mortality				
Staffing on Day of Admission	-0.2422	0.2157	0.78(0.53, 1.23)	0.2610
Staffing and Census:Beds Ratio on Day of Admission	-0.0623	0.2083	0.94(0.63, 1.39)	0.7649
Staffing and Census:Staff Ratio on Day of Admission	-0.1026	0.2686	0.90(0.56, 1.57)	0.7025
Staffing and Census:Service Ratio on Day of Admission	-0.3626	0.1954	0.70(0.49, 1.07)	0.0635
Admission Count on Day of Admission for Orthopedics Unit (6SE) & In-Hospital Mortality				
Admission Count on Day of Admission	-0.0271	0.1266	0.97(0.75, 1.24)	0.8310
Admission Count and Census:Beds Ratio on Day of Admission	0.0365	0.1319	1.04(0.80, 1.34)	0.7819
Admission Count and Census:Staff Ratio on Day of Admission	0.0219	0.1327	1.02(0.78, 1.32)	0.8689
Admission Count and Census:Service Ratio on Day of Admission	0.0365	0.1319	1.04(0.80, 1.34)	0.7819
Staffing on Day of Mortality for Orthopedics Unit (6SE) & In-Hospital Mortality				
Staffing on Day of Mortality	-0.0645	0.2991	0.94(0.55, 1.74)	0.8294
Staffing and Census:Beds Ratio on Day of Mortality	0.0780	0.3349	1.08(0.59, 2.12)	0.8160
Staffing and Census:Staff Ratio on Day of Mortality	-0.1627	0.2643	0.85(0.54, 1.64)	0.5380
Staffing and Census:Service Ratio on Day of Previous Discharge	0.0780	0.3349	1.08(0.59, 2.12)	0.8160
Admission Count on Day of Mortality for Orthopedics Unit (6SE) & In-Hospital Mortality				
Admission Count on Day of Mortality	0.0974	0.1360	1.10(0.84, 1.45)	0.4740
Admission Count and Census:Beds Ratio on Day of Mortality	0.0790	0.1367	1.08(0.83, 1.42)	0.5630
Admission Count and Census:Staff Ratio on Day of Mortality	0.0942	0.1341	1.10(0.84, 1.44)	0.4824
Admission Count and Census:Service Ratio on Day of Mortality	0.0790	0.1367	1.08(0.83, 1.42)	0.5630

Table 5.17: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Cancer Patients treated in Hematology/Oncology Unit

	Coefficient Estimate	Standard Errors	Odds Ratio (CI)	$Pr(>\|z\|)$	
Staffing on Day of Admission for Hematology/Oncology Unit (8NE) & In-Hospital Mortality					
Staffing on Day of Admission	0.0017	0.0961	1.00(0.83, 1.22)	0.9863	
Staffing and Census:Beds Ratio on Day of Admission	-0.0844	0.1003	0.92(0.76, 1.12)	0.3999	
Staffing and Census:Staff Ratio on Day of Admission	0.0196	0.1364	1.02(0.78, 1.34)	0.8859	
Staffing and Census:Service Ratio on Day of Admission	-0.0855	0.1019	0.92(0.76, 1.13)	0.4015	
Admission Count on Day of Admission for Hematology/Oncology Unit (8NE) & In-Hospital Mortality					
Admission Count on Day of Admission	-0.1220	0.1307	0.89(0.68, 1.14)	0.3506	
Admission Count and Census:Beds Ratio on Day of Admission	-0.0922	0.1293	0.91(0.71, 1.18)	0.4758	
Admission Count and Census:Staff Ratio on Day of Admission	-0.1018	0.1299	0.90(0.70, 1.17)	0.4336	
Admission Count and Census:Service Ratio on Day of Admission	-0.0962	0.1318	0.91(0.70, 1.18)	0.4654	
Staffing on Day of Mortality for Hematology/Oncology Unit (8NE) & In-Hospital Mortality					
Staffing on Day of Mortality	-0.3205	0.0904	0.73(0.61, 0.87)	0.0004	***
Staffing and Census:Beds Ratio on Day of Mortality	-0.3324	0.0934	0.72(0.60, 0.87)	0.0004	***
Staffing and Census:Staff Ratio on Day of Mortality	-0.2621	0.1530	0.77(0.57, 1.04)	0.0867	.
Staffing and Census:Service Ratio on Day of Mortality	-0.3324	0.0934	0.72(0.60, 0.87)	0.0004	***
Admission Count on Day of Mortality for Hematology/Oncology Unit (8NE) & In-Hospital Mortality					
Admission Count on Day of Mortality	-0.1189	0.1326	0.89(0.68, 1.14)	0.3698	
Admission Count and Census:Beds Ratio on Day of Mortality	-0.1469	0.1378	0.86(0.65, 1.12)	0.2862	
Admission Count and Census:Staff Ratio on Day of Mortality	-0.0874	0.1364	0.92(0.69, 1.19)	0.5219	
Admission Count and Census:Service Ratio on Day of Mortality	-0.1469	0.1378	0.86(0.65, 1.12)	0.2862	

Diabetes Patients

For all nursing units that provided treatment for diabetes patients, staffing on the day of mortality was associated with increased risk of in-hospital mortality, which corresponds with the overall model as well as the previous model for cancer patients who passed away during their hospital visit. Further analysis was conducted on those units that included the highest number of cases, which include critical care (5E), medicine (6NE), and hematology/oncology (8NE). Table 5.18 summarizes the findings. At the unit level, the selected hospital resource variables were not significant.

Tables 5.19 to 5.21 show critical care, medicine, and hematology/oncology respectively. For diabetes patients treated in these units, there were no significant associations between the selected hospital resource variable and mortality when accounting for unit-level complexity. A similar result was found for the hematology/oncology unit overall model, however it contrasts with the critical care overall model that found an association between admission volume and decreased risk of mortality when all three demand:supply measures are included.

Table 5.18: Hospital Resource Factors & In-hospital Mortality for Diabetes Patients

Units	**Coefficient Estimate**	**Standard Errors**	**Odds Ratio (CI)**	**Pr($>|z|$)**	
RN Unit Staffing on Admission Date & Shift					
All Units	0.0028	0.0451	1.00(0.92, 1.10)	0.9510	
5E	-0.0670	0.1443	0.94(0.71, 1.25)	0.6427	
6NE	0.2823	0.2200	1.33(0.88, 2.09)	0.1993	
8NE	0.1070	0.1728	1.11(0.81, 1.61)	0.5357	
Admission Count on Admission Date & Shift					
All Units	0.0062	0.0565	1.01(0.90, 1.12)	0.9130	
5E	-0.1520	0.1181	0.86(0.67, 1.08)	0.1981	
6NE	0.0997	0.1378	1.10(0.84, 1.44)	0.4694	
8NE	-0.1381	0.2125	0.87(0.56, 1.31)	0.5157	
RN Unit Staffing on Discharge Date & Shift					
All Units	0.2919	0.0493	1.34(1.22, 1.48)	0.0000	***
5E	0.3274	0.1903	1.39(0.97, 2.06)	0.0854	.
6NE	-0.0562	0.2486	0.95(0.58, 1.55)	0.8210	
8NE	-0.1202	0.1814	0.89(0.63, 1.31)	0.5076	
Admission Count on Discharge Date & Shift					
All Units	-0.0008	0.0550	0.99(0.90, 1.11)	0.9880	
5E	0.0546	0.1264	1.06(0.82, 1.36)	0.6661	
6NE	0.0379	0.1432	1.04(0.78, 1.37)	0.7910	
8NE	0.0011	0.2352	1.00(0.61, 1.57)	0.9961	

Table 5.19: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Diabetes Patients treated in Critical Care Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**
Staffing on Day of Admission for Critical Care Unit (5E) & In-Hospital Mortality				
Staffing on Day of Admission	-0.0670	0.1443	0.94(0.71, 1.25)	0.6427
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.0981	0.1599	0.91(0.66, 1.25)	0.5397
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.0484	0.1434	0.95(0.72, 1.27)	0.7354
Staffing and Census:Service Ratio on Day of Previous Admission	-0.0981	0.1599	0.91(0.66, 1.25)	0.5397
Admission Count on Day of Admission for Critical Care Unit (5E) & In-Hospital Mortality				
Admission Count on Day of Admission	-0.1520	0.1181	0.86(0.67, 1.08)	0.1981
Admission Count and Census:Beds Ratio on Day of Admission	-0.1522	0.1193	0.86(0.67, 1.08)	0.2023
Admission Count and Census:Staff Ratio on Day of Admission	-0.1434	0.1188	0.87(0.68, 1.09)	0.2275
Admission Count and Census:Service Ratio on Day of Admission	-0.1522	0.1193	0.86(0.67, 1.08)	0.2023
Staffing on Day of Mortality for Critical Care Unit (5E) & In-Hospital Mortality				
Staffing on Day of Previous Discharge	0.3274	0.1903	1.39(0.97, 2.06)	0.0854
Staffing and Census:Beds Ratio on Day of Mortality	0.4660	0.2468	0.59(1.01, 2.67)	0.0590
Staffing and Census:Staff Ratio on Day of Mortalitye	0.3314	0.1905	1.39(0.97, 2.07)	0.0819
Staffing and Census:Service Ratio on Day of Mortality	0.4660	0.2468	1.59(1.01, 2.67)	0.0590
Admission Count on Day of Mortality for Critical Care Unit (5E) & In-Hospital Mortality				
Admission Count on Day of Mortality	0.0546	0.1264	1.06(0.82, 1.36)	0.6661
Admission Count and Census:Beds Ratio on Day of Mortality	0.0585	0.1264	1.06(0.83, 1.36)	0.6436
Admission Count and Census:Staff Ratio on Day of Mortality	0.0574	0.1271	1.06(0.82, 1.36)	0.6517
Admission Count and Census:Service Ratio on Day of Mortality	0.0585	0.1264	1.06(0.83, 1.36)	0.6436

Table 5.20: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Diabetes Patients treated in Medicine Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**
Staffing on Day of Admission for Medicine Unit (6NE) & In-Hospital Mortality				
Staffing on Day of Admission	0.2823	0.2200	1.33(0.88, 2.09)	0.1993
Staffing and Census:Beds Ratio on Day of Admission	0.2931	0.2210	1.34(0.88, 2.11)	0.1848
Staffing and Census:Staff Ratio on Day of Admission	0.1493	0.3291	1.16(0.62, 2.27)	0.6501
Staffing and Census:Service Ratio on Day of Admission	0.2931	0.2210	1.34(0.88, 2.11)	0.1848
Admission Count on Day of Admission for Medicine Unit (6NE) & In-Hospital Mortality				
Admission Count on Day of Admission	0.0997	0.1378	1.10(0.84, 1.44)	0.4694
Admission Count and Census:Beds Ratio on Day of Admission	0.0950	0.1400	1.10(0.83, 1.44)	0.4974
Admission Count and Census:Staff Ratio on Day of Admission	0.0794	0.1386	1.08(0.82, 1.41)	0.5670
Admission Count and Census:Service Ratio on Day of Admission	0.0950	0.1400	1.10(0.83, 1.44)	0.4974
Staffing on Day of Mortality for Medicine Unit (6NE) & In-Hospital Mortality				
Staffing on Day of Mortality	-0.0562	0.2486	0.95(0.58, 1.55)	0.8210
Staffing and Census:Beds Ratio on Day of Mortality	-0.0668	0.2504	0.94(0.58, 1.54)	0.7900
Staffing and Census:Staff Ratio on Day of Mortality	0.4109	0.4101	1.51(0.70, 3.53)	0.3160
Staffing and Census:Service Ratio on Day of Mortality	-0.0668	0.2504	0.94(0.58, 1.54)	0.7900
Admission Count on Day of Mortality for Medicine Unit (6NE) & In-Hospital Mortality				
Admission Count on Day of Mortality	0.0379	0.1432	1.04(0.78, 1.37)	0.7910
Admission Count and Census:Beds Ratio on Day of Mortality	0.0503	0.1470	1.05(0.78, 1.40)	0.7320
Admission Count and Census:Staff Ratio on Day of Mortality	0.0659	0.1444	1.07(0.80, 1.41)	0.6480
Admission Count and Census:Service Ratio on Day of Mortality	0.0503	0.1470	1.05(0.78, 1.40)	0.7320

Table 5.21: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Diabetes Patients treated in Hematology/Oncology Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $|z|$)**
Staffing on Day of Admission for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Staffing on Day of Admission	0.1070	0.1728	1.11(0.81, 1.61)	0.5357
Staffing and Census:Beds Ratio on Day of Admission	0.1304	0.1809	1.14(0.82, 1.69)	0.4710
Staffing and Census:Staff Ratio on Day of Admission	-0.4745	0.2903	0.62(0.34, 1.07)	0.1022
Staffing and Census:Service Ratio on Day of Admission	0.1304	0.1809	1.14(0.82, 1.69)	0.4710
Admission Count on Day of Admission for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Admission Count on Day of Admission	-0.1381	0.2125	0.87(0.56, 1.31)	0.5157
Admission Count and Census:Beds Ratio on Day of Admission	-0.1371	0.2109	0.87(0.56, 1.31)	0.5158
Admission Count and Census:Staff Ratio on Day of Admission	-0.1390	0.2145	0.87(0.56, 1.31)	0.5170
Admission Count and Census:Service Ratio on Day of Admission	-0.1371	0.2109	0.87(0.56, 1.31)	0.5158
Staffing on Day of Mortality for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Staffing on Day of Mortality	-0.1202	0.1814	0.89(0.63, 1.31)	0.5076
Staffing and Census:Beds Ratio on Day of Mortality	0.0183	0.2194	1.02(0.70, 1.64)	0.9336
Staffing and Census:Staff Ratio on Day of Mortality	-0.2426	0.2728	0.78(0.45, 1.33)	0.3738
Staffing and Census:Service Ratio on Day of Mortality	0.0183	0.2194	1.02(0.70, 1.64)	0.9336
Admission Count on Day of Mortality for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Admission Count on Day of Mortality	-0.1202	0.1814	0.89(0.63, 1.31)	0.5076
Admission Count and Census:Beds Ratio on Day of Mortality	-0.1042	0.2480	0.90(0.53, 1.44)	0.6743
Admission Count and Census:Staff Ratio on Day of Mortality	0.0014	0.2369	1.00(0.61, 1.58)	0.9954
Admission Count and Census:Service Ratio on Day of Mortality	-0.1042	0.2480	0.90(0.53, 1.44)	0.6743

Sepsis Patients

For all nursing units that provided treatment for sepsis patients, admission volume on day of admission had an association with decreased risk of in-hospital morality, while staffing on the day of mortality was associated with increased risk of in-hospital mortality, which corresponds with the overall model. Further analysis was conducted on those units that included the highest number of cases, which include medicine (6NE), oncology (7SE), and hematology/oncology (8NE). Table 5.22 summarizes the findings. At the unit level, the selected hospital resource variables were not significant.

Tables 5.23 to 5.25 show medicine, oncology, and hematology/oncology respectively. For sepsis patients treated in these units, there were no significant associations between the selected hospital resource variable and mortality when accounting for unit-level complexity. A similar result was found for the hematology/oncology unit overall model.

Table 5.22: Hospital Resource Factors & In-hospital Mortality for Sepsis Patients

Units	**Coefficient Estimate**	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**	
RN Unit Staffing on Admission Date & Shift					
All Units	0.0141	0.0339	1.01(0.95, 1.08)	0.6788	
6NE	0.1522	0.1864	1.16(0.81, 1.69)	0.4142	
7SE	-0.0250	0.2154	0.98(0.63, 1.49)	0.9077	
8NE	0.1421	0.1272	1.15(0.90, 1.48)	0.2641	
Admission Count on Admission Date & Shift					
All Units	-0.1460	0.0470	0.86(0.79, 0.95)	0.0019	**
6NE	0.0901	0.1169	1.09(0.87, 1.38)	0.4410	
7SE	-0.1472	0.1374	0.86(0.64, 1.11)	0.2840	
8NE	-0.1613	0.1710	0.85(0.60, 1.18)	0.3458	
RN Unit Staffing on Discharge Date & Shift					
All Units	0.3580	0.0413	1.43(1.32, 1.55)	<0.0005	***
6NE	-0.4459	0.3036	0.64(0.35, 1.17)	0.1418	
7SE	-0.0826	0.2315	0.92(0.58, 1.46)	0.7212	
8NE	-0.2470	0.1264	0.78(0.61, 1.00)	0.0507	.
Admission Count on Discharge Date & Shift					
All Units	0.0120	0.0452	1.01(0.93, 1.11)	0.7906	
6NE	0.0526	0.1987	1.05(0.71, 1.56)	0.7914	
7SE	-0.0224	0.1440	0.98(0.73, 1.30)	0.8760	
8NE	-0.0089	0.1703	0.99(0.70, 1.38)	0.9584	

Table 5.23: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Sepsis Patients treated in Medicine Unit

	Coefficient Estimate	Standard Errors	Odds Ratio (CI)	Pr($>\|z\|$)
Staffing on Day of Previous Admission for Medicine Unit (6NE) & In-Hospital Mortality				
Staffing on Day of Previous Admission	0.1522	0.1864	1.16(0.81, 1.69)	0.4142
Staffing and Census:Beds Ratio on Day of Previous Admission	0.0754	0.1931	1.08(0.74, 1.59)	0.6961
Staffing and Census:Staff Ratio on Day of Previous Admission	0.0331	0.2589	1.03(0.63, 1.75)	0.8984
Staffing and Census:Service Ratio on Day of Previous Admission	0.0754	0.1931	1.08(0.74, 1.59)	0.6961
Admission Count on Day of Previous Admission for Medicine Unit (6NE) & In-Hospital Mortality				
Admission Count on Day of Previous Admission	0.0901	0.1169	1.09(0.87, 1.38)	0.4410
Admission Count and Census:Beds Ratio on Day of Previous Admission	0.1511	0.1232	1.16(0.91, 1.48)	0.2202
Admission Count and Census:Staff Ratio on Day of Previous Admission	0.0788	0.1178	1.08(0.86, 1.36)	0.5032
Admission Count and Census:Service Ratio on Day of Previous Admission	0.1511	0.1232	1.16(0.91, 1.48)	0.2202
Staffing on Day of Previous Discharge for Medicine Unit (6NE) & In-Hospital Mortality				
Staffing on Day of Previous Discharge	-0.4459	0.3036	0.64(0.35, 1.17)	0.1418
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.4324	0.3039	0.65(0.35, 1.18)	0.1547
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.6976	0.4219	0.50(0.21, 1.14)	0.0983 .
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.4324	0.3039	0.65(0.35, 1.18)	0.1547
Discharge Count on Day of Previous Discharge for Medicine Unit (6NE) & In-Hospital Mortality				
Discharge Count on Day of Previous Discharge	0.0526	0.1987	1.05(0.71, 1.56)	0.7914
Discharge Count and Census:Beds Ratio on Day of Previous Discharge	0.0279	0.2056	1.03(0.68, 1.54)	0.8920
Discharge Count and Census:Staff Ratio on Day of Previous Discharge	0.0583	0.1988	1.06(0.72, 1.57)	0.7693
Discharge Count and Census:Service Ratio on Day of Previous Discharge	0.0279	0.2056	1.03(0.68, 1.54)	0.8920

Table 5.24: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Sepsis Patients treated in Oncology Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**
Staffing on Day of Previous Admission for Oncology Unit (7SE) & In-Hospital Mortality				
Staffing on Day of Previous Admission	-0.0250	0.2154	0.98(0.63, 1.49)	0.9077
Staffing and Census:Beds Ratio on Day of Previous Admission	-0.2190	0.3188	0.80(0.42, 1.48)	0.4922
Staffing and Census:Staff Ratio on Day of Previous Admission	-0.0008	0.2218	1.00(0.64, 1.55)	0.9970
Staffing and Census:Service Ratio on Day of Previous Admission	-0.2190	0.3188	0.80(0.42, 1.48)	0.4922
Admission Count on Day of Previous Admission for Oncology Unit (7SE) & In-Hospital Mortality				
Admission Count on Day of Previous Admission	-0.1472	0.1374	0.86(0.64, 1.11)	0.2840
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.1511	0.1396	0.86(0.62, 1.11)	0.2794
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.1417	0.1390	0.87(0.64, 1.12)	0.3080
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.1511	0.1396	0.86(0.63, 1.11)	0.2794
Staffing on Day of Previous Discharge for Oncology Unit (7SE) & In-Hospital Mortality				
Staffing on Day of Previous Discharge	-0.0826	0.2315	0.92(0.58, 1.46)	0.7212
Staffing and Census:Beds Ratio on Day of Previous Discharge	0.0567	0.4239	1.06(0.45, 2.45)	0.8937
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.0914	0.2297	0.91(0.58, 1.44)	0.6910
Staffing and Census:Service Ratio on Day of Previous Discharge	0.0567	0.4239	1.06(0.45, 2.45)	0.8937
Discharge Count on Day of Previous Discharge for Oncology Unit (7SE) & In-Hospital Mortality				
Discharge Count on Day of Previous Discharge	-0.0224	0.1440	0.98(0.73, 1.30)	0.8760
Discharge Count and Census:Beds Ratio on Day of Previous Discharge	-0.0011	0.1499	1.00(0.74, 1.34)	0.9942
Discharge Count and Census:Staff Ratio on Day of Previous Discharge	-0.0284	0.1443	0.97(0.72, 1.29)	0.8440
Discharge Count and Census:Service Ratio on Day of Previous Discharge	-0.0011	0.1499	1.00(0.74, 1.34)	0.9942

Table 5.25: Hospital Resource & Demand:Supply Variables associated with In-hospital Mortality for Sepsis Patients treated in Hematology/Oncology Unit

	Coefficient Estimate	**Standard Errors**	**Odds Ratio (CI)**	**Pr(> $\|z\|$)**
Staffing on Day of Previous Admission for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Staffing on Day of Previous Admission	0.1421	0.1272	1.15(0.90, 1.48)	0.2641
Staffing and Census:Beds Ratio on Day of Previous Admission	0.1834	0.1344	1.20(0.93, 1.57)	0.1724
Staffing and Census:Staff Ratio on Day of Previous Admission	0.3002	0.1948	1.35(0.93, 2.01)	0.1234
Staffing and Census:Service Ratio on Day of Previous Admission	0.1834	0.1344	1.20(0.93, 1.57)	0.1724
Admission Count on Day of Previous Admission for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Admission Count on Day of Previous Admission	-0.1613	0.1710	0.85(0.60, 1.18)	0.3458
Admission Count and Census:Beds Ratio on Day of Previous Admission	-0.1999	0.1783	0.82(0.57, 1.15)	0.2623
Admission Count and Census:Staff Ratio on Day of Previous Admission	-0.1622	0.1712	0.85(0.60, 1.18)	0.3434
Admission Count and Census:Service Ratio on Day of Previous Admission	-0.1999	0.1783	0.82(0.57, 1.15)	0.2623
Staffing on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Staffing on Day of Previous Discharge	-0.2470	0.1264	0.78(0.61, 1.00)	0.0507
Staffing and Census:Beds Ratio on Day of Previous Discharge	-0.1846	0.1395	0.83(0.63, 1.11)	0.1859
Staffing and Census:Staff Ratio on Day of Previous Discharge	-0.3858	0.2121	0.68(0.44, 1.01)	0.0689
Staffing and Census:Service Ratio on Day of Previous Discharge	-0.1846	0.1395	0.83(0.63, 1.11)	0.1859
Discharge Count on Day of Previous Discharge for Hematology/Oncology Unit (8NE) & In-Hospital Mortality				
Discharge Count on Day of Previous Discharge	-0.0089	0.1703	0.99(0.70, 1.38)	0.9584
Discharge Count and Census:Beds Ratio on Day of Previous Discharge	-0.1528	0.1842	0.86(0.59, 1.23)	0.4069
Discharge Count and Census:Staff Ratio on Day of Previous Discharge	0.0080	0.1724	1.01(0.71, 1.41)	0.9632
Discharge Count and Census:Service Ratio on Day of Previous Discharge	-0.1528	0.1842	0.86(0.59, 1.23)	0.4069

5.3.4 Discussion

The models described in this chapter had similarities and dissimilarities to the overall model described in Chapter 4. Similarities for health condition and overall models for 30-day readmission include associations between staffing at the time of patient admission with increased risk of readmission for all patients, cancer patients, and diabetes patients; which is similar to the overall model. Alternatively, admission volume on the day of admission was associated with increased risk of readmission for sepsis patients, while admission volume on day of discharge was associated with a decreased risk of readmission for cancer patients. This differs from the overall model where admission volume was not significant. When taking demand:supply measures into account at the unit level, the overall model only found significant association between staffing on day of admission and 30-day readmission for all patients treated in the orthopedic unit. A similar result was observed for cancer patients treated on the orthopedic units. Based on the similar findings from the overall model and cancer patient model for patients treated within the orthopedic unit, the association between staffing and increased readmission risk should be studied further to identify if confounding factors not studied in this dissertation contribute to an increased number of nurses being staffed and higher risks of 30-day readmission for all patients treated in the orthopedic unit.

For in-hospital mortality, the only significant hospital resource factor similarities for the health conditions and overall models were nurse staffing at the time of mortality which had an association with increased mortality for cancer patients and all patients. At the unit level, nurse staffing on day of mortality was associated with decreased risk of mortality for cancer patients treated within the hematology/oncology unit featured in the model, which was a similar result to the overall model.

The differences observed between the overall model and the health condition models may suggest that in addition to studying hospital resource associations at the unit-level, the associations also be studied at the patient-level in terms of health conditions.

Chapter 6

DISCUSSION

The objective of this dissertation was to identify associations between hospital resource factors and adverse health outcomes by controlling for significant patient risk factors and by taking into account variations in association across different nursing units. Since the patient population included in this study were all patients susceptible to an adverse health outcome, the findings of these study can be used by healthcare administrators, decision makers, and policy makers to develop interventions aimed at improving overall patient safety for all patients treated in the hospital.

The studies presented in this dissertation first identify patient risk factors for all patients who are more susceptible to experiencing an adverse health outcome. With information on patient risk factors, susceptible patient can be identified earlier and interventions can be implemented to mitigate adverse health outcomes for these patients. Next, controllable hospital resource levels on day of admission and day of discharge that increase likelihood of of adverse health outcome were identified. Since the hospital resource measures included in this study can be controlled by hospital administrators, policies can be put into place to change resource levels, which would improve patient safety. Unlike previous studies that typically assess resource levels on either day of admission or day of discharge, this study aimed to find associations on both day of admission and day of discharge/mortality. By assessing both the day of admission and day of discharge, interventions related to the findings would be aimed at reducing adverse outcomes from the time the patient enters the hospital to the time the patient leaves. Finally, the association between hospital resource levels and adverse health outcomes from unit to unit and the possible effect of demand per supply of resources and services on these associations were explored. The unit to unit variation was important to consider due to the different types of health conditions treated on each unit that could possibly require unit-level policies to mitigate the occurrence of adverse health outcomes. Demand and supply of resources and services were explored to assess potential confounding.

Generalizability

The findings described in these studies may not be generalizable across various healthcare facilities. The University of Washington Medical Center is an urban teaching hospital that may have a unique patient population and/or resource and service capacity in comparison to other healthcare facilities. The methodology and findings presented in this dissertation can assist hospital decision and policy makers identify unique interventions based on the hospital's unique patient-level and unit-level characteristics.

Future Work

The 30-day readmission adverse health outcome measure included in this study is a quality of care measure recognized by healthcare agencies, such as the Centers for Medicare & Medicaid Services. In addition to this measure, other readmission measures related to morbidity and disease or illness progression can be examined. Research has found the majority of preventable readmission occur within 30-days from discharge [10], however since readmissions that occur after 30-days may also be preventable, the usefulness of 30-day readmission as a quality of care measure has been debated [10]. After completing their research on health outcome effectiveness in 1991, Gornick et al. (as cited in Benbassat & Taragin, 2000) concluded readmissions after discharge "often indicated...the progression of disease, rather than discrete outcomes of care..." [10]. Based on this conclusion, future research should account for disease/illness progression by measuring the time until a readmission, which could be a more appropriate quality of care measure.

Fluctuations in admission volume, resulting from epidemics, as well as resource utilization and capacity, resulting from hospital interventions, can impact the results found in this study. In terms of admission volume, increased patient demand can exceed hospital resources and service capacity and potentially increase the occurrence of adverse health outcomes. Previous studies have found associations between seasonal influenza as it relates to hospital overcrowding and increased likelihood of in-hospital mortality [20]. Additionally, changes in available hospital resources, such as opening a new nursing unit, can relieve strained bed capacity and potentially reduce the occurrence of adverse health outcomes. Researchers found that after interventions to reduce bed occupancy were implemented, which included commissioning additional community hospital beds, in-hospital mortality reduced significantly [41]. Future studies assessing the association between hospital resources and adverse health outcomes should account for time periods when patient volume changes due to epidemics and when resource utilization and capacity changes due to hospital interventions.

Factors external to a hospital, such as insurance-mix of their patient population, can influence the findings presented in this research. In this study, only Medicare insurance was considered as a patient risk factor associated with adverse health outcomes. Having an alternative type of insurance or not having insurance could have a possible association with adverse health outcomes. Previous studies have found that lack of health insurance has an association with increased risk of mortality ([93]; [94]). Based on these findings, future studies should include insurance measures as a potential patient risk factor associated with adverse health outcomes.

The following sections summarize and discuss the study findings for each research question.

6.1 Influence of Patient Risk Factors with Adverse Health Outcomes Findings

To address research question 1 (RQ1), patient risk factors that could potentially influence the association between hospital resource factors and in-hospital mortality and 30-day readmissions were examined in chapter 2. Binomial logistic regression and LASSO logistic regression models were both considered to avoid over-fitting the models. Although both methods had similar discrimination performance as measured by the AUC, the goodness-of-fit showed better results for binomial logistic regression. The model showed 19 patient risk factors that significantly impacted readmission and 8 patient risk factors associated with mortality. Patient risk factors associated with decreased risk of readmission included receiving treatment from the ICU and being a Medicare beneficiary, while risk factors associated with increased risk of readmission included receiving treatment for cancer and being admitted from the emergency department (ED). Patient risk factors associated with decreased risk of mortality included receiving treatment for heart failure. Receiving palliative care and staying in the ICU significantly increased the risk of mortality. Palliative care was expected to have a strong association with in-hospital mortality since palliative care is a service aimed at easing patient symptoms and offering support for the patient's family members [95]. Patients who stayed in the ICU have higher risk of mortality and severity of illness, and are therefore more susceptible to experiencing adverse health outcomes ([64]; [18]; [21]; [77]; [28]; [23]; [29]; [30]; [31]; [78]; [79]; [54]; [80]; [44]; [22]).

The hypothesis of RQ1 was age, sex, chronic health conditions, severity of illness, risk of mortality, and length of stay would be associated with increased the risk of both adverse health outcomes. For 30-day readmission, age, chronic health conditions such as cancer and diabetes, extreme severity of illness, and length of stay were significantly associated with increased risk of 30-day readmission, corresponding with the hypothesis. In addition to these patient risk factors, receiving a procedure, identifying as black/African-American, being admitted through the emergency department, receiving treatment for heart failure; and being discharged home were also associated with increased risk of 30-day readmission. These findings correspond with past research that included age, sex, and ethnicity([68]; [69]; [70]; [71]); chronic health conditions, ([72]; [70]; [73]); severity of illness [74]; and admission source [50] patient risk factors when studying associations with adverse health outcomes.

For in-hospital mortality, both extreme severity of illness and risk of mortality were associated with increased risk of in-hospital mortality, which corresponded with the hypothesis. Interestingly, age, sex, receiving treatment for chronic health conditions, and length of stay—patient risk factors that were previously studied for their potential association with adverse health outcomes ([68]; [69]; [72]; [70]; [73])—were not significantly associated with in-hospital mortality when other patient risk factors were included in the model. The possible reason for the discrepancy could be due to the study design and setting. Similar studies have included larger patient populations spanning across multiple healthcare facilities. The study presented in this dissertation included one healthcare facility, so it is possible that the findings are not as generalizable to patient populations outside the University of Washington Medical Center.

Hospital policy makers can develop patient safety measures to prevent adverse health outcomes for susceptible patient groups. Patients who self-identified as black/African-American as well as patients who were admitted through the emergency department had an increased likelihood of being readmitted within 30 days, and preventative interventions can help to mitigate future readmission. A combination of previously studied interventions aimed at reducing 30-day readmission include scheduling outpatient follow-up visits, providing patient-centered discharge instructions to patients before they are discharged from the hospital, and providing follow-up phone calls after discharge [96]. These interventions should be implemented to prevent 30-day readmission for the most susceptible patients found in this study, including patients admitted through the emergency department and those treated for chronic health conditions, such as cancer and diabetes. To prevent in-hospital mortality, hospitals should consider establishing medical emergency teams consisting of experienced nurses and physicians who are dispersed to provide resuscitation procedures when a patient becomes unstable [97]. Additionally, licensed health care providers can further investigate root causes by reviewing patient medical records to identify similarities in treatment that may explain why specific patient groups are more susceptible to adverse health outcomes. Once these similarities are identified, policies can be developed to prevent adverse health outcomes.

6.2 Influence of Hospital Resource Factors with Adverse Health Outcomes Findings

The resource variables that influence in-hospital mortality and 30-day readmission rates were found for all units with readmission and mortality cases in chapter 3. After adjusting for the significant patient risk factors found in chapter 2, the hospital resource factors associated with increased risk of readmission included nursing staff scheduled to work, being admitted during the evening (3:00pm to 10:59pm) and night (11:00pm to 6:59am) shifts, and being discharged during the evening shift. After hours discharge was previously identified to increase the risk of 30-day readmission ([21]; [23]; [50]). The study findings in this research suggest the limited resources available after-hours on both the time of admission and time of discharge influence the likelihood of readmission. For mortality, nursing staff scheduled to work and scheduled to be on vacation on the day of mortality were measures associated with increased mortality risk. This study introduced the number of nurses vacationing measure, which was significantly associated with increased mortality risk.

The hypothesis of research question 2 (RQ2) was that all included hospital resource factors (e.g. number of scheduled registered nurses, number of available beds) and proxy measures (admission/discharge during the evening shift, admission count to the unit), are associated with an increased risk of adverse health outcomes. Interestingly, the number of nursing staff (staffing) who were scheduled to work at the time a patient was admitted and the time a patient was discharged was associated with increased risk of 30-day readmission, and staffing at the time when a patient passed away was associated with increased risk of risk-adjusted in-hospital mortality. The result is contrary to the hypothesis and previous readmission and mortality research ([7]; [16]), since it is assumed more resources available to provide care to patients will reduce the likelihood of adverse health outcomes. Similar studies have included nurse education skill levels and accounted for nurses who provided direct patient care as opposed to nursing staff who performed administrative duties. Additionally, the nurse staffing data included in this study does not take into consideration the possibility that the actual number of nurses who worked during a given shift may differ from the number of nurses scheduled to work.

The research findings in this study proposed hospital resource measures that can be controlled in order to reduce the occurrence of adverse health outcomes, which can improve overall patient care. The research findings propose that after-hour admission to and discharge from the nursing unit when accessibility to resources is more likely to be limited (i.e. during the evening shift) increases the likelihood to experience readmission. Healthcare decision makers can put implement policies and programs to either increase the level of resources or access to equipment during evening and night shifts [26] or limit admission to and discharge from the nursing units to morning/day shifts when hospital resources are more accessible. Additionally, the number of registered nurses scheduled to be on vacation was found to increase the risk of mortality. Staffing policies should be put into place that ensure adequate staffing levels are maintained during each shift.

Due to the discrepancy in nurse staffing findings presented in this research compared with previous studies, future studies should consider including nurse staffing measures other than the number of nurses scheduled to work. It is recommended that nursing surveys, similar to those used in previous studies [92], are used to capture the actual number of nurses that worked each shift; the number of nurses who provided direct patient care versus performed administrative duties, such as supervision and education; the education level of each nurse; and the experience level of each nurse in terms of amount of time working as a registered nurse.

6.3 Unit-to-Unit Variation in Hospital Resource Influence on Adverse Health Outcomes Findings

Finally, the association between resource factors and risk-adjusted 30-day readmission and mortality were assessed for selected individual units, and demand:supply ratio measures were assessed to explore if these ratio variables could explain the unit-to-unit variation in chapter 4. For individual units, selected hospital resource factors did not have different significance or direction of association with readmission when compared against the whole hospital associations explored in chapter 3. For mortality, the number of scheduled nursing staff on the day of admission for the orthopedic unit and the number of scheduled nursing staff on the day of mortality for the medical/surgical and hematology/oncology units decreased the risk of mortality, which is a similar association found in previous studies [16]. The demand:supply ratio measures selected in this study did not account for the unit-to-unit variation.

It was hypothesized that demand per supply measures at the unit-level could confound the association between the resource factors and adverse health outcomes. This study explored the difference in association of hospital resources variables and adverse health outcomes for a subset of nursing units at the University of Washington Medical Center. The exploratory study presented in chapter 4 included 2 of the hospital resource factors studied in chapter 3 and 4 of the 14 nursing units in the hospital. Before policies can be developed and implemented, more research should be conducted for the remaining units to identify the risk-adjusted associations between hospital resource factors and adverse health outcomes specific to each unit and how demand and supply impact these associations.

6.4 Conclusion

The findings presented in this dissertation can be used for hospital operations and healthcare delivery process planning in order to mitigate the risk of readmission and mortality. At the University of Washington Medical Center, there is evidence that admission and discharge during the evening shift is associated with increased risk of adverse health outcomes on the day of admission and the day of discharge for readmitted patients. In terms of in-hospital mortality, the number of nurses vacationing is associated with increased risk of mortality. Additionally, the number of scheduled nurse staffing reduces the risk of mortality in the orthopedic, medical/surgical, and hematology/oncology units. Policies can be developed or revised in an attempt to control resource factors found to significantly influence adverse patient health outcomes.

BIBLIOGRAPHY

[1] Jan Vissers and Roger Beech. *Health operations management: patient flow logistics in health care*. Psychology Press, 2005.

[2] David A Thompson, Paul R Yarnold, Diana R Williams, and Stephen L Adams. Effects of actual waiting time, perceived waiting time, information delivery, and expressive quality on patient satisfaction in the emergency department. *Annals of emergency medicine*, 28(6):657–665, 1996.

[3] Nathan R Hoot and Dominik Aronsky. Systematic review of emergency department crowding: causes, effects, and solutions. *Annals of emergency medicine*, 52(2):126–136. e1, 2008.

[4] Charles D. Flagle. Operations research in the health services. *Operations Research*, 10(5):591–603, 1962.

[5] R.S. Valdez, E. Ramly, and P.F. Brennan. Industrial and systems engineering and health care: Critical areas of research–final report. Report, Agency for Healthcare Research and Quality, 2010.

[6] CMS. Hospital quality initiative: Outcome measures, 2015.

[7] Luwis Diya, Koen Van den Heede, Walter Sermeus, and Emmanuel Lesaffre. The relationship between inhospital mortality, readmission into the intensive care nursing unit and/or operating theatre and nurse staffing levels. *Journal of advanced nursing*, 68(5):1073–1081, 2012.

[8] Geoffrey Gerhardt, Alshadye Yemane, Peter Hickman, Allison Oelschlaeger, Eric Rollins, and Niall Brennan. Medicare readmission rates showed meaningful decline in 2012. *Medicare Medicaid Res Rev*, 3(2):E1–E12, 2013.

[9] Joel S Weissman, John Z Ayanian, Scott Chasan-Taber, Marjorie J Sherwood, Carol Roth, and Arnold M Epstein. Hospital readmissions and quality of care. *Medical care*, 37(5):490–501, 1999.

[10] Jochanan Benbassat and Mark Taragin. Hospital readmissions as a measure of quality of health care: advantages and limitations. *Archives of internal medicine*, 160(8):1074–1081, 2000.

[11] CHIA. A focus on provider quality. Report, Center for Health Information and Analysis, January 2015 2015.

[12] Anika L Hines, Marguerite L Barrett, H Joanna Jiang, and Claudia A Steiner. Conditions with the largest number of adult hospital readmissions by payer. 2014.

[13] CMS. Acute inpatient: Readmissions reduction program (hrrp), 2016.

[14] Mitchell J Barnett, Peter J Kaboli, Carl A Sirio, and Gary E Rosenthal. Day of the week of intensive care admission and patient outcomes: a multisite regional evaluation. *Medical care*, 40(6):530–539, 2002.

[15] Linda H Aiken, Sean P Clarke, Douglas M Sloane, Julie Sochalski, and Jeffrey H Silber. Hospital nurse staffing and patient mortality, nurse burnout, and job dissatisfaction. *Jama*, 288(16):1987–1993, 2002.

[16] Jack Needleman, Peter Buerhaus, V. Shane Pankratz, Cynthia L. Leibson, Susanna R. Stevens, and Marcelline Harris. Nurse staffing and inpatient hospital mortality. *New England Journal of Medicine*, 364(11):1037–1045, 2011.

[17] Linda H Aiken, Douglas M Sloane, Luk Bruyneel, Koen Van den Heede, Peter Griffiths, Reinhard Busse, Marianna Diomidous, Juha Kinnunen, Maria Kózka, and Emmanuel Lesaffre. Nurse staffing and education and hospital mortality in nine european countries: a retrospective observational study. *The Lancet*, 383(9931):1824–1830, 2014.

[18] W. O. Tarnow-Mordi, C. Hau, A. Warden, and A. J. Shearer. Hospital mortality in relation to staff workload: a 4-year study in an adult intensive-care unit. *Lancet*, 356(9225):185–9, 2000.

[19] CA Bond, Cynthia L Raehl, Michael E Pitterle, and Todd Franke. Health care professional staffing, hospital characteristics, and hospital mortality rates. *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy*, 19(2):130–138, 1999.

[20] Peter L Schilling, Darrell A Campbell Jr, Michael J Englesbe, and Matthew M Davis. A comparison of in-hospital mortality risk conferred by high hospital occupancy, differences in nurse staffing levels, weekend admission, and seasonal influenza. *Medical care*, 48(3):224–232, 2010.

[21] D. Gantner, K. Farley, M. Bailey, S. Huckson, P. Hicks, and D. Pilcher. Mortality related to after-hours discharge from intensive care in australia and new zealand, 2005-2012. *Intensive Care Med*, 40(10):1528–35, 2014.

[22] Kevin B Laupland, Reza Shahpori, Andrew W Kirkpatrick, and H Thomas Stelfox. Hospital mortality among adults admitted to and discharged from intensive care on weekends and evenings. *Journal of critical care*, 23(3):317–324, 2008.

[23] D. V. Pilcher, G. J. Duke, C. George, M. J. Bailey, and G. Hart. After-hours discharge from intensive care increases the risk of readmission and death. *Anaesth Intensive Care*, 35(4):477–85, 2007.

[24] Peter Cram, Stephen L Hillis, Mitchell Barnett, and Gary E Rosenthal. Effects of weekend admission and hospital teaching status on in-hospital mortality. *The American journal of medicine*, 117(3):151–157, 2004.

[25] Flemming Madsen, Steen Ladelund, and Allan Linneberg. High levels of bed occupancy associated with increased inpatient and thirty-day hospital mortality in denmark. *Health Affairs*, 33(7):1236–1244, 2014.

[26] William J Kostis, Kitaw Demissie, Stephen W Marcella, Yu-Hsuan Shao, Alan C Wilson, and Abel E Moreyra. Weekend versus weekday admission and mortality from myocardial infarction. *New England Journal of Medicine*, 356(11):1099–1109, 2007.

[27] GJ Duke, JV Green, and JH Briedis. Night-shift discharge from intensive care unit increases the mortality-risk of icu survivors. *Anaesthesia and intensive care*, 32(5):697, 2004.

[28] Ian J Morales, Steve G Peters, and Bekele Afessa. Hospital mortality rate and length of stay in patients admitted at night to the intensive care unit*. *Critical care medicine*, 31(3):858–863, 2003.

[29] J. D. Santamaria, G. J. Duke, D. V. Pilcher, D. J. Cooper, J. Moran, and R. Bellomo. The timing of discharge from the intensive care unit and subsequent mortality. a prospective, multicenter study. *Am J Respir Crit Care Med*, 191(9):1033–9, 2015.

[30] S Allen Ensminger, Ian J Morales, Steve G Peters, Mark T Keegan, Javier D Finkielman, James F Lymp, and Bekele Afessa. The hospital mortality of patients admitted to the icu on weekends. *CHEST Journal*, 126(4):1292–1298, 2004.

[31] Hannah Wunsch, James Mapstone, Tony Brady, Rosa Hanks, and Kathryn Rowan. Hospital mortality associated with day and time of admission to intensive care units. *Intensive care medicine*, 30(5):895–901, 2004.

[32] Drew B Richardson. Increase in patient mortality at 10 days associated with emergency department overcrowding. *Medical journal of Australia*, 184(5):213, 2006.

[33] Peter C Sprivulis, J Da Silva, Ian G Jacobs, Amanda RL Frazer, and George A Jelinek. The association between hospital overcrowding and mortality among patients admitted via western australian emergency departments. *Medical Journal of Australia*, 184(5):208, 2006.

[34] B. C. Sun, R. Y. Hsia, R. E. Weiss, D. Zingmond, L. J. Liang, W. Han, H. McCreath, and S. M. Asch. Effect of emergency department crowding on outcomes of admitted patients. *Ann Emerg Med*, 61(6):605–611 e6, 2013.

[35] Adam J Singer, Henry C Thode Jr, Peter Viccellio, and Jesse M Pines. The association between length of emergency department boarding and mortality. *Academic Emergency Medicine*, 18(12):1324–1329, 2011.

[36] D. B. Chalfin, S. Trzeciak, A. Likourezos, B. M. Baumann, R. P. Dellinger, and Delay-Ed study group. Impact of delayed transfer of critically ill patients from the emergency department to the intensive care unit. *Crit Care Med*, 35(6):1477–83, 2007.

[37] G. Iapichino, L. Gattinoni, D. Radrizzani, B. Simini, G. Bertolini, L. Ferla, G. Mistraletti, F. Porta, and D. R. Miranda. Volume of activity and occupancy rate in intensive care units. association with mortality. *Intensive Care Medicine*, 30(2):290–297, 2004. 770DK Times Cited:37 Cited References Count:23.

[38] René Robert, Jean Reignier, Caroline Tournoux-Facon, Thierry Boulain, Olivier Lesieur, Valérie Gissot, Vincent Souday, Mouldi Hamrouni, Cécile Chapon, and Jean-Paul Gouello. Refusal of intensive care unit admission due to a full unit: impact on mortality. *American journal of respiratory and critical care medicine*, 185(10):1081–1087, 2012.

[39] Elliott S Fisher, John E Wennberg, Therese A Stukel, Jonathan S Skinner, SM Sharp, JL Freeman, and AM Gittelsohn. Associations among hospital capacity, utilization, and mortality of us medicare beneficiaries, controlling for sociodemographic factors. *Health services research*, 34(6):1351, 2000.

[40] Gary C Geelhoed and Nicholas H de Klerk. Emergency department overcrowding, mortality and the 4-hour rule in western australia. *Med J Aust*, 196(2):122–6, 2012.

[41] DG Boden, A Agarwal, T Hussain, SJ Martin, N Radford, MS Riyat, K So, Y Su, A Turvey, and CI Whale. Lowering levels of bed occupancy is associated with decreased inhospital mortality and improved performance on the 4-hour target in a uk district general hospital. *Emergency Medicine Journal*, pages emermed–2014–204479, 2015.

[42] Jesse M. Pines, Charles V. Pollack, Deborah B. Diercks, Anna Marie Chang, Frances S. Shofer, and Judd E. Hollander. The association between emergency department crowding and adverse cardiovascular outcomes in patients with chest pain. *Academic Emergency Medicine*, 16(7):617–625, 2009.

[43] Asa Viccellio, Carolyn Santora, Adam J Singer, Henry C Thode, and Mark C Henry. The association between transfer of emergency department boarders to inpatient hallways and mortality: a 4-year experience. *Annals of emergency medicine*, 54(4):487–491, 2009.

[44] Theodore J Iwashyna, Andrew A Kramer, and Jeremy M Kahn. Intensive care unit occupancy and patient outcomes. *Critical care medicine*, 37(5):1545, 2009.

[45] John D Birkmeyer, Andrea E Siewers, Emily VA Finlayson, Therese A Stukel, F Lee Lucas, Ida Batista, H Gilbert Welch, and David E Wennberg. Hospital volume and surgical mortality in the united states. *New England Journal of Medicine*, 346(15):1128–1137, 2002.

[46] Matthew D McHugh, Julie Berez, and Dylan S Small. Hospitals with higher nurse staffing had lower odds of readmissions penalties than hospitals with lower staffing. *Health Affairs*, 32(10):1740–1747, 2013.

[47] Matthew D McHugh and Chenjuan Ma. Hospital nursing and 30-day readmissions among medicare patients with heart failure, acute myocardial infarction, and pneumonia. *Medical care*, 51(1):52, 2013.

[48] Heather L Tubbs-Cooley, Jeannie P Cimiotti, Jeffrey H Silber, Douglas M Sloane, and Linda H Aiken. An observational study of nurse staffing ratios and hospital readmission among children admitted for common conditions. *BMJ quality & safety*, pages bmjqs–2012–001610, 2013.

[49] Michelle Butler, Rita Collins, Jonathan Drennan, Phil Halligan, Dónal P O'Mathúna, Timothy J Schultz, Ann Sheridan, and Eileen Vilis. Hospital nurse staffing models and patient and staff-related outcomes. *Cochrane Database Syst Rev*, 7, 2011.

[50] J. Renton, D. V. Pilcher, J. D. Santamaria, P. Stow, M. Bailey, G. Hart, and G. Duke. Factors associated with increased risk of readmission to intensive care in australia. *Intensive Care Med*, 37(11):1800–8, 2011.

[51] Philipp GH Metnitz, Fabienne Fieux, Barbara Jordan, Thomas Lang, Rui Moreno, and Jean-Roger Le Gall. Critically ill patients readmitted to intensive care units—lessons to learn? *Intensive care medicine*, 29(2):241–248, 2003.

[52] Torhild Heggestad. Operating conditions of psychiatric hospitals and early readmission — effects of high patient turnover. *Acta Psychiatrica Scandinavica*, 103(3):196–202, 2001.

[53] D. R. Baker, P. J. Pronovost, L. L. Morlock, R. G. Geocadin, and C. G. Holzmueller. Patient flow variability and unplanned readmissions to an intensive care unit. *Crit Care Med*, 37(11):2882–7, 2009.

[54] Carla A Chrusch, Kendiss P Olafson, Patricia M McMillan, Daniel E Roberts, and Perry R Gray. High occupancy increases the risk of early death or readmission after transfer from intensive care*. *Critical care medicine*, 37(10):2753–2758, 2009.

[55] J. A. Town, M. M. Churpek, T. C. Yuen, M. T. Huber, J. P. Kress, and D. P. Edelson. Relationship between icu bed availability, icu readmission, and cardiac arrest in the general wards. *Crit Care Med*, 42(9):2037–41, 2014.

[56] Mathias C Blom, Karin Erwander, Lars Gustafsson, Mona Landin-Olsson, Fredrik Jonsson, and Kjell Ivarsson. The probability of readmission within 30 days of hospital discharge is positively associated with inpatient bed occupancy at discharge–a retrospective cohort study. *BMC emergency medicine*, 15(1):37, 2015.

[57] Debra F. Hillier, Gareth J. Parry, Michael W. Shannon, and Anne M. Stack. The effect of hospital bed occupancy on throughput in the pediatric emergency department. *Annals of Emergency Medicine*, 53(6):767–776.e3, 2009.

[58] Shane M Tibby, Joanna Correa-West, Andrew Durward, Lesley Ferguson, and Ian A Murdoch. Adverse events in a paediatric intensive care unit: relationship to workload, skill mix and staff supervision. *Intensive care medicine*, 30(6):1160–1166, 2004.

[59] William T Abraham, Gregg C Fonarow, Nancy M Albert, Wendy Gattis Stough, Mihai Gheorghiade, Barry H Greenberg, Christopher M O'Connor, Jie Lena Sun, Clyde W Yancy, and James B Young. Predictors of in-hospital mortality in patients hospitalized for heart failure: insights from the organized program to initiate lifesaving treatment in hospitalized patients with heart failure (optimize-hf). *Journal of the American College of Cardiology*, 52(5):347–356, 2008.

[60] Mario Bo, Massimiliano Massaia, Silvio Raspo, Francesca Bosco, Paola Cena, Mario Molaschi, and Fabrizio Fabris. Predictive factors of inhospital mortality in older patients admitted to a medical intensive care unit. *Journal of the American Geriatrics Society*, 51(4):529–533, 2003.

[61] Francois G Brivet, Dieter J Kleinknecht, Philippe Loirat, and Paul JM Landais. Acute renal failure in intensive care units–causes, outcome, and prognostic factors of hospital mortality: a prospective, multicenter study. *Critical care medicine*, 24(2):192–198, 1996.

[62] Paul N Casale, Jayne L Jones, Flossie E Wolf, Yanfen Pei, and L Marlin Eby. Patients treated by cardiologists have a lower in-hospital mortality for acute myocardial infarction. *Journal of the American College of Cardiology*, 32(4):885–889, 1998.

[63] C. G. Durbin and R. F. Kopel. A case-control study of patients readmitted to the intensive-care unit. *Critical Care Medicine*, 21(10):1547–1553, 1993.

[64] Omar Badawi and Michael J. Breslow. Readmissions and death after icu discharge: Development and validation of two predictive models. *PLoS ONE*, 7(11):e48758, 2012.

[65] Kathleen Daly, R Beale, and RWS Chang. Reduction in mortality after inappropriate early discharge from intensive care unit: logistic regression triage model. *Bmj*, 322(7297):1274, 2001.

[66] Astrid Guttmann, Michael J Schull, Marian J Vermeulen, and Therese A Stukel. Association between waiting times and short term mortality and hospital admission after departure from emergency department: population based cohort study from ontario, canada. *Bmj*, 342:d2983, 2011.

[67] Peter A Hampshire, Catherine A Welch, Lawrence A McCrossan, Katharine Francis, and David A Harrison. Admission factors associated with hospital mortality in patients with haematological malignancy admitted to uk adult, general critical care units: a secondary analysis of the icnarc case mix programme database. *Crit Care*, 13(4):R137, 2009.

[68] John Billings, Jennifer Dixon, Tod Mijanovich, and David Wennberg. Case finding for patients at risk of readmission to hospital: development of algorithm to identify high risk patients. *BMJ*, 333(7563):327, 2006.

[69] Alison J Campbell, Jonathan A Cook, Gillian Adey, and Brian H Cuthbertson. Predicting death and readmission after intensive care discharge. *British journal of anaesthesia*, 100(5):656–662, 2008.

[70] Patricia S. Keenan, Sharon-Lise T. Normand, Zhenqiu Lin, Elizabeth E. Drye, Kanchana R. Bhat, Joseph S. Ross, Jeremiah D. Schuur, Brett D. Stauffer, Susannah M. Bernheim, Andrew J. Epstein, Yongfei Wang, Jeph Herrin, Jersey Chen, Jessica J. Federer, Jennifer A. Mattera, Yun Wang, and Harlan M. Krumholz. An administrative

claims measure suitable for profiling hospital performance on the basis of 30-day all-cause readmission rates among patients with heart failure. *Circulation: Cardiovascular Quality and Outcomes*, 1(1):29–37, 2008.

[71] Hanna Bloomfield Rubins and Mark A Moskowitz. Discharge decision-making in a medical intensive care unit: identifying patients at high risk of unexpected death or unit readmission. *The American journal of medicine*, 84(5):863–869, 1988.

[72] K. M. Ho, G. J. Dobb, K. Y. Lee, J. Finn, M. Knuiman, and S. A. Webb. The effect of comorbidities on risk of intensive care readmission during the same hospitalization: a linked data cohort study. *J Crit Care*, 24(1):101–7, 2009.

[73] Sue E. Kirby, Sarah M. Dennis, Upali W. Jayasinghe, and Mark F. Harris. Patient related factors in frequent readmissions: the influence of condition, access to services and patient choice. *BMC Health Services Research*, 10(1):1–8, 2010.

[74] Andrew A Kramer, Thomas L Higgins, and Jack E Zimmerman. Intensive care unit readmissions in us hospitals: Patient characteristics, risk factors, and outcomes*. *Critical care medicine*, 40(1):3–10, 2012.

[75] Carole A Estabrooks, William K Midodzi, Greta G Cummings, Kathryn L Ricker, and Phyllis Giovannetti. The impact of hospital nursing characteristics on 30day mortality. *Nursing research*, 54(2):74–84, 2005.

[76] Herng-Ching Lin, Sudha Xirasagar, Chi-Hung Chen, and Yi-Ting Hwang. Physician's case volume of intensive care unit pneumonia admissions and in-hospital mortality. *American journal of respiratory and critical care medicine*, 177(9):989–994, 2008.

[77] Tarik Hanane, Mark T Keegan, Edward G Seferian, Ognjen Gajic, and Bekele Afessa. The association between nighttime transfer from the intensive care unit and patient outcome*. *Critical care medicine*, 36(8):2232–2237, 2008.

[78] L. Fuchs, V. Novack, S. McLennan, L. A. Celi, Y. Baumfeld, S. Park, M. D. Howell, and D. S. Talmor. Trends in severity of illness on icu admission and mortality among the elderly. *PLoS One*, 9(4):e93234, 2014.

[79] J. Wagner, N. B. Gabler, S. J. Ratcliffe, S. E. Brown, B. L. Strom, and S. D. Halpern. Outcomes among patients discharged from busy intensive care units. *Ann Intern Med*, 159(7):447–55, 2013.

[80] Saqib I. Dara and Bekele Afessa. Intensivist-to-bed ratio*: Association with outcomes in the medical icu. *Chest*, 128(2):567–572, 2005.

[81] Ciaran S Phibbs, Janet M Bronstein, Eric Buxton, and Roderic H Phibbs. The effects of patient volume and level of care at the hospital of birth on neonatal mortality. *Jama*, 276(13):1054–1059, 1996.

[82] Ognjen Gajic, Michael Malinchoc, Thomas B Comfere, Marcelline R Harris, Ahmed Achouiti, Murat Yilmaz, Marcus J Schultz, Rolf D Hubmayr, Bekele Afessa, and J Christopher Farmer. The stability and workload index for transfer score predicts unplanned intensive care unit patient readmission: Initial development and validation*. *Critical care medicine*, 36(3):676–682, 2008.

[83] Arnold M. Epstein, Ashish K. Jha, and E. John Orav. The relationship between hospital admission rates and rehospitalizations. *New England Journal of Medicine*, 365(24):2287–2295, 2011.

[84] Michael Tatchell. Measuring hospital output: a review of the service mix and case mix approaches. *Social Science & Medicine*, 17(13):871–883, 1983.

[85] Peter Peduzzi, John Concato, Elizabeth Kemper, Theodore R. Holford, and Alvan R. Feinstein. A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology*, 49(12):1373–1379, 1996.

[86] David W Hosmer Jr and Stanley Lemeshow. *Applied logistic regression*. John Wiley & Sons, 2004.

[87] David A Belsey, Edwin Kuh, and Roy E Welsch. *Regression diagnostics: Identifying influential data and sources of collinearity*. John Wiley, 1980.

[88] R. Tibshirani. Regression shrinkage and selection via the lasso. *Journal of the Royal Statistical Society Series B-Methodological*, 58(1):267–288, 1996.

[89] E. W. Steyerberg, Jr. Harrell, F. E., G. J. Borsboom, M. J. Eijkemans, Y. Vergouwe, and J. D. Habbema. Internal validation of predictive models: efficiency of some procedures for logistic regression analysis. *J Clin Epidemiol*, 54(8):774–81, 2001.

[90] E. W. Steyerberg, A. J. Vickers, N. R. Cook, T. Gerds, M. Gonen, N. Obuchowski, M. J. Pencina, and M. W. Kattan. Assessing the performance of prediction models: a framework for traditional and novel measures. *Epidemiology*, 21(1):128–38, 2010.

[91] D. W. Hosmer, T. Hosmer, S. Le Cessie, and S. Lemeshow. A comparison of goodness-of-fit tests for the logistic regression model. *Stat Med*, 16(9):965–80, 1997.

[92] Ann E Tourangeau, Lisa A Cranley, and L Jeffs. Impact of nursing on hospital patient mortality: a focused review and related policy implications. *Quality and Safety in Health Care*, 15(1):4–8, 2006.

[93] Paula Braveman, Geraldine Oliva, Marie Grisham Miller, Randy Reiter, and Susan Egerter. Adverse outcomes and lack of health insurance among newborns in an eight-county area of california, 1982-1986. *The New England Journal of Medicine*, 321(8):508–513, 1989.

[94] Peter Franks, Carolyn M. Clancy, and Marthe R. Gold. Health insurance and mortality: Evidence from a national cohort. *JAMA*, 270(6):737–741, 1993.

[95] Ahmed Elsayem, Martin L. Smith, Lee Parmley, J. Lynn Palmer, Rosell Jenkins, Suresh Reddy, and Eduardo Bruera. Impact of a palliative care service on in-hospital mortality in a comprehensive cancer center. *Journal of Palliative Medicine*, 9(4):894–902, 2006.

[96] Luke O Hansen, Robert S Young, Keiki Hinami, Alicia Leung, and Mark V Williams. Interventions to reduce 30-day rehospitalization: a systematic review. *Annals of internal medicine*, 155(8):520–528, 2011.

[97] Michael D Buist, Gaye E Moore, Stephen A Bernard, Bruce P Waxman, Jeremy N Anderson, and Tuan V Nguyen. Effects of a medical emergency team on reduction of incidence of and mortality from unexpected cardiac arrests in hospital: preliminary study. *BMJ*, 324(7334):387–390, 2002.

Appendix A

VARIABLES INCLUDED IN THE PATIENT DETAIL REPORT DATASET

The following is a list of the variables featured in the Patient Detail Report and their definitions.

Acute Myocardial Infarction (AMI) Flag: Indicator variable set to “1” if a patient had AMI prior to (ie. reason for hospital visit) or during their hospital stay; “0” otherwise

Admit Date: The date a patient was admitted to an inpatient unit for a given encounter (*format: mm/dd/yyyy*)

Admit Source: The origin location through which the inpatient arrives to the hospital

Admit Time: The time a patient was admitted to an inpatient unit for a given encounter (*format: hh:mm:ss am/pm*)

Admit Type: The manner in which a patient is admitted to the hospital

Age: Patient’s age at the beginning of their encounter

All Patient Refined Diagnosis-Related Group (APR-DRG): A pricing code based on 1) negotiated rates between the hospital and commercial insurance for a patient’s diagnosis and 2) the average amount or resources used to treat the patient’s diagnosis

APR-DRG Risk of Mortality (ROM): A classification of a patient’s risk of mortality based on the patient’s APR-DRG assigned after discharge

APR-DRG Severity of Illness (SOI): A classification of a patient's severity of illness based on the patient's APR-DRG assigned after discharge

APR-DRG Weight: The average amount of resources required to treat an individual patient within the given DRG and who has a commercial insurance payor

Cancer Flag: Indicator variable set to "1" if a patient had sepsis prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Chronic Obstructive Pulmonary Disease (COPD) Flag: Indicator variable set to "1" if a patient had COPD prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Coronary Artery Bypass Grafting (CABG) Flag: Indicator variable set to "1" if a patient had a CABG surgical procedure prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Days: The number of days a patient receives treatment in the hospital from the admission date to the discharge date. Also referred to as the length of stay (LOS)

Deaths: An indicator variable set to "1" if the patient passed away during their hospital visit; "0" otherwise

Diabetes: Indicator variable set to "1" if a patient had diabetes prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Diagnosis-related Group (DRG) Code: A code classification assigned to an inpatient during their encounter for payment purposes based on their diagnosis

Discharge Date: The date a patient was discharged from an inpatient unit for a given encounter (*format: mm/dd/yyyy*)

Discharge Medical Doctor (MD) Code: The unique code assigned to the physician who provided care to the patient prior to the patient's discharge

Discharge Medical Doctor (MD) Name: The name of the physician who provided care to the patient prior to the patient's discharge

Discharge Status Code & Name: A description of the location to which the patient was discharged and its corresponding code number, including expiration, discharge home, and discharge to a different facility

Discharge Time: The time a patient was discharged from an inpatient unit for a given encounter (*format: mm/dd/yyyy*)

DRG Weight: The average amount of resources required to treat an individual patient within the given DRG

Emergency Department (ED) Admits: Indicator variable set to "1" for when a patient is admitted to a unit from the Emergency Department; "0" otherwise

Group UWMC Discharge Medicine (Med) Service: The specialty services the patient requires during their stay

Group UWMC Discharge Nursing Unit: The nursing unit from which a patient is discharged during a given encounter

Heart Failure (HF) Flag: Indicator variable set to "1" if a patient had HF prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Home County: The name of the county from which the patient resides

Home ZIP: The zip code from which the patient resides

Hospice Flag: Indicator variable set to "1" if a patients had received hospice care prior to their hospital stay; "0" otherwise

Intensive Care Unit (ICU) Days: The number of days a patient receives intensive and/or critical care treatment in the hospital from the admission date to the discharge date. This includes ICU days for patients who received treatment in the ICU

Lack of Housing: Indicator variable set to "1" if a patient does not have housing; "0" otherwise

Length of Stay (LOS): The duration of time the patient stays in the hospital. For admitted patients, this is the time from admission to external discharge

LOS Expected: The expected length of stay for a patient based on risk models developed by the University HealthSystem Consortium (UHC). Variables contributing to predictors of length of stay include age, sex, race, socioeconomic status, admit source, admit status, severity of illness at the time of admission, co-morbidities present on admission, and other variables specific to certain patient populations

Medical Record Number (MRN): A unique patient identifier assigned to a patient upon each new encounter/admission into the hospital. For patients who have multiple UWMC admissions, the patient is assigned a new medical record number for each encounter

Medicare Fee-for-Service (FFS): An indicator variable set to "1" if the patient participates in the Medicare FFS plan; "0" otherwise. Patients who have a "1" are 65 or older and qualify for social security benefits (*note: no patient encounter included in the Patient Detail Report dataset participated in the Medicare FFS program.*)

Mortality Expected: The probability of mortality calculation for each patient encounter based on risk models developed by the University Health System Consortium (UHC).

Variables that contribute to predictors of mortality include age, sex, race, socioeconomic status, admit source, admit status, risk of mortality at the time of admission, co-morbidities present on admission, and other variables specific to certain populations

Palliative Care Flag: Indicator variable set to "1" if a patients had received palliative care prior to their hospital stay; "0" otherwise

Patient Account Number: A patient identifier assigned to a patient upon their first admission to the hospital. For patients who have multiple UWMC admissions, the patient account number remains the same for each encounter

Payor Group: The patient's health insurance company authorized to provide health insurance for the encounter

Pneumonia (PN) Flag: Indicator variable set to "1" if a patient had PN prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Primary (Prim) Language: The primary language the patient speaks

Principal Diagnosis Code: The code assigned to the principal, or main, condition or diagnosis causing the patient to seek treatment in the hospital

Principal Diagnosis Name: The name of the principal, or main, condition or diagnosis causing the patient to seek treatment in the hospital

Principal Procedure Code: The code assigned to the principal or main, procedure the patient received during their hospital visit

Principle (Prin) Procedure Date: The date a patient had a procedure during their hospital stay

Principal Procedure Name: The name of the principal or main, procedure the patient received during their hospital visit

Principle (Prin) Surgeon Code: The unique code assigned to the surgeon who performed a surgical procedure for a patient who had a procedure during their hospital stay

Principle (Prin) Surgeon Name: The name of the surgeon who performed a surgical procedure for a patient who had a procedure during their hospital stay

Race: Patient's self-identified race

Seattle Cancer Care Alliance (SCCA) Encounter: Indicator variable set to "1" for patients who receive treatment as part of the SCCA; "0" otherwise

Sepsis Flag: Indicator variable set to "1" if a patient had sepsis prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Sex: Patient's self-identified sex

Stroke Flag: Indicator variable set to "1" if a patient had a stroke prior to (ie. reason for hospital visit) or during their hospital stay; "0" otherwise

Total Direct Cost: The total cost of healthcare resources used to provide treatment to patients during an encounter. Direct costs include those cost that can be directly attributed to the care of the patient, such as room charges, lab work, pharmaceuticals, etc

Total Direct Cost Expected: The expected direct cost of care calculated for each patient encounter, based on risk models developed by the University Health System Consortium (UHC). Direct costs include those cost that can be directly attributed to the care of the patient, such as room charges, lab work, pharmaceuticals, etc. Variables that contribute to predictors of direct cost include age, sex, race, socioeconomic status, admit source, admit status, severity of illness at the time of admission, comorbidities present on admission, and other variables specific to certain populations

University Health System Consortium (UHC) Service Line: A standardized classification of services provided to the patient based on patient diagnosis or procedures received identified by UHC