Reducing Intraday Patient Wait Times Through Just-In-Time Bed Assignment

by

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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Abstract

Massachusetts General Hospital (MGH) is the oldest and largest hospital in New England as well as the original and largest teaching hospital of the Harvard Medical School. The neuroscience units experience patient flow issues similar to those observed throughout MGH, including high bed utilization and long intraday patient wait times. This project focuses on the neuroscience units as a microcosm of the hospital.

MGH consistently operates near capacity. Patients from the emergency department, the perioperative environment, intensive care units (ICUs) and other sources compete for beds. The admitting department manages the bed assignment process across MGH. Assignments are often made without access to all relevant information, such as expected admission, surgery and discharge timing. As a result of common procedures, patients are frequently assigned to a bed before they are clinically ready to move.

Our analysis reveals that suboptimal bed assignment and patient transfer processes are among the leading root causes of intraday patient delays. The primary objective of the project is to develop a bed assignment policy to reduce intraday patient wait times. The policy consists of a bed assignment algorithm and enabling bed management processes. To account for patient acuity, the algorithm segments patients by movement (e.g., ED-to-ICU). The target maximum wait for each segment is the acceptable wait length (AWL). The algorithm ranks patients based on their ready times and the AWLs, and assigns beds primarily on a just-in-time (JIT) basis. The enabling bed management processes include small-scale early discharge and early transfer interventions to better align the intraday timing of demand for inpatient beds with available capacity.

A simulation of neuroscience patient flow is used to evaluate different approaches. The model shows that adoption of the JIT policy would increase the percentage of patients who experience bed waits within the AWL for all movement types. Predicted bed waits for patients who require ICU-level care would be 30 minutes or less for 90% of ED patients and 95% of OR patients (improvements from historical baselines of 44% and 91%, respectively). Predicted bed waits for transfers to floor beds would be two hours or less for 81% of ED patients and 93% of OR patients (improvements from historical baselines of 63% and 84%, respectively). The solution significantly reduces intraday patient wait times without a major increase in hospital capacity.

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1 Introduction

This work is part of a larger effort by the MGH – MIT Collaboration to develop predictive models, operational processes and decision support tools for managing inpatient bed resources at the Massachusetts General Hospital (MGH). The adoption of new bed management practices in a large and complex hospital like MGH requires significant effort and carries substantial clinical, operational and financial risks. Consequently, it is critical to thoroughly evaluate new approaches before making policy or process changes.

This project focuses on the neuroscience units at MGH as a microcosm of the hospital. The neuroscience clinical specialties (i.e., neurosurgery and neurology) serve both medical and surgical patients from a variety of admissions sources with a dedicated, 22-bed intensive care unit (ICU) and two inpatient floor units of 32-beds each. The neuroscience units consistently operate near capacity and experience patient flow issues similar by nature to the ones observed throughout MGH.

Patients admitted to the neuroscience clinical specialties often experience long intraday wait times. Various studies measure the negative impacts of long patient wait times for inpatient beds on clinical outcomes. Our analysis reveals that the leading root causes of long intraday patient wait times include suboptimal bed assignments, late intraday discharge timing and delayed intraday transfer timing. The primary objective of this project is to develop a bed assignment policy to reduce intraday patient wait times. The policy consists of a bed assignment algorithm and enabling bed management processes.

This project relies on a simulation of neuroscience patient flow based on historical data to assess the efficacy of several new approaches. In close collaboration with MGH clinicians and administrators, this work addresses three of the root causes of long intraday patient wait times by developing a just-in-time (JIT) bed assignment policy, a small-scale early discharge intervention and a small-scale early transfer intervention. Under the JIT bed assignment policy, patients who are clinically ready to transfer to a particular unit are assigned to beds that become available in that unit on a first-ready, first-assigned basis. The small-scale early discharge intervention aims to discharge one patient from each neuroscience clinical service to home by 10 a.m. on selected days and the small-scale early transfer intervention designs processes to allow the transfer of one neuroscience patient from the neuroscience ICU to the inpatient floors by 11 a.m. on selected days.

A simulation of neuroscience patient flow predicts that a just-in-time bed assignment policy and the new small-scale early discharge and transfer interventions would significantly reduce wait times for all patient movements. These predicted results have motivated a pilot of the small-scale early discharge intervention in the neuroscience units.

The collaborative approach outlined in Section 1.4.2 was critical in finding opportunities to achieve significant improvements by modifying existing processes and in motivating an otherwise very busy group of clinicians and administrations to undertake a pilot program. If newly proposed operational policies prove to be effective in the neuroscience units, the approaches could be extended to more units and other clinical specialties in order to improve patient flow throughout MGH.

1.1 Massachusetts General Hospital

Massachusetts General Hospital (MGH) is the oldest and largest hospital in New England as well as the original and largest teaching hospital of the Harvard Medical School. MGH's mission is to deliver the very best health care in a safe, compassionate environment; to advance that care through innovative research and education; and to improve the health and well-being of the communities served [1]. MGH is regularly ranked among the top hospitals in the United States [2].

MGH consistency operates near capacity. Each year, the 999-bed hospital handles nearly 1.5 million outpatient appointments, records over 100,000 emergency room visits, admits approximately 48,000 inpatients and performs more than 42,000 operations [1]. MGH is also a founding member of Partners HealthCare, an integrated healthcare delivery system, which includes two founding academic medical centers, community hospitals, primary care and specialty physicians, specialty facilities and community health centers. Partners HealthCare is a nonprofit organization offering patient a continuum of coordinated, high-quality and cost-effective care [3].

MGH has a rich history of research and innovation. In 1846, the hospital's operating theater hosted the first demonstrated used of an inhaled anesthetic [4]. Today, MGH conducts the largest hospital-based research program in the nation with an annual budget of more than $786 million [1].

1.2 MGH – MIT Collaboration

The MGH – MIT Collaboration is a research partnership between MGH and the Massachusetts Institute of Technology (MIT), which aims to leverage operations research techniques to improve the system design, quality of care and operational effectiveness of the major systems in the hospital. The partnership formed over eight years ago as the Perioperative Services department at MGH and Professor Retsef Levi of the MIT Sloan School of Management used optimization methods to improve surgical scheduling processes. Several subsequent projects developed (among others) important insights into demand patterns, patient flow dynamics and bed management processes at the hospital. The MGH – MIT Collaboration now includes MGH leaders, MIT faculty, post-doctoral fellows in the Operations Management group at the MIT Sloan School of Management, and graduate students in the MIT Leaders for Global Operations (LGO) program.

1.3 MGH Neurosciences

MGH offers sophisticated diagnostic and therapeutic care in essentially every specialty and subspecialty of medicine and surgery. The neuroscience clinical specialties include the hospital's neurosurgery and neurology departments. The Department of Neurology provides comprehensive consultative services, diagnostic testing and treatment for a broad spectrum of neurological conditions, including diseases of the brain, spinal cord, peripheral nerves and muscles [5]. The Department of Neurosurgery provides a complete range of surgical services for the diagnosis, surgical treatment and rehabilitation of neurologic disorders, performing over 2,500 procedures annually [6].

The neuroscience clinical specialties serve a variety of medical and surgical patient populations. Neuroscience patients are admitted through multiple sources, including the emergency department (ED), emergent and elective surgeries, front door (i.e., scheduled) clinical admissions and transfers from other hospitals. Neuroscience patients are cared by the neuroscience teams primarily in three inpatient units in the Lunder building on MGH's main campus. The intensive care unit (ICU) contains 22 beds on the sixth floor ("Lunder 6 ICU"). The floor care units comprise of 32 beds on the seventh floor ("Lunder 7 floor") and 32 beds on the eighth floor ("Lunder 8 floor"). All beds are located in private, single-patient rooms.

The neuroscience units experience patient flow issues similar to those observed throughout MGH, including high bed utilization and long intraday patient wait times. This project focuses on the neuroscience units at MGH as a microcosm of the hospital.

1.4 Project Overview

1.4.1 Problem Statement

MGH consistently operates near capacity and patients often experience long intraday wait times. Various studies measure the negative impacts of long patient wait times for inpatient beds on clinical outcomes and patient experience. For example, 'ED boarding' (i.e., the practice of holding patients in the ED after admission because no inpatient beds are available) is associated with several negative patient-oriented outcomes, including higher inpatient mortality rates [7]. Further, critical patient outcomes from mean hospital length of stay to mortality rate increase with increasing ED boarding times [7]. Longer wait times are also negatively associated with clinical provider scores of patient satisfaction [8]. Recent research indicates that other aspects of the patient experience, such as confidence in the care provider and perceived quality of care, correlate negatively with longer wait times [8].

Patient queuing in essential units, particularly the ED and the post-anesthesia care units (PACU), can significantly disrupt hospital operations. Overcrowding and delays in the PACU negatively affect surgical patient flow, limit access to the ICU and can even result in cancelled elective procedures. If the ED reaches or exceeds its maximum occupancy, state regulations mandate that clinicians move all admitted patients out of the ED as quickly and safely as possible (ideally within 30 minutes) [9]. In some instances, Massachusetts state policy also requires diverting patients to other hospitals and reporting to government officials [9].

Our analysis reveals that suboptimal bed assignment and patient transfer processes are among the leading root causes of long intraday wait times at MGH. A centralized admitting department manages the bed assignment process across the hospital. Patients from the ED, the perioperative environment, ICUs and other sources compete for beds. Admitting bed managers are often forced to make assignments without access to all relevant information, such as expected admissions as well as surgery and discharge timing. Guidelines for the prioritization of patients are limited and nontransparent. As a result of common procedures, patients are frequently assigned to a bed before they are clinically ready to move into the assigned bed (or have even arrived to the hospital for their surgery). After assignment, patients often continue to wait for additional transfer processing steps, such as handoffs between the respective clinical teams and the physical transport from one location to another.

Patients are most often discharged from the hospital in the late afternoon. This late intraday discharge timing is another significant root cause of long patient wait times. Specifically, the intraday timing of admissions and discharges are misaligned. Like most units throughout the hospital, the neuroscience units consistency experience high utilization rates. In the morning, demand for inpatient floor beds frequently exceeds available supply as clinicians prioritize inpatient care and teaching over discharge processing. Patients who are ready to transfer to inpatient floor beds in the morning thus often wait for beds that occupied by patients who are clinically ready to discharge, but who have not been discharged yet.

Most neuroscience patients who require ICU-level care stabilize in the ICU and then transfer to inpatient floor units for further treatment. Patient transfers from the neuroscience ICU to the neuroscience inpatient floors most often occur in the late afternoon. Patients who are newly admitted to MGH (e.g., from the ED or the OR) are typically prioritized over ICU patients who are transferring internally from the ICU. This results in interday delays as well as late intraday transfer timing. The intraday timing of demand for neuroscience ICU beds and patient transfers from the ICU are misaligned. In the morning, demand for ICU beds frequently exceeds the available supply. Late ICU-to-floor intraday transfer timing is one of the leading root cause of long intraday patient wait times. Ongoing research by the MGH – MIT Collaboration is underway to quantify and understand the widespread transfer delays from ICUs throughout the hospital.

1.4.2 Objective and Approach

The primary goal of this project is to reduce intraday patient wait times by developing more efficient bed assignment policies and bed management processes. We used a collaborative and iterative methodology to develop and evaluate several solution approaches. First, we carefully documented the current state of neuroscience patient flow and inpatient bed management processes. We relied on prior MGH – MIT Collaboration research, historical data and an extensive number of interviews and shadowing days with clinicians and administrators. Next, we assembled a working group of committed practitioners from both neuroscience clinical services, the perioperative and critical care teams, the emergency and admitting departments, and case management. These clinicians and administrators shared insights to explain observations in the historical data and nuances in the current processes. All stakeholders provided potential solution approaches and process improvement suggestions. Our solution approaches are also informed by operations research concepts including lean and supply chain scheduling.

The adoption of new operational practices at MGH requires significant effort and carries substantial risk. Before implementing policy or process changes, we performed data analysis to evaluate hypotheses and MGH clinicians shared essential feasibility considerations. In particular, we used a model of neuroscience patient flow[1] based on historical data to assess the efficacy of several new approaches. We used several performance metrics to characterize and evaluate patient flow, including patient wait times, the percentage of patients who experience waits within certain durations, and the cumulative *delay unrelated to bed availability* (DUBA)[2]. The simulation results revealed the system-wide impacts of each new potential operational intervention. When considering the entire patient flow system, some process improvements had clear, positive effects while other potential policies presented mixed consequences. The predicted results of the data-driven simulation provided context to facilitate discussion between hospital leaders about the inherent tradeoffs in a complex inpatient environment like MGH.

We followed this process iteratively by revisiting each step as we revealed insights and developed solutions. After the simulation of a potential policy, the working group provided feedback on the results and frequently refined process details and developed additional new ideas. The perspectives of the committed MGH leaders enriched our research throughout this project. The most promising solution approaches are a just-in-time (JIT) bed assignment policy, a small-scale early discharge intervention and a small-scale early transfer intervention.

Just-In-Time Bed Assignment Policy

This work develops a just-in-time (JIT) bed assignment policy where patients who are clinically ready to transfer to a particular unit are assigned to beds that become available in that unit on a first-ready, first-assigned basis. Patients are segmented by *movement type* (e.g., ED-to-ICU) and

[1] For a comprehensive discussion of the development of the simulation model, see: J. Hiltrop, *Modeling Neuroscience Patient Flow and Inpatient Bed Management*. 2014.
[2] Section 3.3 defines each patient flow performance in further detail.

an *acceptable wait length* (AWL) defines the target maximum wait length for each segment[3]. To account for relative priorities among segments, the algorithm ranks patients based on their ready times and the AWLs. The JIT policy permits early bed assignments (i.e., assignments before the patient is clinically ready to transfer), but only when patients' imminent readiness can be predicted with very high certainty. New processes enable the JIT bed assignment policy for each patient movement type.

Small-Scale Early Discharge Intervention

This project develops a small-scale early discharge intervention to address the misalignment between the intraday timing of floor discharges and the demand for floor beds. In the intervention, the neurosurgery and neurology teams each aim to discharge one patient from the floor care units before 10 a.m. each Tuesday through Saturday. Both clinical services focus on patients who will be discharged directly home. Clinicians identify candidate patients early in the morning on the day before the potential early morning discharge. The clinicians then use a new checklist that specifies the discharge processing tasks to be completed for the target patients on the day before discharge. The intervention relies on clear accountability for the execution of the discharge processing tasks, and it will be a valuable vehicle for identifying bottlenecks that limit early intraday discharges. New processes enable the small-scale early discharge intervention for each neuroscience clinical service.

Small-Scale Early Transfer Intervention

This work also develops a small-scale early transfer intervention to improve the intraday alignment between the timing of patient transfers from the ICU and demand for neuroscience

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[3] Table 3 in Section 3.3.2 lists the established acceptable wait lengths (AWLs) by movement type. For example, for ED-to-ICU and OR-to-ICU movements, the AWL is 30 minutes. For ED-to-Floor and OR-to-Floor movements, the AWL is two hours.

ICU beds. This intervention depends on the small-scale early discharge intervention. In the new bed management process, the neuroscience critical care team transfers one patient from the neuroscience ICU to an available neuroscience inpatient floor unit before 11 a.m. every Tuesday through Saturday. Critical care clinicians identify candidate patients early in the morning on the day before the potential early morning transfer. The intervention requires efficient communication between the neuroscience critical care and inpatient floor care clinical teams, and it will be a valuable vehicle for identifying challenges in achieving continuity of care between the two units. New processes enable the small-scale early transfer intervention for both neuroscience clinical services.

1.4.3 Predicted Results

This work uses a simulation model of neuroscience patient flow to evaluate the efficacy of the solution approaches. Prior MGH – MIT Collaboration research validated the model against historical patient movement data. The distributions of patient wait times in the current state simulation are not statistically different from their true historical distributions [10].

This work uses the model to predict the impact of several new policies. The simulation shows that the new bed assignment policy and the small-scale early discharge and transfer interventions would reduce wait times for all patient movements. This project defines the *bed wait* as one component of the total patient wait[4]. The bed wait begins once a patient is clinically ready to move and ends when a patient is assigned to a ready (i.e., available and clean) bed. The predicted bed waits for patients who require ICU-level care would be 30 minutes or less (i.e., the desired AWL) for 90.4%[5] of ED patients and 94.9%[6] of OR patients (improvements from historical

[4] Section 3.3.1 explains how this project measures patient movements in full detail.
[5] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=804.
[6] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=1,571.

baselines of 43.9%[7] and 91.2%[8], respectively). Bed waits for transfers to floor beds would be two hours or less (i.e., the desired AWL) for 80.8%[9] of ED patients and 92.8%[10] of OR patients (improvements from historical baselines of 62.7%[11] and 83.8%[12], respectively). These predicted results have motivated a pilot of the small-scale early discharge intervention in the neuroscience units at MGH. If new approaches prove to be effective in the neuroscience units, the policies could be extended to more units and other clinical specialties in order to improve patient flow throughout MGH.

1.4.4 Thesis Outline

This thesis consists of eight chapters. Chapter 2 reviews relevant research findings, including prior work by the MGH – MIT Collaboration. Chapter 3 provides key preliminary information. It lists the key data sources referenced throughout this work (Section 3.1), provides an overview of neuroscience patient flow (Section 3.2), and introduces several performance metrics to characterize and evaluate patient flow (Section 3.3). Chapter 4 begins with a summary of the key current state challenges and the leading root causes of long intraday patient wait times (Section 4.1). Next, it provides detailed descriptions of the bed assignment and patient transfer processes (Section 4.2), the neuroscience inpatient floor discharge processes (Section 4.3), and the neuroscience inpatient floor transfer processes (Section 4.4). Section 4.1 is an overview of the key elements of Section 4.2, Section 4.3 and Section 4.4. Chapter 5 describes the key elements of the simulation of neuroscience patient flow. It provides an overview of the simulation model (Section 5.1) and summarizes how the model uses key input data (Section 5.2). Lastly, it

[7] Sources: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=390.
[8] Sources: Patcom, Periop Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=1,510.
[9] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,815.
[10] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,835.
[11] Sources: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=1,409.
[12] Sources: Patcom, Periop Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=1,658.

explains how the model was validated against historical data (Section 5.3). Chapter 6 begins with a summary of the key benefits and the outstanding challenges of the solution approaches (Section 6.1). Next, it provides detailed descriptions of the just-in-time bed assignment policy (Section 6.2), the small-scale early discharge intervention (Section 6.3) and the small-scale early transfer intervention (Section 6.4). Section 6.1 is an overview of the key elements of Section 6.2, Section 6.3 and Section 6.4. Chapter 7 presents the predicted results of the neuroscience patient flow simulation under the conditions outlined in these solution approaches. Section 7.1 provides an overview of the predicted results and Section 7.2 discusses the predicted results in further detail by patient movement type. Finally, Chapter 8 includes a few final comments. It summarizes of the key results of this work (Section 8.1) and presents several opportunities for further study (Section 8.2).

For a quick reading of this thesis, we recommend the following critical path: Chapter 0, Section 4.1, Chapter 5, Section 6.1, Section 7.1 and Chapter 8. This path provides background on the scale and nature of the problem, the methods we used in this work, the primary solution approaches, the predicted results and the consequences for MGH.

2 Literature Review

Several researchers have investigated patient flow dynamics and inpatient bed management policies in the healthcare sector. Pinedo (2010) comments on the significance of the problem, explaining that healthcare productivity is to a great extent based on the proper planning and scheduling of all the actives involved [11]. He addresses the underlying randomness that is at the heart of most scheduling and assignment problems by presenting a set packing formulation, a stochastic approach and a constraint programming approach. Harper et al. (2002) characterize the internal dynamics of a hospital as a complex non-linear system. They recommend evaluating bed management policies within an environment of uncertainty, variability and limited resources, such as simulation model of hospital bed capacities [12]. Bachouch et al. (2012) investigate the management of hospital bed planning and propose a decision support tool based on an integer linear program [13]. Thomas et al. (2013) use a mixed-integer goal-programming approach to develop a prototype bed-assignment solution for the Mount Sinai Medical Center in New York. The solution periodically recommends bed-patient assignments based on analytical decision support tools with embedded mathematical models [14].

Previous MGH – MIT Collaboration research projects developed valuable insights into patient flow dynamics and operational processes at MGH. Price (2011) performs a system-level analysis of surgical patient flow and presents several opportunities for performance improvements. She uses a discrete event simulation model to more effectively characterize and manage the stochastic demand for non-elective surgical cases [15]. Our work is informed by Price's insights into surgical patient flow and constructs like the percentage of patients exceeding the maximum recommend wait time based.

Range (2013) extends Price's research by modelling various surgery scheduling rules to measure their impact on patient flow in each step of the perioperative process [16]. She shows that the inpatient floors are the biggest bottleneck in the system and that alignment between the timing of demand and the timing of discharges is critical to patient flow. Our work builds on these insights.

Christensen (2012) studies transfer delays for patients in the surgical intensive care unit (SICU) at MGH. He models the SICU and its six primary downstream units in a detailed discrete event simulation. He finds that one of the most promising solution approaches is transferring patients as soon as possible after medical clearance, eliminating the current practice of waiting to see if other patients might need downstream beds [17]. This recommendation informs our primary solution approach where patients who are clinically ready to transfer to a particular unit are assigned to beds that become available in that unit on a first-ready, first-assigned basis.

Most important, Hiltrop (2014) first investigates neuroscience patient flow and neuroscience bed management policies at MGH. He develops and validates the data-driven simulation of neuroscience patient flow that is used throughout this project [10]. Hiltrop also quantifies the effectiveness of multiple process interventions to improve neuroscience patient flow, including a preliminary just-in-time bed assignment intervention. He recommends prioritizing further research focused into a detailed just-in-time bed assignment algorithm and enabling processes that, in part, instigated this project.

The just-in-time approach used throughout this work is a fundamental principle of lean operations. Beckman and Rosenfield explain how the lean movement began with the development of just-in-time production and inventory management systems in the automotive and electronics sectors [18]. The primary goals of lean operations are to reduce waste and to make systems as efficient and consistent as possible. Our solution approaches rely on many principles of lean operations, such as efforts to reduce variability and signals to trigger downstream process steps.

3 Preliminaries

This chapter begins with a summary of the key data sources referenced throughout this work (Section 3.1). It provides an overview of neuroscience patient flow (Section 3.2) and introduces several performance metrics to characterize and evaluate patient flow (Section 3.3). Section 3.3.1 explains how patient movements are measured, Section 3.3.2 introduces *acceptable wait lengths* (AWLs) and Section 3.3.3 defines *delay unrelated to bed availability* (DUBA).

3.1 Data Sources

This work uses historical data to characterize processes, quantify patient flow dynamics, and simulate and evaluate operational policies. This section defines the key data sources.

Patcom is the primary data source for patient movements between all inpatient care units at MGH. This includes the neuroscience ICU (i.e., Lunder 6), the neuroscience inpatient floor care units (i.e., Lunder 7 and Lunder 8), overflow ICUs and overflow inpatient floor units. Patcom also includes several important patient characteristics such as each patient's clinical service.

The Data for Quality (D4Q) data source is a special manifestation of the general Patcom data. MGH administrators maintain the D4Q data specifically to monitor and analyze various quality metrics. For each patient, the D4Q data are organized by hospital visit. This work uses the discharge location and discharge disposition data elements from D4Q.

Data from the Emergency Department Information System ("EDIS") serve as the primary source of information about each emergency room visit at MGH. EDIS captures patient arrival and departure details, as well as timing data for several intermediate steps such as bed requests, bed assignments, and clinical handoffs.

Perioperative case data provides information about surgical patients' movements to and from operating rooms as well as their preoperative and postoperative care. For each surgical patient, the data includes preoperative, OR and postoperative arrival and departure times. The perioperative case data also includes patient ready-to-depart times, although this particular field is somewhat unreliable (Section 4.2.4 explains how the timely input of this timestamp often does not occur in the current state bed management process).

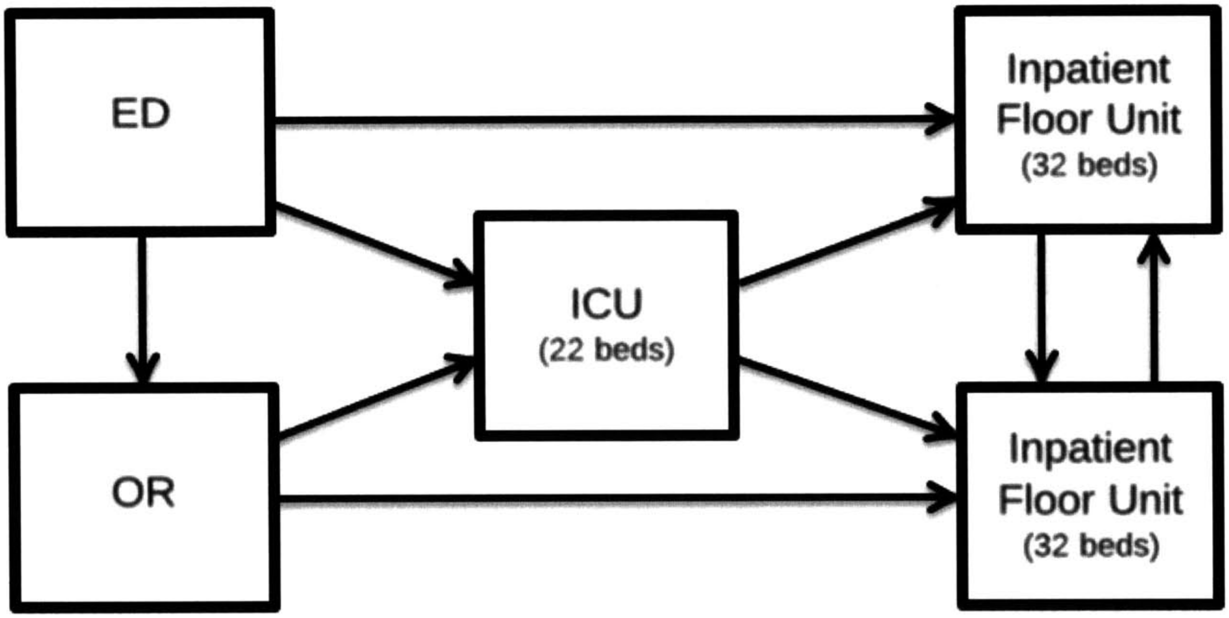
Lastly, "CBEDs" is a bed management information system that contains detailed bed cleaning data. The CBEDs data are organized by bed cleaning events and include information about the timing of bed cleanings throughout MGH. Section 3.3.1 explains how this work uses bed clean time as an indication of bed readiness for patient movement measurements.

3.2 Overview of Neuroscience Patient Flow

This section is an overview of neuroscience patient flow at MGH. With one dedicated ICU and two inpatient floor units, the neuroscience clinical specialties serve both medical and surgical patients from virtually all admissions sources – primarily the emergency department (51.3%[13]) and the perioperative environment (29.2%[14]). Other sources of neuroscience admissions include front door (i.e., scheduled) clinical admissions and transfers from other hospitals. Figure 1 is an overview of the most common patient flow pathways for neuroscience patients at MGH.

[13] Sources: Patcom, EDIS. Timeframe: September 1, 2011 to June 30, 2013. N=5,103.

[14] Sources: Patcom, Perioperative Case Data. Includes elective and emergent procedures. Timeframe: September 1, 2011 to June 30, 2013. N=2,900.



Notes: Other origin units include front door (i.e., scheduled) clinical admissions and transfers from other hospitals. Other destination units include overflow ICUs and overflow inpatient floor units.

Figure 1: Overview of Neuroscience Patient Flow Pathways

Most neuroscience patients begin treatment in the ED or the perioperative environment. After admission and evaluation in the ED, most ED patients transfer to an inpatient floor unit for further recovery. The more acute ED patients transfer to the intensive care unit; a few patients move from the ED directly to the OR for emergent surgeries. After successful surgical procedures, most OR patients transfer from the perioperative environment to an inpatient floor unit for further recovery. The more acute OR patients transfer to the intensive care unit. After stabilization in the ICU, most neuroscience patients transfer to inpatient floor units for further treatment. Depending on clinical needs, patients can move between inpatient floor units or sometimes even from a floor unit to the perioperative environment or to the ICU. Finally, most neuroscience patients are discharged from inpatient floor units to a variety of discharge destinations. Table 1 summarizes the most common patient flow pathways for neuroscience patients at MGH.

		Destination Unit					
		ED	OR	ICU	Floor	Other	Discharge
Origin Unit	ED	-	6.4%	22.3%	54.6%	16.7%	-
	OR	-	-	37.6%	44.2%	17.4%	0.8%
	ICU	-	14.6%	-	68.5%	4.1%	12.8%
	Floor	-	12.1%	2.2%	-	1.5%	84.2%

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: September 1, 2011 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. 'Other' includes overflow ICUs and overflow inpatient floor units. Transfers to a different bed within the same unit and patient expirations are excluded. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). The percentages are the portion of patients from each origin unit who transfer to a given destination unit. For example, 6.4% of neuroscience transfers from the ED are to the OR. Total number of transfers from each origin unit: N=5,103 (ED); N=5,315 (OR); N=3,702 (ICU); N=10,066 (Floor).

Table 1: Distribution of Neuroscience Patient Flow Pathways

The neuroscience ICU and inpatient floor units experience consistently high occupancy rates. On an average day, the neurosciences admit seven patients via the ED and eight patients via the OR. Usually two of the ED patients will transfer to the neuroscience ICU and five will transfer to inpatient floor units. On average, three neurosurgical patients will require stabilization in the ICU and five will move from the perioperative environment to an inpatient floor for further recovery. In the ICU, there are typically patients that are clinically ready to transfer to an inpatient floor unit due to the progress of their recovery. However, patients who are newly admitted to MGH (e.g., from the ED or the OR) are typically prioritized over ICU patients who are transferring internally. After the inpatient floors accommodate all transfers from the ED and the OR, ICU patients move to available inpatient floor beds. On an average day, four neuroscience patients transfer from the ICU to an inpatient floor unit. When there is more demand for beds than available capacity, some neuroscience patients move to other 'overflow' ICUs and inpatient floor units. Additional capacity is created as patients fully recover and are discharged from MGH. On average, 13 patients are discharged from the neuroscience inpatient floors each day and an additional five patients are discharged from the neuroscience ICU each week. Table 2 lists the average number of patient transfers that occur each day for each movement type.

		Destination Unit					
		ED	OR	ICU	Floor	Other	Discharge
Origin Unit	ED	-	0.5	1.7	4.2	1.3	-
	OR	-	-	3.0	3.5	1.4	0.1
	ICU	-	0.8	-	3.8	0.2	0.7
	Floor	-	1.8	0.3	-	0.2	12.7

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: September 1, 2011 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. 'Other' includes overflow ICUs and overflow inpatient floor units. Transfers to a different bed within the same unit and patient expirations are excluded. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). Number of transfers from origin unit: N=5,103 (ED); N=5,315 (OR); N=3,702 (ICU); N=10,066 (Floor).

Table 2: Average Daily Neuroscience Patient Movements

3.3 Patient Flow Performance Metrics

This section introduces several performance metrics to characterize and evaluate patient flow. It is important to note the distinction between interday (i.e., multiple day) delays and intraday delays. Interday delays at MGH are typically the result of chronic capacity issues in particular units, such as inpatient floor care units. In the neurosciences, the patients who most often experience interday delays are ICU patients. Bed requests from newly admitted patients (e.g., patients transferring from the ED or OR) are generally are prioritized over those from ICU patients because the ICU patients already have a bed at MGH. On the other hand, intraday delays at MGH are typically the result of suboptimal bed assignment policies and temporary capacity issues at peak hours during a given day (see Chapter 4).

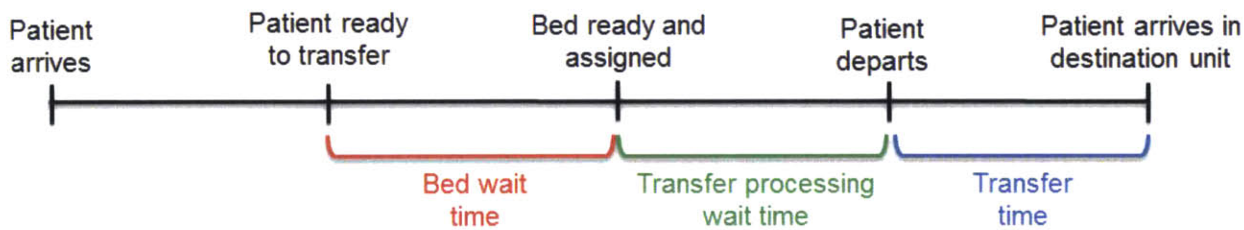
Intraday delays can cause interday delays. For example, a patient who experiences a long intraday delay might arrive to their destination unit late in the evening and not begin specialized treatment until the following morning. Without a long intraday delay, this patient could have arrived to their destination unit early in the morning and in time to begin specialized treatment on the day of their transfer. Thus, the intraday delays also contributed to interday delays. Section 1.4.1 explains how both interday and intraday delays negatively affect clinical outcomes and patient experience, and can significantly disrupt hospital operations. This work focuses on reducing intraday delays because these delays directly depend on operational bed management policies.

Section 3.3.1 explains how patient movements are measured, Section 3.3.2 introduces *acceptable wait lengths* (AWLs) and Section 3.3.3 defines *delay unrelated to bed availability* (DUBA).

3.3.1 Measuring Patient Movements

This work uses the predicted bed wait times as the primary performance metric to compare the results of simulation scenarios to historical bed wait times. This project develops interventions specifically targeting bed wait reductions because operational bed management policies directly affect the bed wait times.

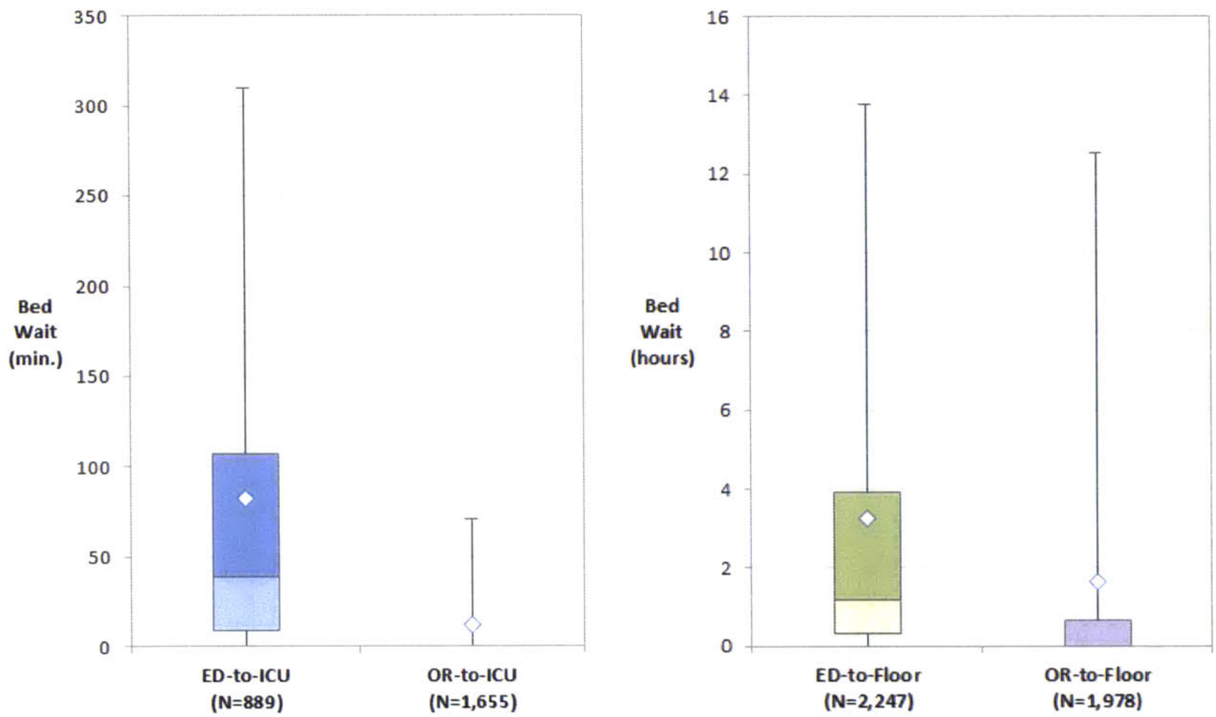
The total patient movement time between units includes the duration from when a patient is ready to transfer until the patient arrives in the destination unit. Figure 2 illustrates how this project defines and measures three main components of patient movement timing.



Notes: The historical data source and elements for the above process steps vary based on the origin and destination units. See Section 3.1 for a definition of the key data sources and Section 5.2 for a summary of how the simulation uses key data elements from each source.

Figure 2: Measuring Patient Movements

The bed wait time begins once a patient is clinically ready to move and ends when a patient is assigned to a ready (i.e., available and clean) bed. If a patient's destination bed is ready and assigned before the patient is ready to transfer, then the bed wait time is zero. Figure 3 summarizes the historical bed wait times by patient movement type.



Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=889 (ED-to-ICU); N=1,655 (OR-to-ICU); N=2,247 (ED-to-Floor); N=1,978 (OR-to-Floor). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

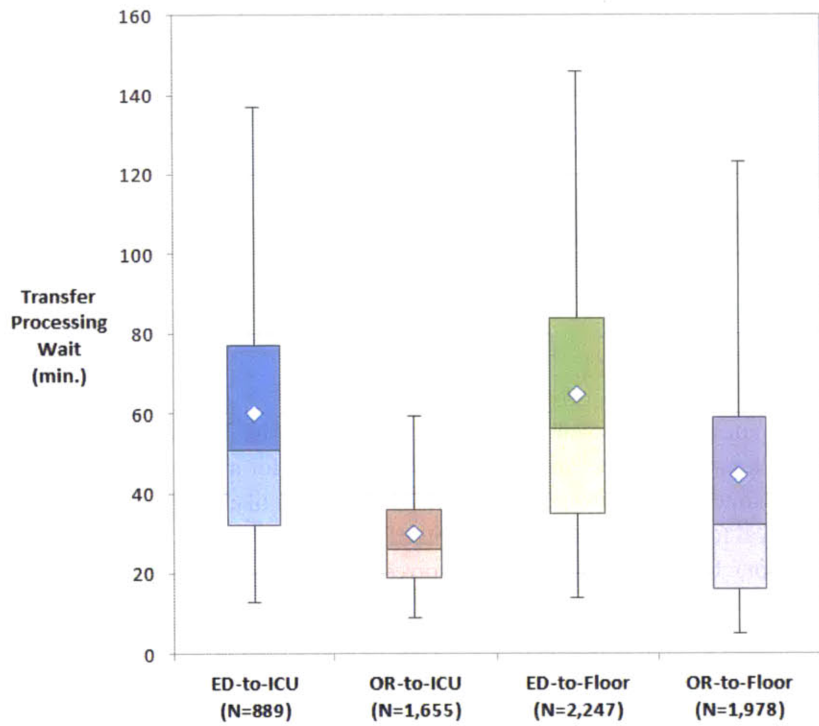
Figure 3: Historical Bed Wait Times by Patient Movement

The bed wait time depends on both bed availability and bed management policies. Patients that transfer from the ED wait much longer than patients that transfer from the perioperative environment for both ICU and inpatient floor beds. For ED patients who require ICU-level care, the average historical bed wait is over 80 minutes and more than 56.1%[15] of patients wait more than 30 minutes. For transfers from the ED to the inpatient floors, the average historical bed wait

[15] Source: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=499.

is over three hours and at the high end of the distribution, over 11.3%[16] of patients wait more than ten hours.

The transfer processing wait begins once a patient is ready to transfer, the patient is assigned to a bed and the bed is ready (i.e., available and clean). The transfer processing wait ends when the patient actually departs the origin unit. Figure 4 presents the historical transfer processing wait times by patient movement type.



Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=889 (ED-to-ICU); N=1,655 (OR-to-ICU); N=2,247 (ED-to-Floor); N=1,978 (OR-to-Floor). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 4: Historical Transfer Processing Wait Times by Patient Movement

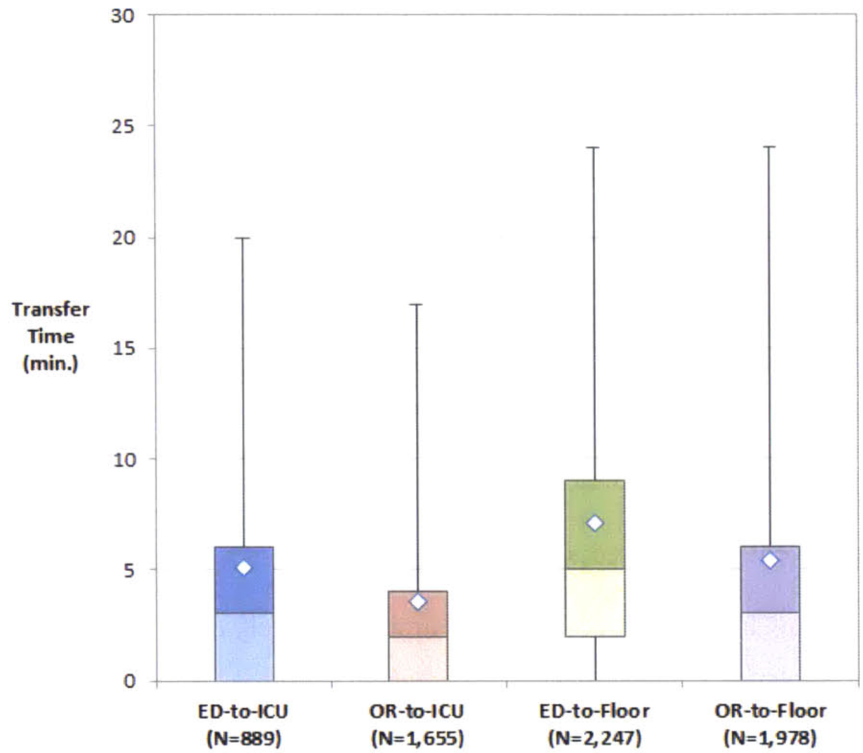
[16] Source: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=254.

The transfer processing wait time includes the time it takes to complete nursing handoffs and to coordinate with MGH transporters. The distributions of transferring processing wait times vary by patient movement, with most patients waiting between 30 and 90 minutes. At the high end of the distribution, over 7.3%[17] of ED-to-ICU transfers and 9.4%[18] of ED-to-Floor transfers include transfer processing waits of more than two hours.

In the simulation of neuroscience patient flow, the transfer processing wait times are calculated from historical data and held constant across all simulation scenarios, including scenarios corresponding to interventions that reduce bed wait times. This is a conservative approach. Section 6.2 explains how transfer processing wait times will likely decrease as interventions improve bed management policies (e.g., by enabling nurses in the ED and in inpatient floor units to more reliably predict when they will need to execute the required nursing handoffs).

Finally, the transfer time captures the amount of time between the actual departure from the origin unit and the arrival to the destination unit. Figure 5 resents the historical transfer times by patient movement type.

[17] Source: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=65.
[18] Source: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=213.



Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=889 (ED-to-ICU); N=1,655 (OR-to-ICU); N=2,247 (ED-to-Floor); N=1,978 (OR-to-Floor). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 5: Historical Transfer Times by Patient Movement

For each movement, over 75% of all patients experience transfer times of less than ten minutes and over 95% of all patients experience transfer times of less than 25 minutes. If patients were in transit for more than 60 minutes after departure from either the ED or the perioperative environment, then the historical data is likely inaccurate or incomplete. These patients likely received care in an unknown intermediate unit before arrival to their destination unit. Thus, the simulation of neuroscience patient flow excludes these patients from all wait time calculations.

3.3.2 Acceptable Wait Lengths

This project segments patients by movement type (e.g., ED-to-ICU). For each movement, MGH clinicians establish an acceptable wait length (AWL), which defines the target maximum patient wait length. Table 3 lists the established AWLs by movement type.

Patient Movement	Acceptable Wait Length
ED-to-ICU	30 min
OR-to-ICU	30 min
Other-to-ICU	8 h
ED-to-Floor	2 h
OR-to-Floor	2 h
ICU-to-Floor	N/A[i]
Other-to-Floor	8 h

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. 'Other' includes overflow ICUs, overflow inpatient floor units, front door (i.e., scheduled) clinical admissions and transfers from other hospitals. Patient movements to other modules in the simulation (i.e., OR, ED and overflow units) are executed at the historical transfer times; the patients are not ranked because these units are not explicitly capacity constrained.

[i] An AWL for ICU-to-Floor transfers is not applicable. Instead, the simulation executes these patient movements at the end of the day (i.e., after all other pending transfers to floor units are processed) on the day of historical transfer, given available floor capacity. This effectively deprioritizes ICU patients relative to all other patients competing for floor beds, which reflects MGH's current and desired protocol.

Table 3: Acceptable Wait Lengths by Movement Type

Section 6.2 explains how one solution approach uses the AWLs to account for relative priorities among different patient segments. The percentage of patients who experience bed waits within the AWL for each movement type is the foremost patient flow performance metric

3.3.3 Delay Unrelated to Bed Availability

Delay unrelated to bed availability (DUBA) is the bed wait time incurred by patients in their origin unit while clean beds are available in their destination units. Prior MGH – MIT research developed DUBA specifically to track bed wait times that are unrelated to bed capacity constraints at MGH[19]. Cumulative DUBA is the sum of all DUBA incurred by patients during the timeframe, or the total amount of time that patients wait for beds while suitable beds are available. Table 4 lists the historical cumulative DUBA by unit.

Scenario	Neuroscience ICU		Neuroscience Floors	
	DUBA (h)	DUBA (days)	DUBA (h)	DUBA (days)
Historical	1,147	47.8	6,495	270.6

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Neuroscience ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Neuroscience Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. Delay unrelated to bed availability (DUBA) is the bed wait time incurred by patients in their origin unit while clean beds are available in their destination units. Cumulative DUBA is the sum of all DUBA incurred by patients during the timeframe.

Table 4: Historical Cumulative Delay Unrelated to Bed Availability by Unit

DUBA is a useful performance metric because it quantifies unused capacity by directly measuring the delays resulting from suboptimal bed assignment polices.

[19] For a comprehensive discussion of the development of the DUBA metric, see: J. Hiltrop, *Modeling Neuroscience Patient Flow and Inpatient Bed Management*. 2014.

4 Current State Analysis

This chapter begins with a summary of the key current state challenges and the leading root causes of long intraday patient wait times (Section 4.1). Next, it provides detailed descriptions of the bed assignment and patient transfer processes (Section 4.2), the neuroscience inpatient floor discharge processes (Section 4.3) and the neuroscience inpatient floor transfer processes (Section 4.4) at the hospital. Section 4.1 is an overview of the key elements of Section 4.2, Section 4.3 and Section 4.4. The insights from this analysis inform the solution approaches developed in Chapter 6.

4.1 Summary of Key Challenges

Bed Assignment and Patient Transfer Process

Suboptimal bed assignments are one of the leading causes of long intraday wait times at MGH. Admitting bed managers currently assign patients to beds based on information from bed requests as well as other clinical and administrative sources (e.g., daily surgery schedule). Frequently, admitting bed managers make assignments without access to all relevant information, such as expected discharge timing and evolving surgical plans (e.g., rescheduling to accommodate variable procedure durations and emergent cases). More importantly, bed requests do not uniformly indicate that a patient is ready to move, so admitting lacks insight into many patients' true clinical readiness to transfer.

As a result of common practices, patients are often assigned to a bed before they are ready to move. Surgical patients are frequently assigned beds based on a static snapshot of the surgery schedule and assignment decisions are usually made early in the morning. In fact, bed assignments are often made before the surgical patients have arrived to the hospital on the day of their procedures. These premature bed assignments imply an implicit prioritization of surgical patients over other patients. Note that this implied prioritization is not based on patients' clinical readiness to transfer.

Admitting bed managers follow general protocols to prioritize bed assignments among patients admitted to the same clinical service and who need the same level of care. For example, patients who are newly admitted to MGH are generally prioritized over patients who are transferring internally. However, deviations from the protocols frequently occur based on clinical acuity, inpatient unit occupancy, personnel and other case-by-case considerations. Admitting bed managers often negotiate particular placements with clinical staff such as critical care nursing supervisors and inpatient unit resource nurses. Overall, current prioritization guidelines for bed assignment decisions are limited, nontransparent and not widely recognized throughout the hospital.

Decision-making authority in the bed management process is highly decentralized. Admitting bed managers are responsible for assigning admitted patients to inpatient units based on their hospital-wide view of demand and capacity constraints. Yet once a bed manager determines the appropriate inpatient unit, he cannot make the final room or bed assignments. Resource nurses in each inpatient unit are responsible for assigning inbound patients to rooms and beds. The criteria that resource nurses make these decision based on are not standard across units and admitting bed managers occasionally feel that the decisions are not made in as timely of a manner as possible.

Section 6.2 develops a just-in-time (JIT) bed assignment policy, which addresses many of these challenges.

Neuroscience Inpatient Floor Discharge Process

Our analysis reveals that late intraday discharge timing is one of the leading causes of long intraday patient wait times. Clinicians and administrators perform a number of tasks to discharge a patient from the neuroscience inpatient floor units. Throughout the day, operations assistants ('OAs') inform the admitting bed managers of new discharge timing information.

Most neuroscience patients treated at MGH are discharged from the neuroscience inpatient floor units. These patients are discharged to a variety of destinations. Most go directly home with a discharge disposition of 'Home or Self Care' or 'Home Health Services'. The distribution of discharge dispositions does not vary substantially between the neurosurgery and neurology clinical services. This project focuses on neuroscience patients that are discharged from the neuroscience inpatient floor units (i.e., Lunder 7 and Lunder 8) directly to home. Most neuroscience patients (84.2%[20]) are discharged from the inpatient floor units. Of all discharge destinations, home is the most common (71.5%[21]) for neuroscience patients. The discharge process is also simpler for discharges to home as clinicians and administrators do not need to spend time coordinating with other care facilities.

On a typical day, four or five neurosurgery patients and four or five neurology patients are discharged from the neuroscience inpatient floors to home. These patients are generally discharged in the afternoon as current clinical processes prioritize inpatient care and teaching early in the morning. For both neuroscience clinical services, the average discharge time from the neuroscience inpatient floors to home is after 2 p.m. and less than 3% of all patients are discharged before 10 a.m. Further, the number of days where at least one neuroscience patient is

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[20] Source: Patcom, D4Q. Timeframe: September 1, 2011 to June 30, 2013. N=8,475.
[21] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=4,785.

discharged early in the morning is small too. If only considering the days when at least one discharge from the floors to home takes place, less than 10% of the first daily discharges for both neuroscience clinical services occur before 10 a.m.

Overall, the intraday timing of neuroscience inpatient floor admissions and discharges are misaligned. In the morning, demand for beds frequently exceeds available supply. Prior MGH – MIT Collaboration research shows that patients experience late intraday discharges independent of their clinical service and of their discharge destination [10]. This implies that capacity constraints at non-home locations like rehabilitation and long-term care hospitals are not the primary driver of late intraday discharge timing. Instead, internal MGH processes could significantly influence the distribution of discharges times.

Section 6.3 develops a small-scale early discharge intervention to better align the intraday timing of floor discharges with the timing of demand for floor beds. The intervention relies on clear accountability for the execution of the discharge processing tasks, and it will be a valuable vehicle for identifying bottlenecks that limit early intraday discharges.

Neuroscience Inpatient Floor Transfer Process

Our analysis also shows that delayed intraday transfer timing is another root cause of long intraday patient wait times. Clinicians and administrators perform several tasks to transfer a patient from the neuroscience ICU to a neuroscience inpatient floor unit. For example, ICU clinicians participate in a number of daily meetings, which inform their approach to patient transfer decisions. Throughout the day, operations assistants in the neuroscience ICU also communicate expected transfer timing to the admitting bed mangers.

Neuroscience patients who require ICU-level care eventually transfer from the ICU to a variety of other inpatient units. This project focuses on neuroscience ICU patients who transfer directly to the neuroscience inpatient floor units (i.e., Lunder 7 and Lunder 8). Of all ICU transfers, this captures the largest (78.6%[22]) by destination unit.

On a typical day, two or three neurosurgery patients and one or two neurology patients transfer from the neuroscience ICU to the neuroscience floors. These patients generally transfer in the afternoon because newly admitted patients (e.g., from the ED or the OR) who require floor-level care are normally prioritized over ICU patients who are clinically ready to transfer to an inpatient floor care unit. For both neuroscience clinical services, the average transfer time from the neuroscience ICU to the floor units is after 3:30 p.m. and less than 10% of all patients transfer before 11 a.m. Further, the number of days where at least one ICU patient transfers early in the morning is small too. If one considers only the days when at least one transfer from the neuroscience ICU to the floors takes place, about 21.2%[23] of the first daily neurosurgery transfers and 7.3%[24] of the first daily neurology transfers occur before 11 a.m.

Overall, the intraday timing of demand for neuroscience ICU beds and patient transfers from the ICU are misaligned. In the morning, demand for ICU beds frequently exceeds available supply. Neuroscience ICU patients who are ready to move to an inpatient floor unit usually transfer late in the day because newly admitted patients (e.g., from the ED or the OR) who require floor-level care are typically prioritized over the ICU patients.

[22] Source: Patcom, D4Q, Perioperative Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=2,536.
[23] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=103.
[24] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=32

Section 6.4 develops a small-scale early transfer intervention to improve the intraday alignment between the timing of patient transfers from the ICU and demand for neuroscience ICU beds. The intervention requires efficient communication between the neuroscience critical care and inpatient floor care clinical teams, and it will be a valuable vehicle for identifying challenges in achieving continuity of care between the two units.

4.2 Bed Assignment and Patient Transfer Processes

The admitting department manages the bed assignment process throughout the hospital. Patients from the ED, the OR, ICUs and other sources compete for inpatient beds. Admitting bed managers assign patients to beds based on requests and other information from clinicians and administrators. Bed managers follow general protocols to prioritize bed assignments among patients admitted to the same clinical service (e.g., neurology), who require the same level of care (i.e., ICU vs. floor). For example, newly admitted patients generally are prioritized over patients who are transferring internally because the internal transfers already have a bed in another unit at MGH. Deviations from the prioritization guidelines occur based on clinical acuity and inpatient unit occupancy. Detailed bed assignment and patient transfer processes vary based on origin and destination unit.

4.2.1 ED-to-ICU Transfers

MGH clinicians generally prioritize ED patients that require ICU-level care based on their arrival time at the hospital. The attending physician in the ED determines if a patient requires admission as well as what level of care is necessary. The attending physician then places an electronic bed request using the Emergency Department Information System ("EDIS") while the ED resident physician ('resident') notifies the critical care nursing supervisor of the inbound ED patient. If ICU bed shortfalls are expected, the critical care nursing supervisor leads the resolution of capacity issues in collaboration with ICU resource nurses and clinicians from the ED and the perioperative services. The critical care nursing supervisor and ICU resource nurses also determine the final ICU room and bed assignments. As decisions are made throughout the day, the critical care nursing supervisor informs the admitting bed managers of the final ICU bed assignments, while the ICU resource nurses inform the ICU operations assistants ('OAs') of the final ICU bed assignments. The bed managers and OAs execute the unit and bed assignments in the Admissions, Discharges and Transfers (ADT) module of Epic, MGH's inpatient electronic health record (EHR) system. Once the ED patient is ready to transfer, the ED nurse informs the responsible ICU bedside nurse about the condition of the patient. The coordination of this nursing handoff takes time and can cause delays. After the nursing handoff is complete, the patient is transported from the ED to the ICU and the ICU OA records the patient's arrival time in Epic ADT. Figure 18 in Appendix A illustrates the current state ED-to-ICU bed assignment and patient transfer process.

One challenge in the current ED-to-ICU bed assignment process is frequent communication delays between ED clinicians and the critical care nursing supervisor. Once the ED attending physician decides that a patient will require an inpatient bed, she immediately places the electronic bed request. The ED resident is then responsible for notifying the critical care nursing supervisor; residents usually call the nursing supervisor directly. However, residents have many competing priorities (including emergent patient care), so they often do not make this call immediately. Once the critical care nursing supervisor receives notification and completes a clinical triage process, she informs the admitting bed managers of the final bed assignments. Anecdotally, admitting bed managers generally receive the electronic bed requests from the ED much earlier they receive notification from the critical care nursing supervisor that an ED patient requires an ICU bed. In these cases, the critical care nursing supervisor often has not received notification from the ED.

4.2.2 OR-to-ICU Transfers

Admitting bed managers review the daily surgical schedule every morning. The schedule specifies the level of inpatient care need likely required by each elective surgery patient. Bed managers assign these patients to units (e.g., Lunder 6 neuroscience ICU), based on current and expected occupancy. Surgical patients who require ICU-level care are frequently assigned to available beds (and to occupied beds that will soon become available) early each morning. These patients are generally prioritized based on the scheduled start times of their procedures; they usually arrive at MGH on the day of their surgeries. The ICU resource nurses determine the final room and bed assignments. If ICU bed shortfalls are expected, the critical care nursing supervisor leads the resolution of capacity issues in collaboration with the ICU resource nurses and a senior physician on call to manage the ORs and OR schedule. In Epic, admitting bed managers execute the unit assignment decisions and ICU OAs execute the final room and bed assignment decisions.

Most neurosurgical patients who need ICU-level care are transferred directly from their operating room to the ICU. In the procedure room, the OR nurse notifies the ICU OA once each patient's procedure is one hour from completion. The ICU resource nurse prepares the unit to receive the surgical patient and once the patient arrives, the ICU OA records the actual arrival time in Epic. Figure 20 in Appendix B illustrates the current state OR-to-ICU bed assignment and patient transfer process.

The primary operational challenge in the current OR-to-ICU process is the premature assignment of inpatient beds based static snapshot of the surgery schedule at a single point in time. More specifically, assigning a surgical patient to an inpatient bed early in the morning (often before the patient has even arrived to the hospital) does not negatively affect that particular patient. In some instances (e.g., certain highly acute surgical cases), an early bed assignment may be needed for clinical reasons. However, in most cases, the premature bed assignments are not medically necessary. In a highly utilized system like MGH, they are a suboptimal use of limited inpatient bed capacity. In one unit, a prematurely assigned bed sits empty, while in other unit, a patient waits. The DUBA[25] performance metric directly measures these delays resulting from these preemptive bed assignments.

4.2.3 ED-to-Floor Transfers

Like ED patients who require ICU-level care, patients admitted via the emergency department who need floor-level care are generally prioritized by their arrival times. Once the attending physician in the ED determines that a patient will eventually need to transfer from the ED to an inpatient floor, she places an electronic bed request using EDIS. The EDIS information system automatically interfaces with the Epic EHR system used by the admitting department for patient registration and inpatient bed management. After receiving a bed request from the ED, admitting bed managers assign (or 'pend') the ED patient to a unit (e.g., Lunder 7 neuroscience inpatient floor unit) based on current and expected unit occupancy. The resource nurses from the assigned inpatient floor unit determine the final room and bed assignments. Admitting bed managers and floor OAs execute the assignments in the Epic ADT module.

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[25] Delay unrelated to bed availability (DUBA) is the bed wait time incurred by patients in their origin unit while clean beds are available in their destination units. See Section 3.3.3 for further details.

Meanwhile, the neuroscience patient often continues to undergo tests (e.g., labs, CT, MRI, X-rays), procedures (e.g., intubation, central line, arterial line, external ventricular drain placement) and consultations in the ED. Once the ED patient is ready to transfer, the ED nurse informs the responsible inpatient floor bedside nurse about the condition of the patient. The coordination of this nursing handoff takes time and often causes delays. After the nursing handoff is complete, the patient is transported from the ED to the inpatient floor and the floor OA records the patient's arrival time in Epic ADT. Figure 22 in Appendix C illustrates the current state ED-to-Floor bed assignment and patient transfer process.

One challenge in the current ED-to-Floor (and, to a lesser extent, ED-to-ICU) bed assignment process is the lack of a clearly defined and widely accepted definition for patient readiness to transfer. ED clinicians typically place bed requests as soon as they believe a patient will likely end up requiring an inpatient bed, regardless of the patient's actual readiness to transfer. Long ED-to-Floor patient wait times and transfer times (see Section 3.3.1 for detailed statistics) are a contributing factor influencing this behavior. During the typically long wait for a floor bed, ED patients often continue to undergo diagnostic procedures. Then once a floor bed becomes available and is assigned to the ED patient, the patient may not be clinically ready to transfer or the nurses may not be available to complete the required handoff. The cumulative effect of this system of behaviors is an overall lack of process consistency and reliability.

4.2.4 OR-to-Floor Transfers

Each morning, admitting bed managers review the daily surgery schedule and attend in-person meetings with inpatient floor clinicians to discuss unit occupancy. The daily surgical schedule specifies which patients will likely require care in a floor unit following their procedures. Admitting bed managers assign these patients to units (e.g., Lunder 7 neuroscience inpatient floor unit) based on current and expected inpatient floor occupancy. The bed managers pend patients to units using the Epic ADT module. Like surgical patient who require ICU-level care, surgical patients who need inpatient floor care are frequently assigned to available beds (and to occupied beds that will soon become available) early each morning. The patients are normally prioritized based on the scheduled start times of their procedures; these patients typically arrive to the hospital on the day of their surgeries. Resource nurses in each inpatient floor unit determine the final room and bed assignments for transfers into their unit. OAs in each floor unit execute the final room and bed decisions using Epic.

Most neurosurgical patients who require floor-level care transfer from their operating room to the post-anesthesia care unit (PACU) for recovery immediately following their surgery. Post-procedure recovery times in the PACU vary. Clinicians in the PACU determine when each patient is ready to transfer and manually input a ready-to-depart timestamp in PRISM, the PACU's information system. However, there is no event or notification on the floor or in the PACU that automatically triggers the initiation of the PACU-to-floor transfer process. A patient actually transfers once her destination bed is clean and ready to receive her. Nurses in the PACU facilitate each patient's transport while, in each floor care unit, resource nurses receive patients from the PACU and OAs record the actual patient arrival times in Epic. Figure 24 in Appendix D illustrates the current state OR-to-Floor bed assignment and patient transfer process.

One challenge in the current OR-to-Floor patient transfer process is the timely recording of the ready-to-depart timestamp in PRISM. Out of 2,321 patients who transferred from the PACU to a neuroscience floor before June 30, 2013, the ready-to-depart timestamp is recorded less than five minutes prior to patients' actual departures in 1,073 cases, implying that only about 50% of patients experienced delays [10]. MGH clinicians explain that almost all patients are actually clinically ready to move more than five minutes prior to leaving the PACU, but clinicians often input the ready-to-depart timestamp in PRISM just as the patient is actually leaving the PACU. The input of the ready-to-depart timestamp does not currently trigger any downstream process steps.

Section 6.2 addresses many of the current state bed management challenges by developing a just-in-time (JIT) bed assignment policy that uses an algorithm to assign beds primarily on a JIT basis.

4.3 Neuroscience Inpatient Floor Discharge Processes

Late intraday discharge timing is one of the leading causes of long patient wait times. This section summarizes the current neuroscience inpatient floor discharge processes by presenting historical patient flow data and by summarizing key current state process steps.

The neuroscience inpatient floor care units comprise of 32 beds on the seventh floor and 32 beds on the eighth floor of Lunder building on MGH's main campus. All beds are located in private, single-patient rooms. Most neuroscience patients treated at MGH are eventually discharged from the neuroscience inpatient floor units (85.2%[26]). Neuroscience patients are also discharged from overflow inpatient floor units (i.e., not Lunder 7 or Lunder 8), the neuroscience ICU, overflow ICUs (i.e., not Lunder 6) and, occasionally, directly from the perioperative environment. Table 5 lists the percentage of discharges that occur from each origin unit.

[26] Source: Patcom, D4Q. Timeframe: September 1, 2011 to June 30, 2013. N=8,475.

Origin Unit	Percentage of Discharges
Neuro. Floors	85.2%
Overflow Floors	6.7%
Neuro. ICU	4.8%
Overflow ICUs	2.9%
Perioperative	0.4%

Sources: Patcom, D4Q, Perioperative Case Data

Timeframe: September 1, 2011 to June 30, 2013

Notes: 'Neuro. Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. 'Overflow Floors' include all other inpatient floor units. 'Neuro. ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Overflow ICUs' include all other intensive care units. Excludes patient expirations. N=8,475 (Neuro. Floors); N=667 (Overflow Floors); N=474 (Neuro. ICU); N=286 (Overflow ICUs); N=43 (Perioperative).

Table 5: Distribution of Neuroscience Discharges by Origin Unit

This project focuses on neuroscience patients that are discharged from the neuroscience inpatient floor units (i.e., Lunder 7 and Lunder 8). This captures the largest segment of patients (85.2%[27]) by origin unit prior to discharge.

Clinicians and administrators perform a number of tasks to discharge a patient from the neuroscience inpatient floor units. Physicians and nurse practitioners communicate the discharge plan to the patient, the patient's family and the patient's primary care physician (PCP). They also record digital notes[28], prescribe medications, write discharge orders and write the discharge

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[27] Source: Patcom, D4Q. Timeframe: September 1, 2011 to June 30, 2013. N=8,475.

[28] Recording digital notes includes: (1) adding an order to CAS (Clinical Application Suite), an electronic medical record designed by MGH and (2) updating the EDD (Estimated Data of Discharge) tool, an application that facilitates communication about the date, destination and barriers to patient discharge.

summary. The bedside nurse caring for the patient informs the unit resource nurse of the expected discharge timing. He also writes the discharge note, reviews the post-discharge medication list (PDML) with the patient, sends prescriptions to the appropriate pharmacy (if necessary), and communicates discharge instructions to the patient and the patient's family. Bedside nurses frequently assist in coordinating transportation from MGH with the patient and the patient's family too. Physical therapists (PT) and occupational therapists (OT) must ensure final PT and OT evaluations are complete. If required, case managers work with patients and patients' families to schedule home services and care coordinators work with patients and patients' families to schedule outpatient appointments.

Clinicians on the neuroscience inpatient floors communicate expected discharge timing to admitting bed managers throughout the day. A daily 9:15 a.m. neuroscience bed meeting initiates the communication each morning. The meeting is held on Lunder 8 and is attended by resource nurses from each neuroscience inpatient floor unit, a resource nurse from the neuroscience ICU and the admitting bed manager assigned to the neuroscience patient population that day. The floor resource nurses share updates regarding bed availability and expected patient discharges. The ICU resource nurse provides an update on bed availability and on patients who are clinically ready to transfer from the ICU to the neuroscience floors. The admitting bed manager shares information about ED and surgical patients with outstanding bed requests for neuroscience ICU and floor beds. The group discusses the overall demand and capacity and then makes bed assignment decisions. Based on these decisions, the admitting bed manager executes the final unit assignments and the unit operations assistants ('OAs') execute the final room and bed assignments in the Epic ADT module. Importantly, the floor OAs use Epic to inform the admitting bed managers of new discharge timing information, which clinicians learn throughout the day.

Neuroscience floor patients are discharged from MGH to a variety of destinations. Most go directly home with a discharge disposition of 'Home or Self Care' or 'Home Health Services'. Home health services are scheduled, in-home services like intermittent skilled nursing, physical therapy, occupational therapy or speech-language pathology services. Other common discharge dispositions include rehabilitation hospitals, skilled nursing facilities, and long-term care hospitals. Table 6 lists the distribution of neuroscience discharges by discharge disposition.

	Discharge Disposition					
	Home or Self Care	Home Health Services	Rehabilitation Hospital	Skilled Nursing Facility	Long-Term Care Hospital	Other
All Neuroscience Patients	53.1%	18.4%	14.5%	7.9%	3.9%	2.2%
Neurosurgery Patients	58.0%	18.4%	12.4%	6.6%	3.6%	1.0%
Neurology Patients	48.7%	18.5%	16.4%	9.1%	4.1%	3.3%

Sources: Patcom, D4Q

Timeframe: January 1, 2012 to June 30, 2013

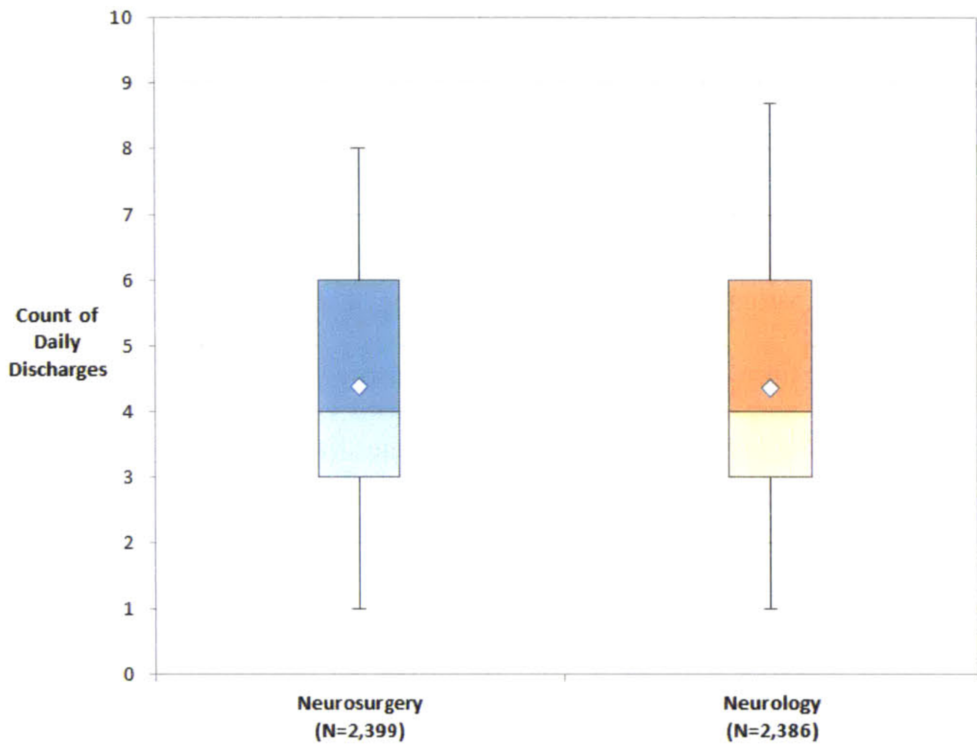
Notes: 'Other' includes: Hospital Swing Bed, Against Medical Advice, Psych Hosp/Dist, Hospice Home, Other Type Facility, Hospice, Fed Hospital, Short Term General Hospital, and Law Enforcement. Excludes expired patients. N=6,691 (All Neuroscience Patients); N=3,140 (Neurosurgery Patients); N=3,551 (Neurology Patients).

Table 6: Distribution of Neuroscience Discharges by Discharge Disposition

Relative to neurology patients, a higher percentage of neurosurgery patients are discharged directly to home. On the other hand, a slightly higher percentage of neurology patients are discharged to non-home locations like rehabilitation and long-term care hospitals and skilled nursing facilities (SNF). Overall, the distribution of discharge dispositions does not vary substantially between the neurosurgery and neurology clinical services.

This project focuses on neuroscience patients who are discharged directly from MGH to home (i.e. patients with a discharge disposition of 'Home or Self Care' or 'Home Health Services'). This captures the largest segment of patients (71.5%[29]) by discharge destination. Importantly, the discharge process is generally simpler for patients who are discharged to home as MGH clinicians and administrators do not need to spend time coordinating with other care facilities. Figure 6 shows the count of daily neuroscience patients discharged from the neuroscience inpatient floors (i.e., Lunder 7 and Lunder 8) directly to home by service.

[29] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=4,785.



Sources: Patcom, D4Q

Timeframe: January 1, 2012 to June 30, 2013

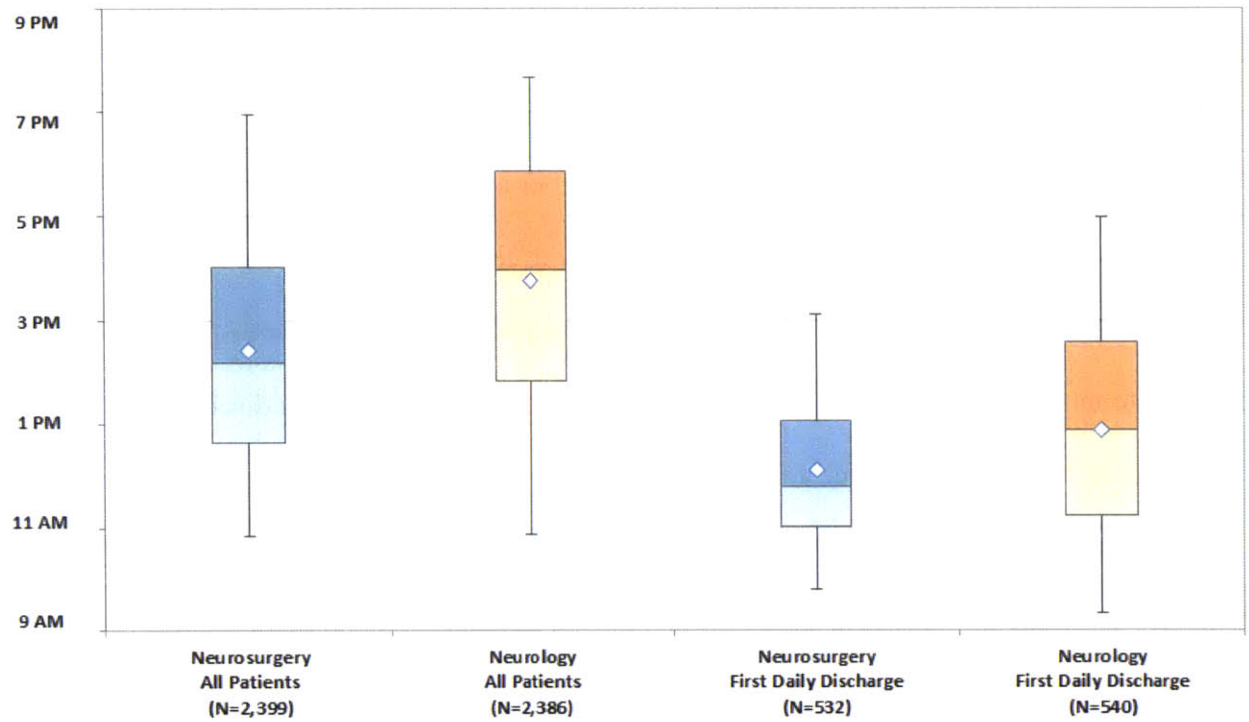
Notes: Excludes expired patients. N=2,399 (Neurosurgery); N=2,386 (Neurology). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 6: Count of Daily Neuroscience Discharges to Home by Service

On average, four or five neurosurgery patients and four or five neurology patients are discharged from the neuroscience inpatient floors to home each day. At the high end (95th percentile and above), each clinical service discharges eight or more patients in a given day. At the low end, everyday includes at least one neuroscience patient discharge from the inpatient floors to home; about 2.7%[30] of days do not include a neurosurgery patient discharge and less than 1.3%[31] of days do not include at least one neurology patient discharge.

[30] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=15.
[31] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=7.

Throughout MGH, discharges tend to occur late in the day. On the neuroscience floor units, patients are generally discharged in the afternoon as current clinical processes prioritize inpatient care and teaching early in the morning. The average discharge time from the neuroscience inpatient floors to home is 2:25 p.m. for all neurosurgery patients and 3:45 p.m. for all neurology patients. For only the first patient to be discharged from the neuroscience floors to home each day, the average discharge time is 12:07 p.m. for the neurosurgery first daily discharge and 12:53 p.m. for the neurology first daily discharge. Figure 7 includes the full intraday timing of discharges from the neuroscience inpatient floor units to home by service. It presents the distribution of discharge times for all patients and for just the first patient to be discharged each day.



Sources: Patcom, D4Q

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Neurosurgery First Daily Discharge' includes only the first neurosurgery patient discharged on each day. 'Neurology First Daily Discharge' includes only the first neurology patient discharged on each day. Excludes expired patients. N=2,399 (Neurosurgery All Patients); N=2,386 (Neurology All Patients); N=532 (Neurosurgery First Daily Discharge); N=540 (Neurology First Daily Discharge). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 7: Intraday Timing of Discharges from Neuroscience Floors to Home by Service

A very small number of neuroscience patients are discharged early in the morning. For discharges from the neuroscience inpatient floors to home, just 1.6%[32] of all neurosurgery patients and 2.4%[33] of all neurology patients are discharged before 10 a.m. The number of days where at least one neuroscience patient is discharged early in the morning is small too. On only the days when at least one discharge from the neuroscience floors to home takes place, just

[32] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=37.
[33] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=58.

7.0%[34] of the first daily neurosurgery discharges and 9.8%[35] of the first daily neurology discharges occur before 10 a.m.

Overall, the intraday timing of neuroscience inpatient floor admissions and discharges are misaligned. In the morning, demand for beds frequently exceeds available supply. Prior MGH – MIT Collaboration research shows that a given patient population or discharge disposition does not drive late intraday discharge timing [10]. Patients experience late intraday discharges independent of their clinical service and of their discharge destination. This implies that capacity constraints at non-home locations like rehabilitation and long-term care hospitals are not the primary driver of late intraday discharge timing. Instead, internal MGH processes could significantly influence the distribution of discharges times.

Section 6.3 develops a small-scale early discharge intervention to better align the intraday timing of floor discharges with the timing of demand for floor beds.

4.4 Neuroscience Inpatient Floor Transfer Processes

Delayed intraday transfer timing is also a leading cause of long patient wait times. Ongoing research by the MGH – MIT Collaboration is underway to quantify and understand the widespread delays experienced by patients transferring from ICUs throughout the hospital. This section summarizes the current neuroscience inpatient floor transfer processes by presenting historical patient flow data and by summarizing key current state process steps.

The neuroscience intensive care unit (ICU) contains 22 beds on the sixth floor of the Lunder building on MGH's main campus. All beds are located in private, single-patient rooms. The focus of care in the ICU is to stabilize critically ill patients. Once highly acute patients are stable,

[34] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=37.
[35] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=53.

complex diagnostic issues are resolved in other inpatient settings. Most neuroscience patients who require ICU-level care are eventually transferred from the neuroscience ICU to the neuroscience inpatient floor units (78.6%[36]). Neuroscience ICU patients are also transferred to the perioperative environment, to overflow inpatient floor units (i.e., not Lunder 7 or Lunder 8) and, occasionally, to overflow ICUs (i.e., not Lunder 6). Table 7 lists the distribution of transfers from the neuroscience ICU by destination unit.

Destination Unit	Percentage of Transfers
Neuro. Floors	78.6%
Perioperative	16.8%
Overflow Floors	4.1%
Overflow ICUs	0.6%

Sources: Patcom, D4Q, Perioperative Case Data

Timeframe: September 1, 2011 to June 30, 2013

Notes: 'Neuro. Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. 'Overflow Floors' include all other inpatient floor units. 'Overflow ICUs' include all other intensive care units. Transfers to a different bed within the neuroscience ICU unit and patient expirations are excluded. N=2,536 (Neuro. Floors); N=542 (Perioperative); N=131 (Overflow Floors); N=19 (Overflow ICUs). Sum of percentages does not equal 100% due to rounding.

Table 7: Distribution of Transfers from the Neuroscience ICU by Destination Unit

[36] Source: Patcom, D4Q, Perioperative Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=2,536.

This project focuses on neuroscience ICU patients who transfer directly to the neuroscience inpatient floor units (i.e., Lunder 7 and Lunder 8). This captures the largest segment of transferring ICU patients (78.6%[37]) by destination unit.

Clinicians and administrators perform several tasks to transfer a patient from the ICU to a neuroscience inpatient floor unit. The neurosurgery clinical team provides continuous care from before a neurosurgery patient's procedure to the patient's stay in the ICU and in an inpatient floor care unit. To initiate neurosurgery patient transfers from the ICU, the neurosurgery attending physician writes transitional order sets and transfer orders. For neurology patients who require ICU-level care, a critical care team manages the patient's recovery while the patient is in the ICU and a neurology team manages the patient's care once the patient reaches an inpatient floor unit. To initiate neurology patient transfers from the ICU, the critical care attending physician writes transitional order sets and transfer orders. Resource nurses in the neuroscience ICU and in each neuroscience inpatient floor unit facilitate the patient transfer between the two units. Once neurology patients arrive to the inpatient floor units, the on-call neurology senior resident sees the patient to perform a work-up. Throughout the process, physicians, residents, resource nurses and bedside nurses communicate expected transfer details to the patient.

Clinicians from the neuroscience ICU participate in a number of daily meetings, which inform their approach to ICU patient transfer decisions. Resource nurses from the neuroscience ICU meet with resource nurses from both neuroscience inpatient floor units daily at 7 a.m. and 7 p.m. For each ICU patient, ICU resource nurses share the following updates: medical status (e.g., exam results, medications), non-medical status (e.g., patient outlook, patient social issues), and

[37] Source: Patcom, D4Q, Perioperative Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=2,536.

appropriate next steps (e.g., ready to transfer to the floor, ready to be discharged from MGH, requires further stabilization in the ICU).

Resource nurses from the neuroscience ICU also attend a daily 7:45 a.m. ICU bed capacity meeting to discuss surgical patients who will require ICU-level care following their procedures. Other attendees include a senior physician on call to manage the ORs and OR schedule, the critical care nursing supervisor, resources nurses from all most surgical ICUs[38], and a resource nurse from the Ellison 3 post-anesthesia care unit (PACU). The attendees review the daily surgical schedule and discuss new demand for ICU beds. The resource nurses each provide an update on unit capacity, including expected transfers and discharges as well as outstanding bed requests from any other sources (e.g., front door clinical admissions and transfers from other hospitals). If ICU bed shortfalls are expected, the critical care nursing supervisor leads the resolution of the issues in collaboration with all other meeting attendees.

Finally, ICU resource nurses attend the daily 9:15 a.m. neuroscience bed meeting with the floor resource nurses and the admitting bed manager assigned to the neuroscience patient population that day. In the neuroscience bed meeting, the ICU resource nurse provides an update on bed availability and shares further details on patients who are clinically ready to transfer from the ICU to the neuroscience floors. The admitting bed manager shares information about ED and surgical patients with outstanding bed requests for neuroscience ICU and floor beds. Based on the overall demand and capacity, the group makes bed assignment decisions. Importantly, the operations assistants in the neuroscience ICU also communicate expected transfer timing to admitting bed mangers throughout the day using Epic.

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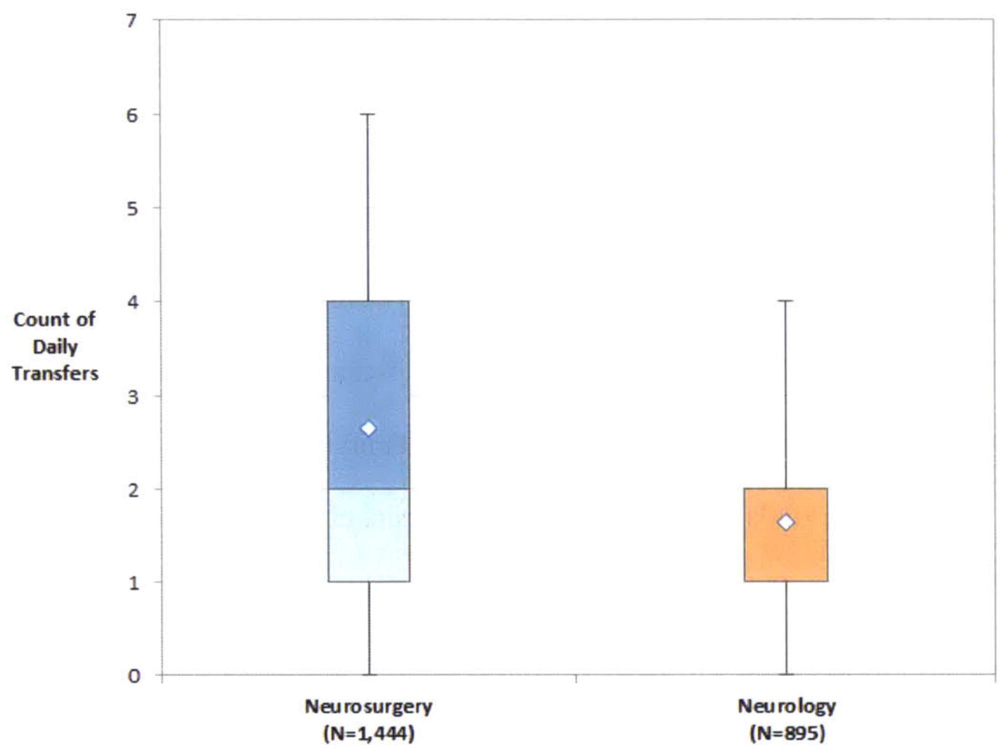
[38] Attendees include resource nurses from all surgical ICUs except the Cardiac Surgery ICU. The Cardiac Surgery ICU independently manages its beds to serve a distinct patient population. The other surgical ICUs include the neuroscience ICU (Lunder 6), the SICU (Ellison 4) and the medical overflow ICU (Blake 12).

This work focuses on patients who transfer directly from the neuroscience ICU (i.e., Lunder 6) to the neuroscience inpatient floor units (i.e., Lunder 7 and Lunder 8). Figure 8 shows the count of daily neuroscience ICU patients transferred to the neuroscience inpatient floors by service.



Sources: Patcom, D4Q

Timeframe: January 1, 2012 to June 30, 2013

Notes: Excludes transfers by non-neuroscience patients (N=42). Excludes expired patients. N=1,444 (Neurosurgery); N=895 (Neurology). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

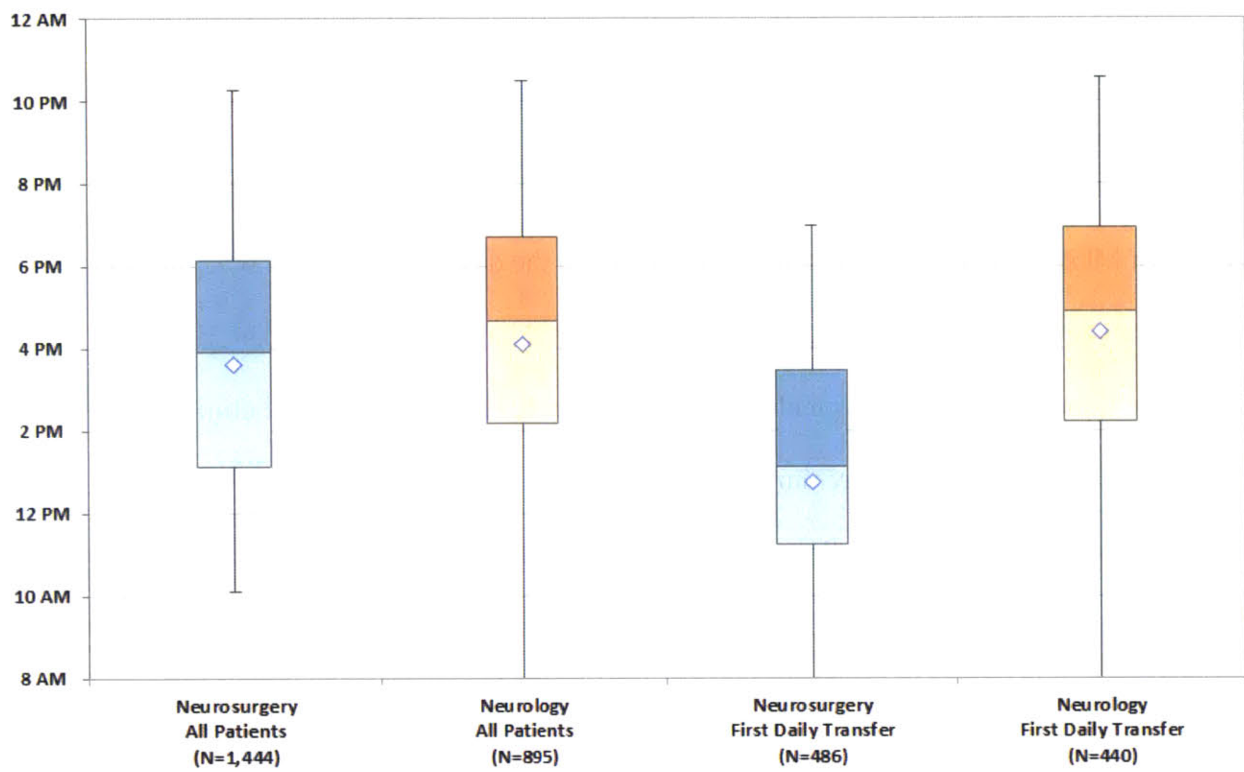
Figure 8: Count of Daily Neuroscience ICU to Floor Transfers by Service

On average, two or three neurosurgery patients and one or two neurology patients transfer from the neuroscience ICU to the neuroscience inpatient floors each day. At the high end (95th percentile and above), the neurosurgery clinical service transfers six or more patients and the neurology clinical service transfers four or more patients in a given day. At the low end, less than

3.2%[39] of days do not include at least one neuroscience patient transfer from the neuroscience ICU to the neuroscience floors; about 11.2%[40] of days do not include a neurosurgery transfer while 19.6%[41] of days do not include at least one neurology patient transfer.

Throughout MGH, patient transfers tend to occur late in the day. Neuroscience ICU patients generally transfer in the afternoon because newly admitted patients (e.g., from the ED or the OR) who require floor-level care are typically prioritized over ICU patients who are clinically ready to transfer to an inpatient floor care unit. The average patient transfer time from the neuroscience ICU to the neuroscience inpatient floors is 3:37 p.m. for all neurosurgery patients and 4:07 p.m. for all neurology patients. For only the first patient transferred from the neuroscience ICU to a neuroscience inpatient floor unit each day, the average transfer time is 12:44 p.m. for the neurosurgery first daily transfer and 4:24 p.m. for the neurology first daily transfer. On most days, only one or two neurology patients transfer from the ICU to the floor, so the distribution of transfer times for the first daily transfers does not vary substantially from the distribution of transfer times for all neurology patients. Figure 9 includes the full intraday timing of transfers from the neuroscience ICU to the neuroscience inpatient floor units by service. It provides the distribution of transfer times for all patients and for just the first patient transferred each day.

[39] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=17.
[40] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=61.
[41] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=107.



Sources: Patcom, D4Q

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Neurosurgery First Daily Transfer' includes only the first neurosurgery patient transferred on each day. 'Neurology First Daily Transfer' includes only the first neurology patient transferred on each day. Excludes transfers by non-neuroscience patients (N=42). Excludes expired patients. N=1,444 (Neurosurgery All Patients); N=895 (Neurology All Patients); N=486 (Neurosurgery First Daily Transfer); N=440 (Neurology First Daily Transfer). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 9: Intraday Timing of Neuroscience ICU to Floor Transfers by Service

A small number of neuroscience ICU patient transfers occur early in the morning. For ICU to floor transfers, less than 8.5%[42] of all neurosurgery patients and 8.2%[43] of all neurology patients transfer before 11 a.m. The number of days where at least one neuroscience ICU patient transfers early in the morning is small too. On only the days when at least one transfer from the

[42] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=122.
[43] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=73.

neuroscience ICU to the neuroscience floors takes place, about 21.2%[44] of the first daily neurosurgery transfers and 7.3%[45] of the first daily neurology transfers occur before 11 a.m.

Overall, the intraday timing of demand for neuroscience ICU beds and patient transfers from the ICU are misaligned. In the morning, demand for ICU beds frequently exceeds available supply. Neuroscience ICU patients typically transfer late in the day because newly admitted patients (e.g., from the ED or the OR) who require floor-level care are typically prioritized over ICU patients who are clinically ready to transfer to an inpatient floor care unit.

Section 6.4 develops a small-scale early transfer intervention to improve the intraday alignment between the timing of patient transfers from the ICU and demand for neuroscience ICU beds.

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[44] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=103.
[45] Source: Patcom, D4Q. Timeframe: January 1, 2012 to June 30, 2013. N=32.

5 Simulation of Neuroscience Patient Flow

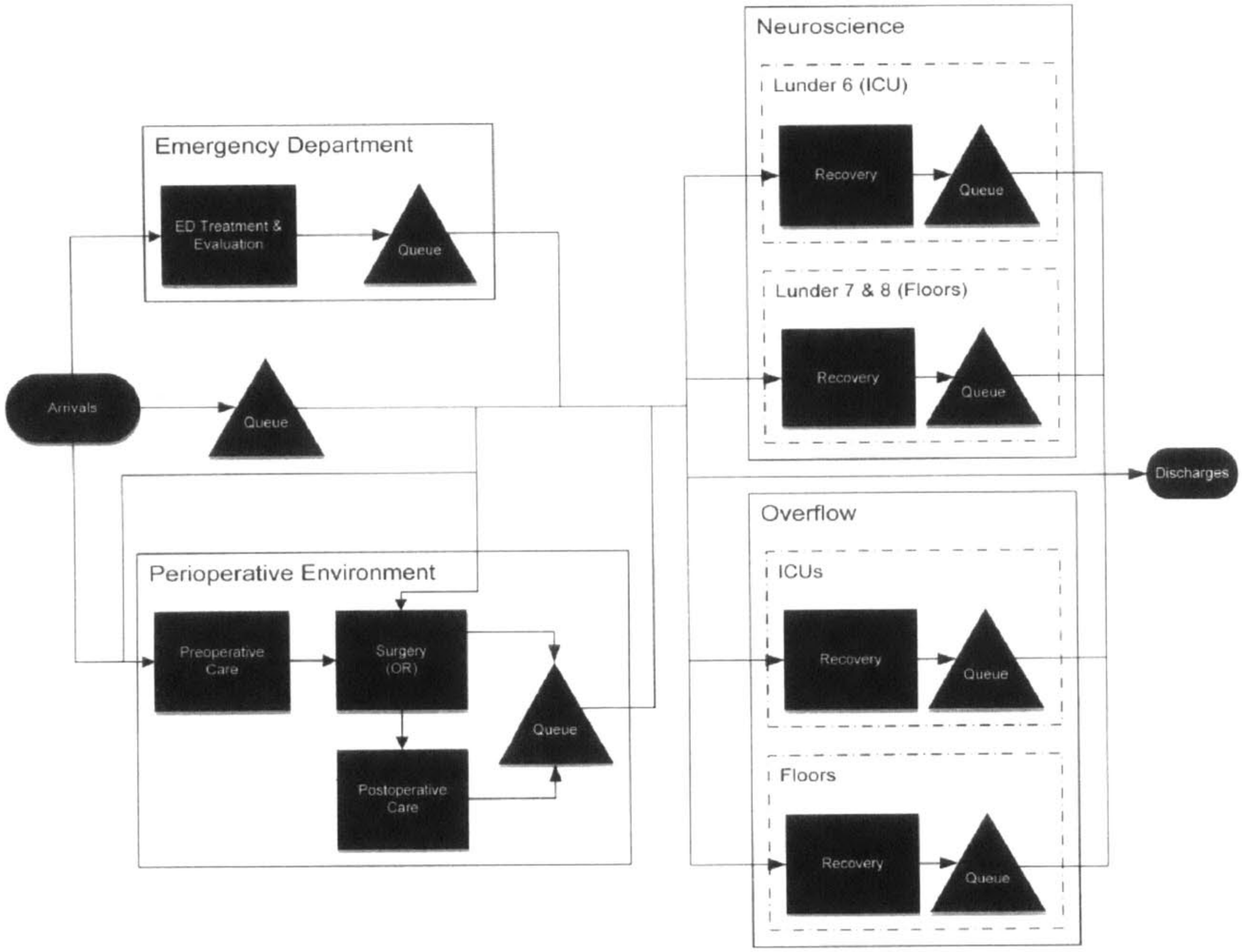
This chapter describes the key elements of the simulation of neuroscience patient flow that this project uses to iteratively evaluate the efficacy of several new policies and interventions. Section 5.1 provides an overview of the simulation model and Section 5.2 summarizes how the model uses key input data from the sources listed in Section 3.1.Section 5.3 explains how the model was validated against historical data. Throughout this work, the predicted results of the patient flow simulation provided valuable context to facilitate discussion among the MGH working group regarding the various solution approaches.

5.1 Model Overview

Jonas Hiltrop, a graduate of the MIT Leaders for Global Operations (LGO) program, built the simulation of neuroscience patient flow while a member of the MGH – MIT Collaboration research group. Hiltrop worked closely with MGH clinicians and administrators, MIT faculty and post-doctoral fellows in the Operations Management group at the MIT Sloan School of Management. For a comprehensive discussion of the development of the simulation model, see J. Hiltrop, *Modeling Neuroscience Patient Flow and Inpatient Bed Management*, 2014.

The simulation model is implemented using the MedModel modeling environment[46] and the SAS software suite[47]. The model consists of multiple interconnected units including the emergency department, the perioperative environment, the neuroscience intensive care unit (ICU), the neuroscience inpatient floor care units, overflow ICUs and overflow inpatient floor units. Figure 10 presents an overview of the neuroscience patient flow simulation model.

[46] MedModel is a product of the ProModel Corporation, a private company.
[47] The SAS software suite is a product of the SAS Institute, a private company.



Source: J. Hiltrop, *Modeling Neuroscience Patient Flow and Inpatient Bed Management*. 2014.

Notes: Rectangles represent processes and triangles represent queues. In this figure, each origin unit (e.g., emergency department) only has one triangle indicating a queue. In the simulation, patients from an origin unit who are moving to different destination units wait in separate queues.

Figure 10: Overview of Neuroscience Patient Flow Simulation Model

5.2 Model Input

The simulation of neuroscience patient flow uses historical data from the sources described in Section 3.1 to trigger patient arrivals and discharges as well as patient movements from one process or queue to another. This section summarizes how the simulation uses key data elements from each source.

Data from the Emergency Department Information System ("EDIS") serve as the primary source of information about each emergency room visit at MGH. For each patient who visits the ED, the simulation uses key data elements from EDIS: ED arrival time, bed request time, bed assignment time, bed clean time, physician handoff time, nurse handoff time and ED departure time.

The simulation relies on perioperative case data for information about surgical patients' movements to and from operating rooms as well as their preoperative and postoperative care. For each surgical patient, the model uses the following key perioperative case data elements: preoperative arrival time, preoperative departure time, OR arrival time, surgery completion time, OR departure time, postoperative arrival time, patient ready-to-depart PACU time, and postoperative departure time. Of the above, the patient ready-to-depart PACU time is somewhat unreliable (Section 4.2.4 explains how the timely input of this timestamp often does not occur in the current state bed management process).

Patcom is the principal data source for hospital-wide patient movements between all inpatient care units. The simulation uses the following key data elements from Patcom: patient admission time, patient arrival time, patient departure time, bed identifier and discharge location. For each patient, the bed identifier indicates each bed visited during their entire inpatient stay.

Finally, the simulation relies on data from CBEDs, a bed management information system, for information about the timing of bed cleaning. The CBEDs data are organized by bed cleaning events and include the following key data elements: bed identifier, bed dirty time, bed cleaning start time, and bed clean time (i.e., bed cleaning completion time). The simulation uses bed clean time as an indication of bed readiness for patient movement measurements.

5.3 Model Validation and Boundaries

Prior MGH – MIT Collaboration research validated the simulation of neuroscience patient flow against historical patient movement data. The distributions of patient wait times in the current state simulation are not statistically different from their true historical distributions [10].

The neuroscience units at MGH are a reasonably closed system. The model simulates patient flow for admitted patients from the neuroscience clinical services and for admitted patients from other clinical services who were treated in the neuroscience ICU or the neuroscience inpatient floor care units. The simulation does not consider outpatients or inpatients from non-neuroscience clinical services who were not treated in the neuroscience units.

The model strictly constrains the capacity of the neuroscience units. At any given moment, the simulation does not permit more than 22 patients in the neuroscience ICU or more than 32 patients in either neuroscience inpatient floor unit. The simulation only considers patient movements between units; it does not consider transfers to a different bed within the same ICU or transfers to a different bed within the same floor care unit.

This work uses the model to predict the impact of several new policies. Simulation scenarios correspond to each new approach. The different simulation scenarios affect patients' length of stay in different processes and queues, but the interventions do not influence the locations that a patient visits or the sequence of movements that a patient follows to visit each location. This project also assumes that the interventions do not affect demand (i.e., if new capacity becomes available, more neuroscience patients are not admitted and neurosurgeons do not perform additional neurosurgical procedures).

6 Solution Approaches

Chapter 4 provides a comprehensive analysis of the bed assignment and patient transfer processes (Section 4.2), the neuroscience inpatient floor discharge processes (Section 4.3) and the neuroscience inpatient floor transfer processes (Section 4.4). It highlights the key current state challenges that contribute to long patient wait times. This chapter develops solution approaches to address many of these current state challenges. The most promising solution approaches are a just-in-time (JIT) bed assignment policy, a small-scale early discharge intervention and a small-scale early transfer intervention.

The solution approaches rely on insights shared by a working group of MGH leaders from the neurosciences, the perioperative and critical care teams, the emergency and admitting departments, and case management. This project used an iterative process to develop these approaches as input from the working group, the neuroscience patient flow simulation and other data analysis revealed new insights. After the simulation of a potential policy, the working group provided feedback on the results and frequently refined process details and suggested additional new ideas. As a result, the solution approaches complement each other. In early versions of the JIT bed assignment approach, surgical patients experienced slightly longer intraday wait times due to the elimination of premature bed assignments. In order to reduce intraday wait times for surgical patients under the JIT policy, we simulated the impact of additional inpatient capacity on patient flow. The small-scale early discharge intervention enhances wait time reductions achieved by the JIT bed assignment policy by slightly alleviating the limiting inpatient floor capacity constraints. The small-scale early transfer intervention depends on the small-scale early discharge intervention to create available floor beds early in the morning and then seeks to best utilize the available capacity to improve system-wide patient flow. The combination of these two interventions with the JIT bed assignment approach results in reduced intraday patient wait times for all patients.

This chapter begins with a summary of the key benefits and the outstanding challenges of the solution approaches (Section 6.1). Next, it provides detailed descriptions of the just-in-time bed assignment policy (Section 6.2), the small-scale early discharge intervention (Section 6.3) and the small-scale early transfer intervention (Section 6.4). Section 6.1 is an overview of the key elements of Section 6.2, Section 6.3 and Section 6.4. The predicted results presented in Chapter 7 summarize the outcome of the neuroscience patient flow simulation under the conditions outlined in these solution approaches.

6.1 Summary of Key Benefits and Outstanding Challenges

Just-In-Time Bed Assignment Policy

Suboptimal bed assignments are one of the leading causes of long intraday wait times (see Section 4.1). This work develops a just-in-time (JIT) bed assignment policy and new processes to enable the JIT bed assignment policy for each patient movement type. This project labels these processes 'JIT Pilot' as they have been designed for a pilot implementation in the neuroscience units at MGH.

The JIT Pilot policy eliminates premature bed assignments (i.e., patients assigned to a bed before they are ready to move or before their destination bed is clean and ready to receive a patient). For example, a surgical patient is not assigned to a bed early in the morning based on a procedure scheduled for late in the afternoon. Instead, all patients, including surgical patients, are assigned to available beds primarily on a first-ready, first-served basis.

In the JIT Pilot policy, bed managers still review the daily surgery schedule and receive bed requests from the ED and other inpatient units. However, bed mangers also receive new information regarding patients' current readiness to transfer. Bed requests for all ED patients now indicate that the patient is clinically ready to move. Nurses in the OR procedure rooms call admitting bed managers when each procedure is one hour from completion and nurses in the PACU call admitting bed managers once a PACU patient is ready to transfer to their next destination. These notifications allow admitting bed managers to make JIT bed assignments. The call from PACU clinicians to admitting now serves as an important trigger to downstream process steps. This will likely improve the timely recording of the ready-to-depart timestamp in PRISM[48] and, importantly, reduce transfer processing wait times. Finally, a new automated notification step will improve the communication between ED clinicians and the critical care nursing supervisors too.

The JIT Pilot policy uses a 'first-due' ranking methodology[49] to prioritize bed assignments among patients who have been admitted to the same clinical service and who require the same level of care. Instead of negotiating placements on a case-by-case basis, the policy calls for decisions based on objective and transparent criteria such as movement types and patients' clinical ready times. Per the input of MGH clinicians and administrators, the JIT Pilot policy preserves certain protocols like the deprioritization of ICU patients relative to other patients competing for floor beds. The JIT Policy can be used to establish realistic and actionable patient placement guidelines, such as:

[48] PRISM is the information system in the PACU.
[49] Section 6.2 describes the 'first-due' ranking methodology in full detail.

1. Priority 1: For movements from the ED and from the OR, assign patients on a first-ready basis per real-time notifications from EDIS, OR nurses and PACU nurses
2. Priority 2: For movements from other units (i.e., overflow units, front door clinical admissions and transfers from other hospitals), wait until the end of the day and until all Priority 1 patients have been placed, then assign Priority 2 patients on a first-ready basis.
3. Priority 3: For ICU-to-Floor movements, wait until the end of the day and until all Priority 1 and Priority 2 patients have been placed, then assign Priority 3 patients on a first-ready basis. (This reflects current MGH priorities.)

Decision-making authority in the JIT Pilot process is decentralized (as it is in the current state bed management process). Admitting bed managers retain responsibility for pending admitted patients to inpatient units, while resource nurses in each inpatient unit continue to assign inbound patients to their final rooms and beds. This decentralization is necessary for clinical reasons. To make the room and bed assignment decisions, resource nurses consider factors that admitting bed managers are not privy to, such as bed proximity to the nursing station, current staffing levels and which clinicians are best prepared to treat certain types of patients. The JIT Pilot process does ensure that all stakeholders know that the patient is clinically ready to move while inpatient unit clinicians make the final room and bed assignment decisions. This will likely reduce the amount of time the resource nurses use to make these decisions. The JIT Pilot also enables nurses in the origin and destination units to more reliably predict when they will need to execute handoffs, which will likely reduce transfer processing wait times too.

There are still outstanding challenges in the JIT Pilot bed management process. All stakeholders would benefit from efforts to make more information readily available and easier to act upon.

For example, processes to capture and share information that emerges throughout the day (e.g. expected discharge timing and surgery schedule changes) could be improved.

Another outstanding challenge in the JIT Pilot process is the lack of a clearly defined and widely accepted definition for patient readiness to transfer for ED patients. This is essential because ED clinicians place EDIS bed requests once patients reach this status in the JIT Pilot process. Please see Section 8.2 for a discussion of ED patient readiness definitions as an opportunity for further study.

Section 6.2 provides detailed descriptions of the new processes that enable the JIT bed assignment policy for each patient movement type.

Small-Scale Early Discharge Intervention

Late intraday discharge timing is a significant cause of long patient wait times (see Section 4.3). In the morning, demand for beds frequently exceeds available supply as clinicians prioritize inpatient care and teaching over discharge processing. This chapter develops a small-scale early discharge intervention that enables clinicians to discharge one patient from each neuroscience clinical service to home by 10 a.m. on selected days.

The small-scale early discharge intervention is designed to minimize the early morning discharge processing time. If neuroscience clinicians can dedicate a small amount of valuable early morning time to discharge processing, then this approach will actually improve patient care by freeing up floor capacity for more appropriate patients. The recovered patient who is ready for discharge no longer requires floor-level care while elsewhere in the hospital, the floor units are the appropriate level of care for a different, more acute patient. Discharging floor patients early in the morning improves system-wide patient flow too. This modest increase in floor capacity yields significant reductions to patient wait times due to the current misalignment between demand for floor beds and typical discharge timing.

Section 6.3 provides detailed descriptions of the new processes that enable the small-scale early discharge intervention for each neuroscience clinical service.

Small-Scale Early Transfer Intervention

Delayed intraday transfer timing is another leading root cause of long patient wait times (see Section 4.4). In the morning, demand for ICU beds frequently exceeds available supply. Neuroscience ICU patients typically transfer late in the day because newly admitted patients (e.g., from the ED or the OR) who require floor-level care are typically prioritized over ICU patients who are clinically ready to transfer to an inpatient floor care unit. This chapter develops a small-scale early transfer intervention that enables clinicians to transfer one neuroscience patient from the neuroscience ICU to the inpatient floors by 11 a.m. on selected days.

The small-scale early transfer intervention depends on the small-scale early discharge intervention to create available floor beds early in the morning. The early transfer intervention only targets one neuroscience patient for an early transfer from the neuroscience ICU to the inpatient floors. The neuroscience patient flow simulation shows how one early ICU to floor transfer (as opposed to zero or two transfers) best impacts system-wide patient flow. One early ICU to floor transfer reduces the predicted wait times for patients transferring to the ICU without significantly increasing wait times for non-ICU patients transferring to the floors. This is desirable because patients transferring to the ICU are generally more sensitive to long wait times than are patients transferring to inpatient floor care units[50].

Section 6.4 provides a detailed description of the new process that enables the small-scale early transfer intervention for neuroscience ICU to floor movements.

6.2 Just-In-Time Bed Assignment Policy

Section 4.1 establishes suboptimal bed assignments as one of the leading causes of long intraday wait times at MGH. This work develops a just-in-time (JIT) bed assignment policy that uses an algorithm to assign beds primarily on a JIT basis. Patients who are clinically ready to transfer to a particular inpatient unit are assigned to beds that become available in that unit on a first-ready, first-assigned basis. A bed is not assigned to a patient before it is clean and ready to receive a patient.

This approach uses a transparent 'first-due' ranking methodology to prioritize patients. First, patients are segmented by movement type (e.g., ED-to-ICU). For each movement, MGH clinicians establish an acceptable wait length (AWL), which defines the target maximum patient wait length. Table 3 in Section 3.3.2 lists the established AWLs by movement type.

The JIT policy only permits early bed assignments (i.e., assignments before the patient is clinically ready to transfer) when patients' imminent readiness can be predicted with very high certainty. In the JIT Pilot processes (detailed below for each patient movement type), the ready time for OR-to-ICU patients is one hour prior to the completion of the patient's procedure. For all other patient movements, the ready time is when the patient is clinically ready to depart the

[50] Table 3 in Section 3.3.2 lists the established acceptable wait lengths (AWLs) by movement type. For example, for ED-to-ICU and OR-to-ICU movements, the AWL is 30 minutes. For ED-to-Floor and OR-to-Floor movements, the AWL is two hours.

origin unit. To account for relative priorities among different patients, the policy ranks patients based on their ready times and the established AWLs. Table 8 illustrates how the algorithm calculates a 'due time' for every patient.

Patient Movement	**Patient Ready Time**	**Acceptable Wait Length**	**Patient Due Time**	**To ICU Transfer Ranking**	**To Floor Transfer Ranking**
Other-to-ICU	9:00 a.m.	8 h	5:00 p.m.	3	
ED-to-ICU	10:00 a.m.	30 min	10:30 a.m.	1	
OR-to-ICU	11:00 a.m.	30 min	11:30 a.m.	2	
ICU-to-Floor	8:00 a.m.	N/A[i]	N/A[i]		4[i]
Other-to-Floor	9:00 a.m.	8 h	5:00 p.m.		3
ED-to-Floor	10:00 a.m.	2 h	12:00 p.m.		1
OR-to-Floor	11:00 a.m.	2 h	1:00 p.m.		2

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. 'Other' includes overflow ICUs, overflow inpatient floor units, front door (i.e., scheduled) clinical admissions and transfers from other hospitals. Patient movements to other modules in the simulation (i.e., OR, ED and overflow units) are executed at the historical transfer times; the patients are not ranked because these units are not explicitly capacity constrained.

[i] An AWL for ICU-to-Floor transfers is not applicable. Instead, the simulation executes these patient movements at the end of the day (i.e., after all other pending transfers to floor units are processed) on the day of historical transfer, given available floor capacity. This effectively deprioritizes ICU patients relative to all other patients competing for floor beds, which reflects MGH's current and desired protocol.

Table 8: Illustration of First-Due Ranking Methodology

The patient flow simulation uses the due time once a neuroscience ICU bed or neuroscience floor bed becomes available. Among all patients in the queue waiting to transfer to a capacity-constrained unit, the bed assignment algorithm selects the patient with the earliest due time. In the simulation, the patient movement occurs as soon as the patient is clinically ready to transfer and the destination bed is clean and ready to receive a patient. In other words, the due time is only used to prioritize among ready patients; the simulation often executes transfers before the actual due time.

New processes enable the JIT bed assignment policy for each patient movement type. This work labels these processes 'JIT Pilot' as they have been developed for a pilot implementation in the neuroscience units at MGH. Detailed JIT Pilot bed assignment and patient transfer processes vary based on origin and destination unit.

6.2.1 ED-to-ICU Transfers

The JIT Pilot bed assignment and patient transfer process begins with the attending physician in the ED determining if a patient requires admission as well as what level of care (i.e., ICU vs. floor) is necessary. As soon as the attending physician in the ED determines the level of care that a patient will eventually require, she notifies the critical care nursing supervisor via a call. An ED resident physician can also perform this notification on behalf of the attending physician. For the neurology service, an illustrative case is an intubated patient who arrives to the ED with an intracerebral hemorrhage. While the patient may not be ready to move right away, it is immediately clear that the patient will eventually require admission to the ICU. Upon receiving notification from the ED, the critical care nursing supervisor begins a clinical triage process. If ICU bed shortfalls are expected, the critical care nursing supervisor still addresses the issue by working with the ICU resource nurses and clinicians from the ED and the perioperative services.

In the meantime, admitting bed managers do not assign admitted ED patients to ICU beds until receiving notification from the ED that a patient is ready to transfer. Once the attending physician in the ED determines that a patient is clinically ready to move, she (or an ED resident on her behalf) places an electronic bed request in the EDIS information system. Like the current state, a bed request submitted via EDIS automatically generates a bed request for admitting in the Epic ADT module. Unlike the current state, the EDIS bed request will now automatically generate a page to the critical care nursing supervisor so she immediately knows that the ED patient is clinically ready to transfer. After receiving the ED bed request, admitting bed managers pend patients to the appropriate unit (e.g., Lunder 6 neuroscience ICU). This transaction automatically generates a page to the ICU resource nurse. The ICU resource nurse and the critical care nursing supervisor then determine the final ICU room and bed assignments. As they make these decisions throughout the day, the critical care nursing supervisor informs the admitting bed managers and the ICU resource nurses inform the ICU OAs. The bed managers and OAs execute the unit and bed assignments in Epic. Within one hour of the initial EDIS bed request, the ED and ICU nurses complete the required nursing handoff. Finally, the ED nurses facilitate the transport of the ED patient to the ICU and the ICU OA records the patient's arrival time in Epic. Figure 19 in Appendix A illustrates the JIT Pilot ED-to-ICU bed assignment and patient transfer process.

The JIT Pilot process will significantly improve the communication between ED clinicians and the critical care nursing supervisor regarding ED patients' readiness to transfer to an ICU bed. In the JIT Pilot process, the EDIS bed request will automatically generate a page to the critical care nursing supervisor. This new step ensures that once an ED patient is clinically ready to move, all the relevant stakeholders (i.e., admitting bed managers, critical care nursing supervisors, ICU resource nurses) are immediately informed by means of automated notifications.

One outstanding challenge in the JIT Pilot process is that the initial notification (i.e., the notification regarding the level of care that an ED patient will eventually require) from the ED clinicians to the critical care nursing supervisor is not automated. However, ED clinicians expect that adherence to this process step will be higher than current state because this notification is now the only bed assignment process step after initial patient evaluation until the patient is ready to transfer. After initial evaluation of a new patient, action-oriented ED clinicians will feel compelled to complete at least one process step in order to 'close the loop'.

6.2.2 OR-to-ICU Transfers

Under the JIT Pilot policy, admitting bed managers still begin each day by reviewing the daily surgery schedule and by working with the critical care nursing supervisor to resolve anticipated ICU capacity issues. The schedule specifies the level of inpatient care likely required by each elective surgery patient and the critical care nursing supervisor is continuously triaging demand for ICU beds based on patient acuity. Unlike the current state, admitting bed managers do not assign surgical patients to ICU beds based on the surgery schedule. Instead, bed managers wait until receiving notification from an OR nurse regarding the readiness of a particular surgical patient. In each procedure room, the OR nurse calls admitting as well as the ICU once the patient's procedure is one hour from completion. At this point, admitting bed mangers consider the surgical patient ready to transfer and assign the patient to the first available bed in the appropriate destination unit (e.g., Lunder 6 neuroscience ICU). Although the surgical patient is not clinically ready to transfer for another hour, the JIT Pilot policy permits the early bed assignment in this case because the patient's future readiness can be predicted with very high certainty based on the event-driven notification from OR procedure room. Admitting bed mangers use Epic to execute unit assignments. This transaction automatically generates a page to the ICU resource nurses. The ICU resource nurses determine the final room and bed assignments and ICU OAs execute the final room and bed assignment decisions in Epic.

Most neurosurgical patients who require recovery time in the ICU are transferred directly from their operating room to the ICU. After receiving notification that a procedure will finish in one hour from the OR nurse, the ICU resource nurse prepares the unit to receive the surgical patient. The OR procedure room nurses facilitates patient transport to the ICU and once the patient arrives, the ICU OA records the actual arrival time in Epic. Figure 21 in Appendix B illustrates the JIT Pilot OR-to-ICU bed assignment and patient transfer process.

The JIT Pilot process addresses the current premature bed assignment practice. Instead of making bed assignment decisions early in the morning based on a static snapshot of the surgery schedule, admitting bed managers assign surgical patients to beds as they finish their procedures approach completion throughout the day. The definition of patient readiness is clearly defined and event-driven. This process enables the more efficient utilization of limited MGH inpatient bed capacity.

6.2.3 ED-to-Floor Transfers

For patient movements from the emergency department to an inpatient floor, the JIT Pilot process still begins with patient evaluation in the ED by the attending physician. Under the JIT Pilot policy, however, ED clinicians only place an electronic bed request in EDIS once an ED patient is clinically ready to transfer to the floor. Admitting bed managers do not assign admitted ED patients to floor beds until receiving a bed request from the ED. Like the current state, a bed request submitted by ED clinicians via EDIS automatically generates a bed request for admitting in Epic. After receiving a bed request from the ED, admitting bed managers use Epic to pend the patient to a floor unit (e.g., Lunder 7 neuroscience inpatient care unit) based on unit occupancy. This transaction automatically generates a page to the floor resource nurses for that inpatient unit. Like the current state, the floor resource nurses determine the final room and bed assignments while the floor OAs execute these decisions in Epic. The JIT Pilot process calls for the ED and floor nurses to complete the required nursing handoff within one hour of the initial EDIS bed request. The ED nurses facilitate the transport of the ED patient to the appropriate inpatient floor and the floor OA records the patient's arrival time in Epic. Figure 23 in Appendix C illustrates the JIT Pilot ED-to-Floor bed assignment and patient transfer process.

One major benefit of the JIT Pilot process is the association between the placement of EDIS bed requests and a specific patient status (i.e., ready to transfer to the floor). Downstream stakeholders can now use the EDIS bed request as a reliable, event-driven trigger to begin other process steps. Admitting bed managers are confident that the ED patient is ready, so they immediately assign the patient to floor units as beds are or become available. After unit assignments by admitting, resource nurses execute final room and bed assignments. The JIT Pilot process will enable inpatient unit resource nurses to make the final bed assignments quicker, again driven by the fact that all stakeholders now know that the pended patient is actually ready to transfer. Critically, this allows nurses in the ED and in the floor unit to more reliably predict when they will need to execute the required nursing handoff. The JIT Pilot process calls for the completion of the nursing handoff within one hour of the initial EDIS bed request. While an hour-long wait from patient readiness to transfer to the nursing handoff is not perfect, it would be a significant improvement over historical transfer processing wait times, particularly the tail of the distribution (see Figure 4 in 3.3.1).

One outstanding challenge in the ED-to-Floor JIT Pilot process (and, to a lesser extent, ED-to-ICU JIT Pilot process) is the lack of a clearly defined and widely accepted definition for patient readiness to transfer. It is critical to establish a clinical definition of patient readiness to transfer because ED clinicians will now place EDIS bed requests once patients reach this status.

Clinicians and administrators from the ED and the neurosciences have explained how this depends on a number of factors. For a full discussion, please see the opportunities for further study in Section 8.2.

6.2.4 OR-to-Floor Transfers

Under the JIT Pilot policy, admitting bed managers still begin each day by reviewing the daily surgery schedule and attending in-person meetings with inpatient floor clinicians to discuss unit occupancy. The schedule specifies which elective surgical patients will likely require floor beds and the floor resource nurses share information about expected discharges. However, unlike the current state, admitting bed managers do not assign surgical patients to inpatient floor beds based on the surgery schedule. Instead, bed managers wait until receiving notification from a PACU nurse regarding the readiness of a particular surgical patient.

Most neurosurgical patients who need recovery time on an inpatient floor first spend time in the PACU. These patients usually transfer from their operating room to the PACU immediately following their surgery. PACU recovery durations vary from patient to patient. Like the current state, clinicians in the PACU determine when each patient is medically ready to transfer and manually input a ready-to-depart timestamp in PRISM. In the JIT Pilot process, the PACU nurse performs an additional process step. As he inputs the ready-to-depart timestamp in PRISM, the PACU nurse also calls admitting directly. Upon receiving notification from the PACU, admitting bed managers pend the surgical patient to a floor unit (e.g., Lunder 7 neuroscience inpatient floor unit) on a first-ready, first-assigned basis. Bed mangers use Epic to execute unit assignments. This transaction automatically generates a page to the appropriate floor resource nurses. The resource nurses determine the room and bed assignments as well as prepare the unit to receive the surgical patient. Nurses in the PACU facilitate the patient's transport and OAs in each floor care unit record the actual patient arrival times in Epic. Figure 25 in Appendix D illustrates the JIT Pilot OR-to-Floor bed assignment and patient transfer process.

The JIT Pilot process for OR-to-Floor movements addresses the premature bed assignment practice as it does for OR-to-ICU patient movements. Surgical patients are assigned to beds based on their actual readiness to transfer (as determined by PACU clinicians) instead of based on the surgery schedule. The definition of patient readiness is clearly defined and the notification of admitting by PACU clinicians effectively triggers the initiation of the PACU-to-floor transfer process. Finally, timely recording of the ready-to-depart timestamp in PRISM will likely improve as this process step is now coupled with the important call to admitting.

6.3 Small-Scale Early Discharge Intervention

Section 4.3 explains how the intraday timing of neuroscience inpatient floor admissions and discharges are misaligned. Demand for floor beds early in the morning often outstrips the available supply. Neuroscience patients are discharged late in the day independent of their clinical service and of their discharge destination. This suggests that capacity constraints at non-home locations like rehabilitation and long-term care hospitals are not the principal driver of late intraday discharge timing. Instead, this project investigates internal MGH processes that could influence the timing of floor discharges. This section develops a small-scale early discharge intervention to better align the intraday timing of floor discharges with the timing of demand for floor beds.

The capacity of inpatient floor care units is currently a limiting constraint to neuroscience patient flow. Patients in the ED, the perioperative environment and especially the ICU are often clinically ready to transfer and waiting for an available floor bed. Earlier intraday discharge times generally improve system-wide patient flow by unloading inpatient floor capacity. To discharge a patient from a neuroscience floor unit, the patient must be clinically ready to discharge and clinicians and administrators must perform a number of discharge processing tasks. This work does not address the former; the interventions are not designed to curtail the duration of a patient's recovery. Instead, this project addresses the latter; the early discharge intervention focuses on operational discharge processing tasks.

The early discharge intervention is intentionally 'small-scale' in that it only targets one patient from each neuroscience clinical service who will be discharged to home on selected days. On a typical day, four or five neurosurgery patients and four or five neurology patients are discharged from the neuroscience inpatient floors to home. Currently, neuroscience clinicians and administers prioritize inpatient care and teaching over discharge processing early in the morning. This reflects MGH's mission to deliver the very best health care as well as MGH's patient-first culture. In the limited early morning hours, physicians will always choose to see a more acute patient than to process a time-consuming discharge for a fully recovered patient. However, if the early morning discharge processing is extremely quick[51], there is value in discharging the healthy patient as early as possible. The recovered patient no longer requires the level of care provided by the inpatient floor care units. Elsewhere in the hospital, the inpatient floors are the appropriate level of care for a different, more acute patient. If clinicians can dedicate a small amount of valuable early morning time to discharge processing, then this approach will actually improve patient care by freeing up floor capacity for more appropriate and more acute patients. Unloading this floor capacity early in the morning improves system-wide patient flow too. Due to the

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[51] . A 'large-scale' early discharge intervention that calls for clinicians and administrators to discharge all patients early in the morning would inherently be very time consuming early in the morning.

current misalignment between demand for floor beds and typical discharge timing, this modest increase in floor capacity yields significant reductions to patient wait times.

The small-scale early discharge intervention is designed to minimize the early morning discharge processing time. Interdisciplinary neurosurgery and neurology teams have each developed detailed processes to enable early morning discharges. Due to lower clinical staffing levels over the weekends, both neuroscience services identify target patients daily on Monday through Friday for early discharge the following day (Tuesday through Saturday). Each weekday, neurosurgery clinicians identify one target patient while each neurology team (RDA and CMF[52]) also identifies a target patient. On a given day, a team may not have a candidate for early discharge, but on other days, every team may have a quality candidate for a total of three target patients. All teams select from patients who will be discharged from MGH to home (with or without home care services) because the required coordination for patients with other discharge dispositions (e.g., placement in a long-term care facility) is more complex.

Critical components of the processes include early identification of target patients as well as early communication of the discharge plan to the target patients. For neurosurgery, the attending physician is responsible for identifying the target patient on the day before the early morning discharge. She makes this decision in consultation with the neurosurgery resident physician and nurse practitioners, who meet for the daily 'card flip' at 7 a.m. Once the attending physician identifies the target patient, the nurse practitioner (who is the 'responding clinician' for that patient) is responsible for three additional processing tasks:

[52] MGH neurology clinicians are divided into two primary teams: RDA and CMF. RDA is named for Raymond D. Adams and CMF is named for C Miller Fisher.

1. Inform the inpatient floor resource nurse and case manager(s) at the daily 9 a.m. Interdisciplinary Rounds
2. By 9:30 a.m., inform the target patient that they will discharged the following morning
3. By 10 a.m., email the JIT Pilot mailbox[53] with the following details: patient name, patient medical record number (MRN), and target discharge date

For neurology, the attending physician for the RDA service and the attending physician for the CMF service are each responsible for identifying target patients on the day before the early morning discharge. For both services, the attending physician makes this decision in consultation with the clinical team during the daily 7:30 a.m. rounds. Once the attending physician identifies the target patient, the senior resident physician (who is the 'responding clinician' for that patient) is responsible for two additional processing tasks:

1. By 8 a.m., inform the target patient that they will discharged the following morning
2. By 8:30 a.m., email the JIT Pilot mailbox with the following details: patient name, patient MRN, patient clinical service, and target discharge date

The early morning discharge processes include a validation step to ensure that each service selects a target patient. If target patient details have not been received by the JIT Pilot mailbox at 10 a.m., a designated administrator will notify the appropriate responding clinician (i.e., the nurse practitioner for neurosurgery and the senior resident for neurology) as well as the neuroscience nursing directors.

[53] The JIT Pilot mailbox is MGH email account designed to facilitate easy status notifications regarding the target early morning discharge patients during the pilot implementation of this intervention. Recipients of the notifications include nursing leadership as well as neuroscience physicians, nursing directors, resource nurses and administrators.

Most patients who are discharged from MGH to home are picked up at the hospital by their family members. To preempt pick up issues and delays, neurosurgery nurse practitioners and neurology senior residents will communicate a message like the following to target patients on the day before discharge: "If your recovery continues to progress as expected, the plan is to discharge you tomorrow morning by 9:45 a.m. to the patient lounge. Your family can pick you up from here any time before 9:45 a.m. or pick you up from the lounge any time after 9:45 am". While the exact wording will vary from day to day and from patient to patient, it is important that clinicians set a clear expectation for an early morning discharge and that discharge to the lounge is not presented as an inferior or unplanned option.

Various clinicians must promptly complete a number of tasks once a patient is identified for an early morning discharge the following day. A multidisciplinary neuroscience team has developed an Early Morning Discharge Checklist (see

Figure 28 in Appendix F), which specifies the discharge processing tasks that must be completed for the target patients on the day before discharge. The early morning discharge intervention relies on clear accountability for the execution of the discharge processing tasks on the Early Morning Discharge Checklist. Throughout the day, the bedside nurse records progress as well as barriers to discharge in the EDD tool[54] and on the whiteboard in the target patient's room. At 2 p.m. on the day before discharge, the bedside nurse for each target patient verifies the status of all discharge tasks with each task owner. If issues arise relating to outstanding tasks, bedside nurses are expected to escalate to the responding clinician (i.e., the nurse practitioner for neurosurgery and the senior resident for neurology) for the target patient. If the responding

[54] The Estimated Data of Discharge (EDD) tool is an enhancement to ONCALL (Apprentice), an application used for MGH eBridge. The tool facilitates communication about the date, destination and barriers to discharge. It is a fast, simple mechanism used in rounding or while reviewing a patient's status.

clinician is unable to resolve the outstanding issues, the responding clinician is expected to escalate to the attending physician for the target patient. The 2 p.m. checkpoint allows enough time after the target patients have been identified for clinicians to execute the discharge processing tasks on the Early Morning Discharge Checklist. It is also early enough so that outstanding issues are identified, escalated (if necessary) and resolved on the day before discharge.

The early morning discharge processes include an additional validation step to ensure that each target patient is progressing towards discharge readiness. At 4 p.m. on the day before discharge, the nursing director for each neuroscience floor will check in with the bedside nurses responsible for each of the target patients. Based on the target patients' status, the nursing directors will assist the bedside nurses in resolving any outstanding tasks, collaborating with other clinicians and escalating issues as necessary.

On the day of discharge, it is critical that the final discharge decision is made and communicated to the entire team early in the morning. For both the neurosurgery and the neurology services, the attending physicians have empowered the responding clinician to make the final discharge decision for patients whose recovery progresses as expected. If a target patient's recovery does not proceed as expected, the responding clinicians will of course consult the attending physician and the target patient will likely not be discharged early in the morning. In either case, the final discharge decision is communicated to the entire clinical team early in the morning. For neurology, the senior resident informs the clinical team during the daily rounds at 7:30 a.m. For neurosurgery, the nurse practitioner notifies the inpatient floor resource nurse by 8 a.m. (after the daily 'card flip' with the neurosurgical residents at 7 a.m.). For all services, the resource nurses work with case management and the bedside nurses to facilitate patient discharge by 10 a.m.

Figure 26 and Figure 27 in Appendix E illustrate the small-scale early discharge process for the neurosurgery and neurology clinical services, respectively. See Appendix H for additional technical details of the simulation of neuroscience patient flow under the conditions of the small-scale early discharge intervention.

6.4 Small-Scale Early Transfer Intervention

Section 4.4 describes how the intraday timing of demand for neuroscience ICU beds and patient transfers from the ICU are misaligned. Demand for ICU beds early in the morning frequently surpasses the available supply. Neuroscience ICU patients typically transfer to the floor units late in the day because newly admitted patients (e.g., from the ED or the OR) who require floor-level care are generally prioritized over the ICU patients. This section develops a small-scale early transfer intervention to better align the intraday timing of patient transfers from the neuroscience ICU with timing of demand for ICU beds.

The small-scale early transfer intervention depends on the small-scale early discharge intervention to create available floor beds early in the morning. The early transfer intervention then seeks to best utilize the available capacity to improve system-wide patient flow. The neuroscience patient flow simulation shows how one early ICU to floor transfer (as opposed to zero or two transfers) best impacts system-wide patient flow. One early ICU to floor transfer reduces the predicted wait times for patients transferring to the ICU without significantly increasing wait times for non-ICU patients transferring to the floors. This is desirable because patients transferring to the ICU are generally more sensitive to long wait times than are patients transferring to inpatient floor care units[55]. Yet two early ICU to floor transfers does increase predicted wait times for non-ICU patients transferring to the floors, without significantly further reducing the predicted wait times for patients transferring to the ICU. Thus, the small-scale early transfer intervention only targets one neuroscience patient for an early transfer from the neuroscience ICU to the floors each day.

Like the processes for early morning discharges from the inpatient floors, an interdisciplinary neuroscience team has developed detailed process enabling early movements from the ICU to the floors. Due to lower clinical staffing levels over the weekend, ICU clinicians only identify ICU patients as target candidates on Monday through Friday for early transfer to the floor the following day (Tuesday through Saturday).

The critical care attending physician is responsible for determining which ICU patients are medical ready to transfer to the inpatient floor. Among all ICU patients who are ready to move, the ICU resource nurse identifies the target patient for an early transfer during the ICU 'resource report', a recurring morning meeting among ICU clinicians. If patients from both neurosurgery and neurology are quality candidates for an early transfer, ICU clinicians prioritize neurosurgery patients because the transfer process is simpler for these patients relative to patients from the neurology clinical service. In particular, the ICU to floor transfer process for a neurosurgery patient does not include a physician handoff, while the same movement for a neurology patient requires a handoff from the critical care physician to a floor-based neurologist. Individual neurosurgery physicians are continuously responsible for their patients from before the procedure to the actual operation and recovery, including both critical and general inpatient care.

[55] Table 3 in Section 3.3.2 lists the established acceptable wait lengths (AWLs) by movement type. For example, for ED-to-ICU and OR-to-ICU movements, the AWL is 30 minutes. For ED-to-Floor and OR-to-Floor movements, the AWL is two hours.

An early morning handoff between the critical care physician and neurologist, on the other hand, is challenging because floor-based neurologists prioritize seeing their existing patients to begin each day.

The ICU resource nurse communicates the final target patient decision to the critical care nursing supervisor, the inpatient floor resource nurses and the JIT Pilot mailbox[56]. Specifically, the ICU resource nurse emails the following details to the JIT Pilot mailbox by 9:30 am: patient name, patient medical record number (MRN), and target transfer date.

The early transfer process includes an additional validation step to ensure that ICU clinicians select a target patient. If target patient details have not been received by the JIT Pilot mailbox at 10 a.m., a designated administrator will notify the neuroscience ICU resource nurse as well as the neuroscience ICU nursing director.

Various clinicians must promptly complete a number of tasks once the ICU resource nurse identifies a patient for an early transfer to the floor the following morning. One key element of the early transfer process is that neurology residents (who typically do not see patients until the patient has transferred to the floor) see patients in the ICU on the day before the transfer. This jumpstarts the required physician handoff for neurology patients transferring from the neuroscience ICU to an inpatient floor care unit.

On the day of the transfer, the ICU clinicians coordinate with the inpatient floor clinicians and admitting staff at the 9:15 a.m. neuroscience bed meeting to facilitate the early movement of the target patient from the ICU to the inpatient floor. In addition to improving patient flow, the

[56] The JIT Pilot mailbox is MGH email account designed to facilitate easy status notifications regarding the target early morning transfer patients during the pilot implementation of this intervention. Recipients of the notifications include nursing leadership as well as neuroscience physicians, nursing directors, resource nurses and administrators.

reliable transfer of one ICU patient to a neuroscience floor bed early in the morning helps neuroscience floor staff better plan clinical staffing. Figure 29 in Appendix G illustrates the small-scale early transfer process for neuroscience ICU to floor movements. See Appendix I for additional technical details of the simulation of neuroscience patient flow under the conditions of the small-scale early transfer intervention.

7 Predicted Results

This work uses a simulation model of neuroscience patient flow to evaluate the effectiveness of several solution approaches. Chapter 5 provides an overview of the simulation model and explains how the simulation measures patient movements based on the time that patients spend in different processes and queues. This project uses multiple performance metrics (see Section 3.3) to compare the results of simulation scenarios to historical patient movement timing. Chapter 6 outlines the three most promising solution approaches. This chapter summarizes the predicted results of the neuroscience patient flow simulation under the conditions outlined in these solution approaches.

7.1 Summary of Predicted Results

The most promising solution approaches are a just-in-time (JIT) bed assignment policy, a small-scale early discharge intervention and a small-scale early transfer intervention. This project creates a 'JIT Policy' simulation scenario that combines these three approaches. Table 9 provides a summary of the predicted results of the JIT Policy simulation scenario by patient movement.

Patient Movement	Acceptable Wait Length	Percentage of Bed Waits within AWL	
		Historical	JIT Policy
ED-to-ICU	30 min	43.9%	90.4%
OR-to-ICU	30 min	91.2%	94.9%
ED-to-Floor	2 h	62.7%	80.8%
OR-to-Floor	2 h	83.8%	92.8%

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

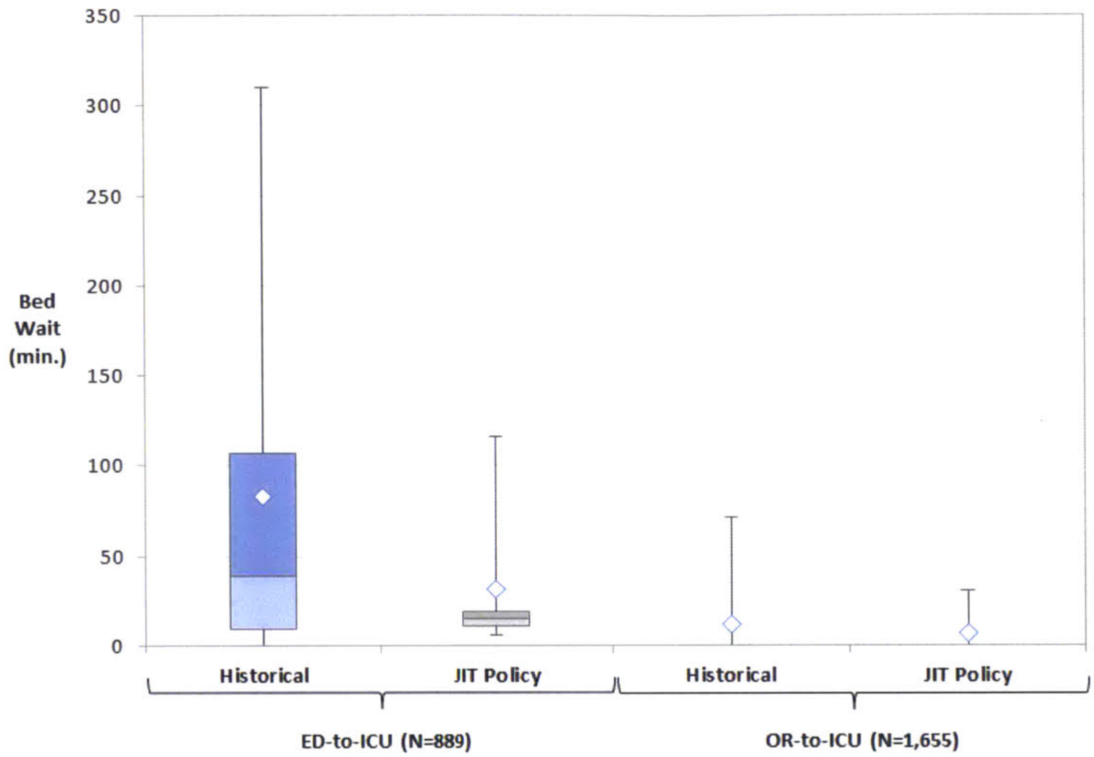
Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=889 (ED-to-ICU); N=1,655 (OR-to-ICU); N=2,247 (ED-to-Floor); N=1,978 (OR-to-Floor).

Table 9: Summary of Predicted Results

The simulation shows that the JIT bed assignment policy and the small-scale early discharge and transfer interventions would significantly reduce intraday patient wait times. In particular, the model predicts that the JIT Pilot scenario would increase the percentage of patients who experience bed waits within the acceptable wait length (AWL) for all movement types[57].

For each patient movement to the neuroscience ICU, Figure 11 compares the full distributions of predicted and historical bed wait times.

[57] Section 3.3.1 explains how patient movements are measured and Table 3 in Section 3.3.2 lists the established acceptable wait lengths (AWLs) by movement type.



Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

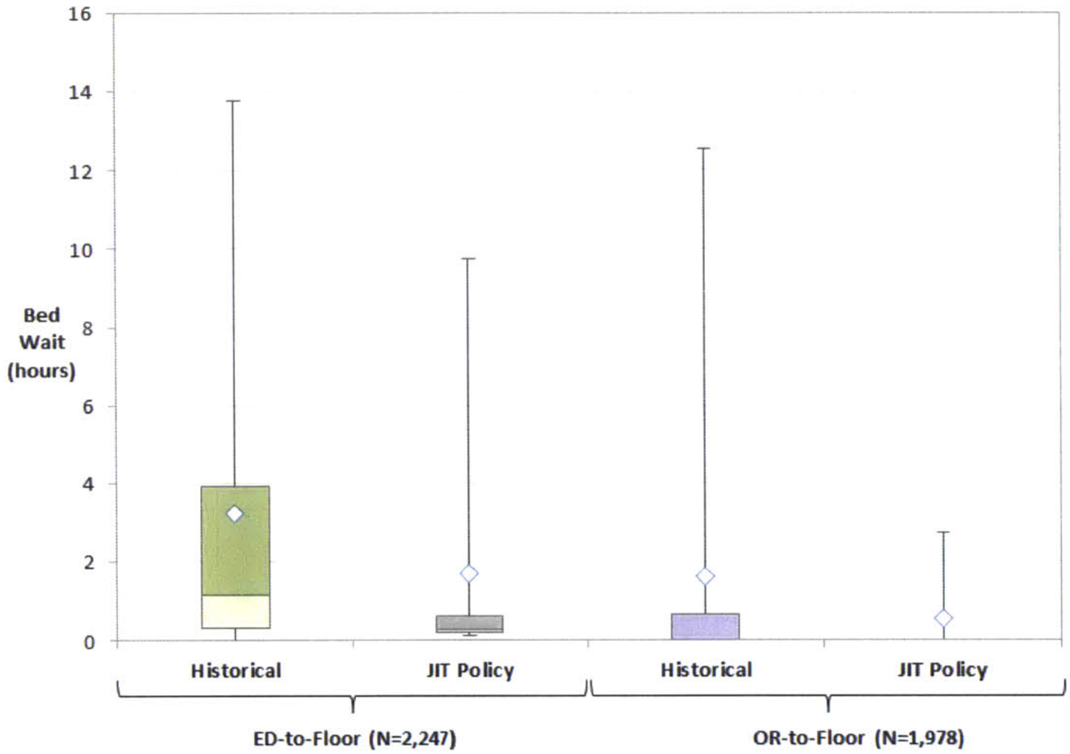
Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=889 (ED-to-ICU); N=1,655 (OR-to-ICU). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 11: Predicted To-ICU Bed Wait Times by Patient Movement

The simulation predicts that bed waits for neuroscience patients who require ICU-level care would be 30 minutes or less for 90.4%[58] of ED patients and 94.9%[59] of OR patients (improvements from historical baselines of 43.9%[60] and 91.2%[61], respectively).

[58] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=804.
[59] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,571.
[60] Sources: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=390.
[61] Sources: Patcom, Periop Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=1,510.

For each patient movement to the neuroscience inpatient floors, Figure 12 compares the full distributions of predicted and historical bed wait times.



Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=2,247 (ED-to-Floor); N=1,978 (OR-to-Floor). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 12: Predicted To-Floor Bed Wait Times by Patient Movement

The simulation predicts that bed waits for transfers to neuroscience inpatient floor beds would be two hours or less for 80.8%[62] of ED patients and 92.8%[63] of OR patients (improvements from historical baselines of 62.7%[64] and 83.8%[65], respectively).

[62] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,815.

The simulation also shows that the JIT bed assignment policy and the small-scale early discharge and transfer interventions would reduce significantly reduce delay unrelated to bed availability (DUBA) experienced by neuroscience patients too. DUBA directly measures the delays resulting from suboptimal bed assignment polices by calculating the bed wait time incurred by patients in their origin unit while suitable beds are available in their destination units. Cumulative DUBA is the sum of all DUBA incurred by patients during the timeframe. Table 10 lists the predicted cumulative DUBA by unit.

Scenario	Neuroscience ICU		Neuroscience Floors	
	DUBA (h)	DUBA (days)	DUBA (h)	DUBA (days)
Historical	1,147	47.8	6,495	270.6
JIT Policy	623	26.0	3,156	131.5

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Neuroscience ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Neuroscience Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. Delay unrelated to bed availability (DUBA) is the bed wait time incurred by patients in their origin unit while clean beds are available in their destination units. Cumulative DUBA is the sum of all DUBA incurred by patients during the timeframe.

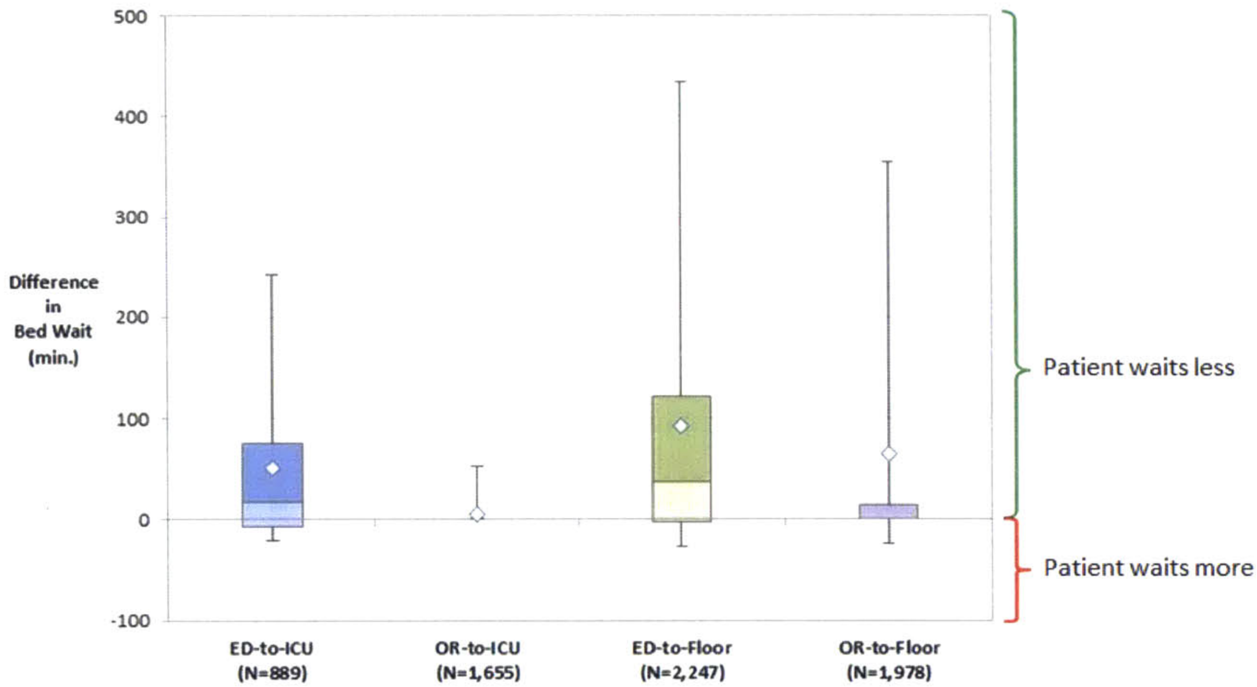
Table 10: Predicted Cumulative Delay Unrelated to Bed Availability by Unit

The simulation predicts that the cumulative DUBA would decrease by over 45% for patients transferring to neuroscience ICU beds and more than 51% for patients transferring to neuroscience inpatient floor beds.

[63] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,835.
[64] Sources: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=1,409.
[65] Sources: Patcom, Periop Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=1,658.

7.2 Predicted Results by Patient Movement

This section discusses the simulation of neuroscience patient flow for the JIT Policy scenario in further detail. First, Figure 13 presents the difference between the predicted bed wait under the conditions of the JIT Policy and the historical bed wait for each patient.



Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes after departure from either the ED or the perioperative environment are excluded). N=889 (ED-to-ICU); N=1,655 (OR-to-ICU); N=2,247 (ED-to-Floor); N=1,978 (OR-to-Floor). Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 13: Difference between JIT Policy and Historical Bed Wait Times for Each Patient

The patient-by-patient comparison of bed wait times shows that under the JIT Policy, the majority of patients wait less than historically. On the other hand, just 4.0%[66] of all patients experience bed wait times more than 30 minutes longer than their historical bed waits.

7.2.1 ED-to-ICU Transfers

The simulation of neuroscience patient flow shows that the JIT Policy would reduce the total ED-to-ICU bed wait time by 62.2%[67]. Under the JIT policy, 66.0%[68] of patients experience bed waits shorter than historical while 32.6%[69] of patients experience bed waits longer than historically. However, only 3.3%[70] of all patients wait more than 30 minutes longer than their historical bed wait times.

For ED patients who require ICU-level care, Figure 14 provides the predicted bed wait times for patients segmented based on their historical bed waits.

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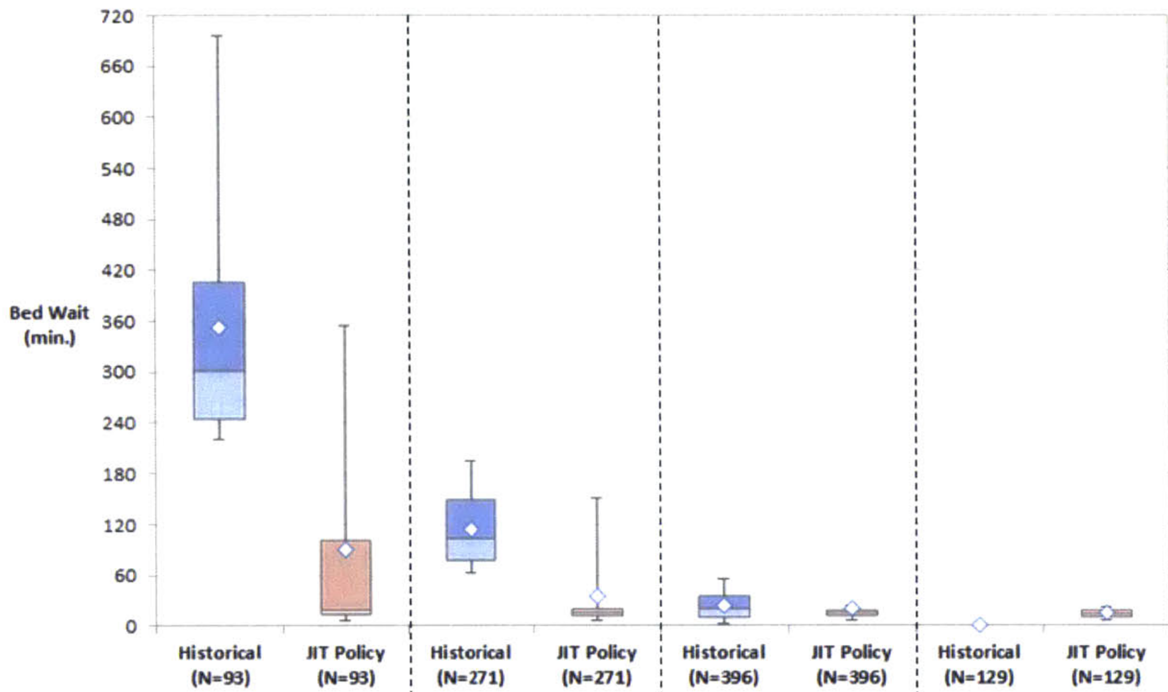
[66] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=270.
[67] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. Historical: 134.4 min./day; JIT Policy: 50.8 min./day.
[68] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=587.
[69] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=290.
[70] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=29.



Percentile	90% - 100%	59% - 90%	15% - 59%	0% - 15%
Historical Bed Wait (BW)	BW > 3.5 hrs	3.5 hrs > BW > 1 hr	1 hr ≥ BW ≥ 1 min	0 mins

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=889 for all ED-to-ICU movements; segmentation by historical bed wait shown above. Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 14: Predicted ED-to-ICU Bed Waits by Historical Bed Wait Segment

The model predicts that patients with the longest 10.5%[71] of historical bed waits (over 3.5 hours) would benefit from the JIT Policy the most. For this segment, the average bed wait decreases from almost six hours to around 90 minutes. Historically, 14.5%[72] of patients did not experience a bed wait (i.e., their destination bed was ready and assigned before they were ready to transfer).

[71] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=93.
[72] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=129.

Under the JIT Policy, all of these patients would experience a nonzero bed wait, although the predicted average is only 15 minutes and more than 95% of these patients would experience a bed wait of 22 minutes or less.

7.2.2 OR-to-ICU Transfers

The simulation of neuroscience patient flow shows that the JIT Policy would reduce the total OR-to-ICU bed wait time by 44.4%[73]. Historically and per the JIT Policy, 85.0%[74] of patients do not experience a bed wait. Under the JIT Policy, 10.9%[75] of patients experience bed waits shorter than historical, 4.1%[76] of patients experience bed waits longer than historical and 2.9%[77] of patients experience bed waits more than 30 minutes longer than their historical bed wait times.

For surgical patients who require ICU-level care, Figure 15 provides the predicted bed wait times for patients segmented based on their historical bed waits.

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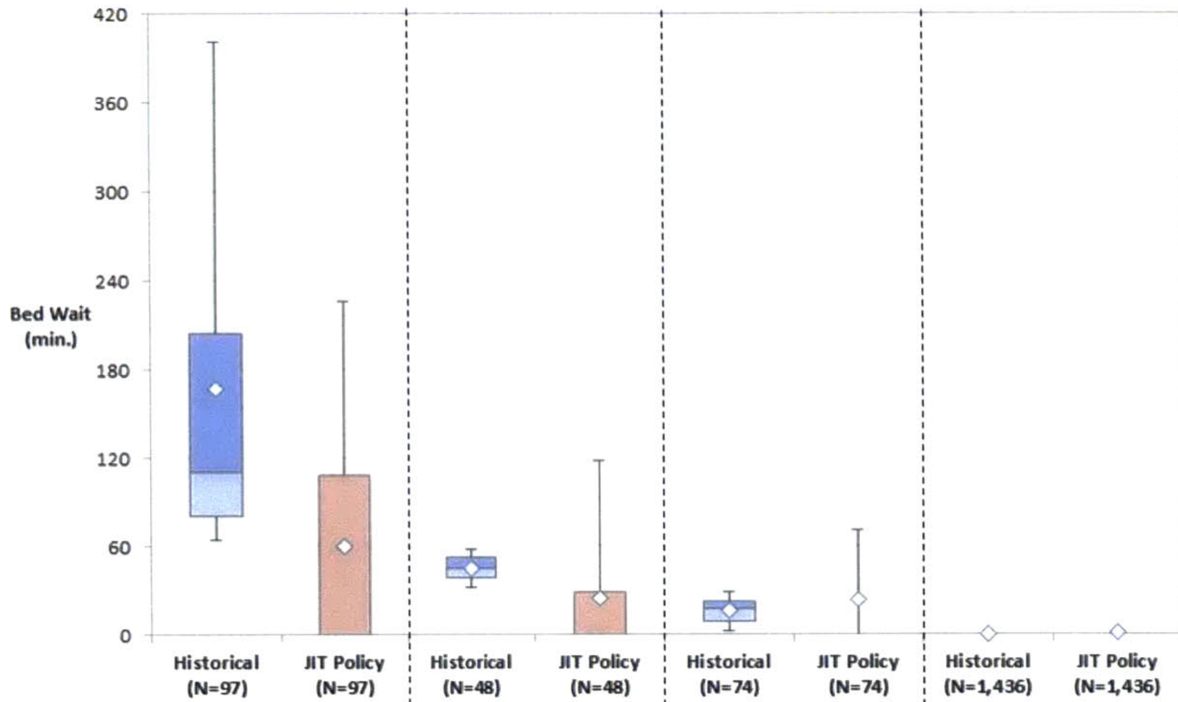
[73] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. Historical: 35.9 min./day; JIT Policy: 19.9 min./day.
[74] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,406.
[75] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=181.
[76] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=68.
[77] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=48.



Percentile	94% - 100%	91% - 94%	87% - 91%	0% - 87%
Historical Bed Wait (BW)	BW > 1 hr	1 hr ≥ BW > 30 mins	30 mins ≥ BW ≥ 1 min	0 mins

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'ICU' is the 22-bed Lunder 6 neuroscience ICU. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=1,655 for all OR-to-ICU transfers; segmentation by historical bed wait shown above. Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 15: Predicted OR-to-ICU Bed Waits by Historical Bed Wait Segment

The model predicts that patients with the longest 6% of historical bed waits (over one hour) would benefit from the JIT Policy the most. For this segment, the average bed wait decreases from almost three hours to around one hour and the median decreases from almost two hours to zero. For patients with nonzero historical bed waits less than or equal to one hour, the JIT Policy reduces the average bed wait but the 95^{th} percentile of the distribution of predicted bed waits is higher than the 95th percentile of the distribution of historical bed waits. In other words, for these specific segments of OR-to-ICU transfers, the JIT Policy reduces overall bed wait time while a few patients end up waiting longer than historically. This represents an opportunity for further research and improvement.

Historically, 86.8%[78] of all surgical patients who require ICU-level care did not experience a bed wait (i.e., their destination bed was ready and assigned before they were ready to transfer). Section 4.1 explains how these patients are often assigned to beds before they have even arrived to the hospital. The model shows that over 97.2%[79] of these patients would not experience a bed wait under the JIT Policy too.

7.2.3 ED-to-Floor Transfers

The simulation of neuroscience patient flow shows that the JIT Policy would reduce the total ED-to-Floor bed wait time by 47.9%[80]. Under the JIT policy, 70.9%[81] of patients experience bed waits shorter than historically while 26.2%[82] of patients experience bed waits longer than historically. Yet just 4.8%[83] of all patients wait more than 30 minutes longer than their historical bed wait times.

For ED patients who require floor-level care, Figure 16 provides the predicted bed wait times for patients segmented based on their historical bed waits.

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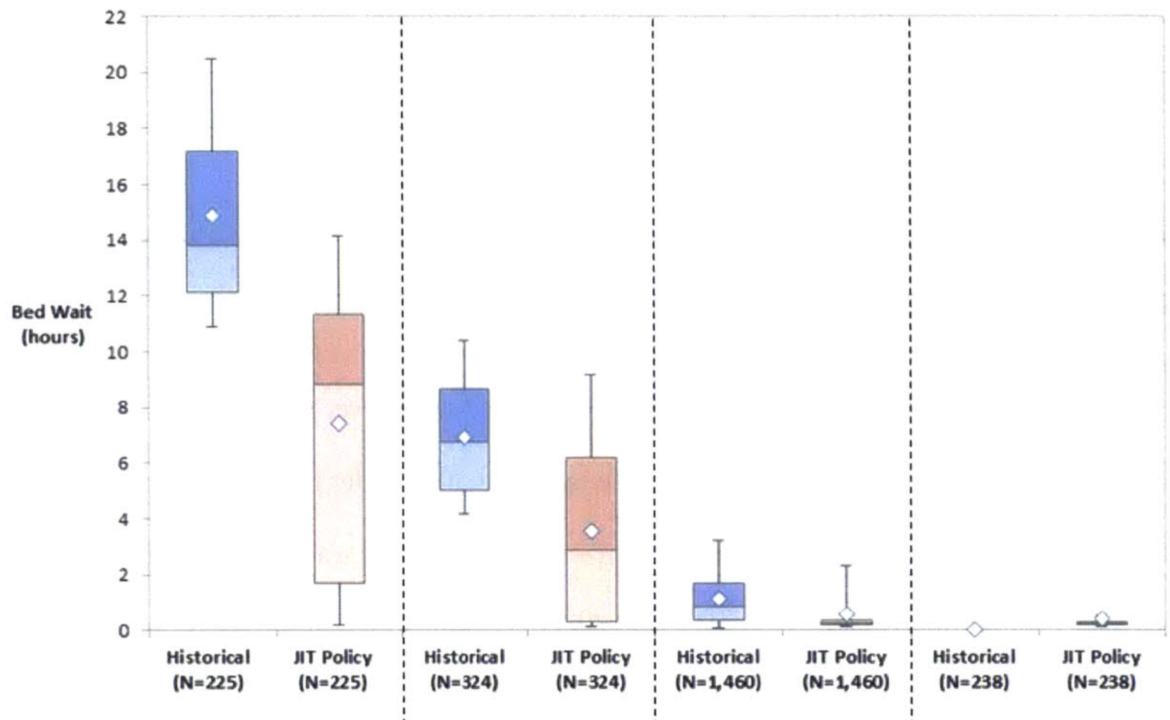
78 Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,436.
79 Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,396.
80 Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. Historical: 13.3 hours/day; JIT Policy: 6.9 hours/day.
81 Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,592.
82 Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=589.
83 Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=107.



Percentile	90% - 100%	76% - 90%	11% - 76%	0% - 11%
Historical Bed Wait (BW)	BW > 10.5 hrs	10.5 hrs > BW > 4 hrs	4 hrs ≥ BW ≥ 1 min	0 mins

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=2,247 for all ED-to-Floor transfers; segmentation by historical bed wait shown above. Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 16: Predicted ED-to-Floor Bed Waits by Historical Bed Wait Segment

For patients transferring from the ED to the neuroscience inpatient floor units, over 10% of patients experience bed waits of more than 10 hours. These patients benefit from the JIT Policy interventions. The model predicts that for patients with the longest 10.0%[84] of historical bed waits (over 10.5 hours), the average bed wait would decrease by over seven hours and the entire

[84] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=225.

distribution of bed waits improves as well. However, the predicted bed waits in the JIT Policy scenario are still quite long. For this particular segment of patients, the predicted average bed wait is over seven hours, the predicted median bed wait is almost nine hours and at the high end of the distribution, over 5% of these patients would wait more than 14 hours. This represents an opportunity for further research and improvement.

For the 14.4%[85] of patients who experienced historical bed waits over four hours but less than 10.5 hours, the average bed wait would decrease by about 50% under than JIT Policy. Similarly, for the 70.0%[86] of patients who experienced nonzero historical bed waits less than four hours, the average bed wait per the JIT Policy would again decreased by about 50%. Lastly, 10.6%[87] of ED patients requiring floor-level care did not experience a historical bed wait (i.e., their destination bed was ready and assigned before they were ready to transfer). Under the JIT Policy, all of these patients would experience a nonzero bed wait, although the predicted average is only 26 minutes and more than 95% of these patients would experience a bed wait of 33 minutes or less.

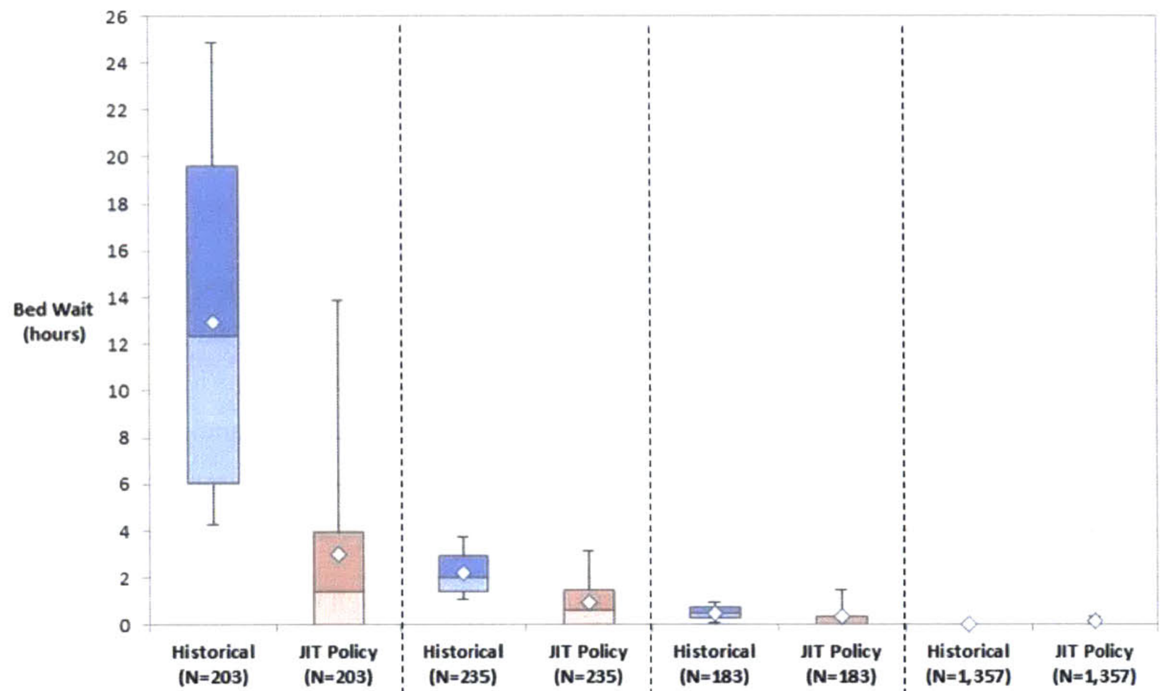
7.2.4 OR-to-Floor Transfers

The simulation of neuroscience patient flow shows that the JIT Policy would reduce the total OR-to-Floor bed wait time by 66.8%[88]. Most patients (i.e., over 65.2%[89]) experience the same bed wait in the simulation of the JIT Policy as they experienced historically. Under the JIT Policy, 26.9%[90] of patients experience bed waits shorter than historical, 7.8%[91] of patients

[85] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=324.
[86] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,460.
[87] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=238.
[88] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. Historical: 5.9 hours/day; JIT Policy: 2.0 hours/day.
[89] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,290.
[90] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=533.
[91] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=155.

experience bed waits longer than historical and 4.3%[92] of patients experience bed waits more than 30 minutes longer than their historical bed wait times.

For surgical patients who require floor-level care, Figure 17 provides the predicted bed wait times for patients segmented based on their historical bed waits.



Percentile	90% - 100%	78% - 90%	69% - 78%	0% - 69%
Historical Bed Wait (BW)	BW > 4 hrs	4 hrs > BW > 1 hr	1 hr ≥ BW ≥ 1 min	0 mins

Sources: Patcom, EDIS, Perioperative Case Data, CBEDs

Timeframe: January 1, 2012 to June 30, 2013

Notes: 'Floor' combines the 32-bed Lunder 7 inpatient floor unit and the 32-bed Lunder 8 inpatient floor unit. The 'JIT Policy' scenario combines the JIT bed assignment policy, the small-scale early discharge intervention and the small-scale early transfer intervention. Patients who were in transit for more than 60 minutes are excluded (as they likely received care in an unknown intermediate unit before arrival to their destination). N=1,978 for all OR-to-Floor transfers; segmentation by historical bed wait shown above. Upper and lower bounds correspond to 95th percentiles and 5th percentiles, respectively.

Figure 17: Predicted OR-to-Floor Bed Waits by Historical Bed Wait Segment

[92] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=86.

The model predicts that patients with the longest 10.3%[93] of historical bed waits (over four hours) would benefit from the JIT Policy the most. For this segment, the average bed wait decreases from almost 13 hours to around three hours and the median decreases from over 12 hours to 83 minutes. For the 11.9%[94] of patients with historical bed waits between one hour and four hours, the average bed wait would decrease by over 55% under than JIT Policy. For the 9.3%[95] of patients with nonzero historical bed waits less than or equal to one hour, the JIT Policy modestly reduces the average bed wait but the 95th percentile of the distribution of predicted bed waits is higher than the 95th percentile of the distribution of historical bed waits. In other words, for this specific segment of surgical patients transferring to the inpatient floors, the JIT Policy reduces overall bed wait time, but a few patients at the high end of the distribution would wait longer than historically. This represents an opportunity for further research and improvement.

Finally, 68.6%[96] of all surgical patients who require floor-level care did not experience a historical bed wait (i.e., their destination bed was ready and assigned before they were ready to transfer). Section 4.1 explains how these patients are often assigned to beds before they have started their procedures and sometimes before they have even arrived to the hospital. The simulation of neuroscience patient flow shows that about 92.9%[97] of these patients would not experience a bed wait under the JIT Policy too. For those patients predicted to experience a bed wait, the average is less than two hours.

[93] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=203.
[94] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=235.
[95] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=183.
[96] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,357.
[97] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,260.

8 Final Comments

This chapter summarizes the key outcomes of this work (Section 8.1) and presents several opportunities for further research (Section 8.2).

8.1 Summary of Key Results

This work supports the MGH – MIT Collaboration's broader goal to develop predictive models, operational processes and decision support tools for managing inpatient bed resources at MGH. This project focuses on the neuroscience units at MGH as a microcosm of the hospital. The neuroscience units consistently operate near capacity and experience patient flow issues similar to those observed throughout MGH, including high bed utilization and long intraday patient wait times. This is an important problem as various studies show how long patient wait times for inpatient beds negatively affect clinical outcomes. Patient accumulation in critical units can also significantly disrupt hospital operations.

This problem is challenging because inpatient care at MGH is a complex system with many stakeholders. Patients from the emergency department, the perioperative environment, intensive care units and other sources compete for beds. The leading causes of long intraday wait times for neuroscience patients include suboptimal bed assignments (e.g., patients are frequently assigned a bed before they are clinically ready to move), late intraday discharge timing and delayed intraday transfer timing. In the morning, demand for inpatient floor beds frequently exceeds available supply as clinicians prioritize inpatient care and teaching over discharge processing. The intraday timing of demand for neuroscience ICU beds and patient transfers from the ICU are also misaligned. The primary goal of this project is to reduce intraday patient wait times by developing more efficient bed assignment policies and bed management processes.

This project used a collaborative and iterative methodology to develop and evaluate several solution approaches. MGH leaders were instrumental in assembling a working group of committed practitioners from both neuroscience clinical services, the perioperative and critical care teams, the emergency and admitting departments, and case management. These clinicians and administrators shared insights to explain observations in the historical data and provided potential solution approaches and process improvement suggestions. We performed data analysis to evaluate hypotheses and the working group shared essential feasibility considerations. In particular, we used a data-driven model of neuroscience patient flow to assess the efficacy of several new approaches. The predicted results of the simulation model provided context to facilitate discussion between hospital leaders about the inherent tradeoffs in a complex inpatient environment like MGH.

In particular, we followed this process iteratively by revisiting each step as we revealed insights and developed solutions. After the simulation of a potential policy, the working group provided feedback on the results and frequently refined process details and developed additional new suggestions. The most promising solution approach is the combination of a just-in-time (JIT) bed assignment policy, a small-scale early discharge intervention and a small-scale early transfer intervention. Under the JIT bed assignment policy, patients who are clinically ready to transfer to a particular unit are assigned to beds that become available in that unit on a first-ready, first-assigned basis. The small-scale early discharge intervention enables clinicians to discharge one patient from each neuroscience clinical service to home by 10 a.m. on selected days and the small-scale early transfer intervention designs processes for the transfer of one neuroscience patient from the neuroscience ICU to the inpatient floors by 11 a.m. on selected days. New processes enable these interventions for each neuroscience clinical service and for each patient movement type.

This project creates a 'JIT Policy' simulation scenario that combines these three solution approaches. The simulation shows that the 'JIT Policy' interventions would reduce intraday wait times for all patient movements. Predicted bed waits for patients who require ICU-level care would be 30 minutes or less for 90.4%[98] of ED patients and 94.9%[99] of OR patients (improvements from historical baselines of 43.9%[100] and 91.2%[101], respectively). Bed waits for transfers to floor beds would be two hours or less for 80.8%[102] of ED patients and 92.8%[103] of OR patients (improvements from historical baselines of 62.7%[104] and 83.8%[105], respectively). The predicted results highlight the ingenuity of the solution approaches because significant reductions in intraday wait times are achieved without a major increase in hospital capacity. If the new approaches prove to be effective in the neuroscience units, then the policies could be extended to more units and other clinical specialties in order to improve patient flow throughout MGH.

This work highlights three key takeaways. First, for this highly utilized system, a small change in capacity contributes to outsized throughput improvements and wait time reductions. Second, we found an accurate and robust model to be the most effective tool to inspire process change, particularly in a complex system like MGH. Finally, we believe that our methodology, particularly the consistent and iterative engagement with various stakeholders to develop the

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[98] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=804.
[99] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,571.
[100] Sources: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=390.
[101] Sources: Patcom, Periop Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=1,510.
[102] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,815.
[103] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: Jan. 1, 2012 to June 30, 2013. N=1,835.
[104] Sources: Patcom, EDIS. Timeframe: January 1, 2012 to June 30, 2013. N=1,409.
[105] Sources: Patcom, Periop Case Data. Timeframe: January 1, 2012 to June 30, 2013. N=1,658.

solution approaches, builds significant organization buy-in for pilot implementation and adherence to new processes.

8.2 Opportunities for Further Research

This section presents several opportunities for further study. First, the simulation of neuroscience patient flow could be used to evaluate the system-wide impact of other new interventions or operational policies. For example, the model could show the effect of a policy to discharge certain neuroscience patient populations directly from the ICU or of a policy to prioritize certain patient population for treatment in a particular neuroscience inpatient care unit (i.e., Lunder 7 or Lunder 8). Similarly, the simulation model could be used to quantify the effectiveness of interventions specifically designed to reduce transfer processing wait times, like a procedure to streamline nursing handoffs for patients transferring from the ED.

There are a few outstanding challenges to address in the JIT Pilot bed management processes. All stakeholders would benefit from efforts to make information about patient readiness more readily available and easier to act upon. Processes to capture and share information that emerges throughout the day, such as expected discharge timing and changes to the surgery schedule, could be improved.

Another outstanding challenge in the JIT Pilot processes is the lack of a clearly defined and widely accepted definition for patient readiness to transfer for ED patients. This is critical because the JIT Pilot processes call for ED clinicians place EDIS bed requests once patients reach this status. The primary question is: for an ED patient who will eventually require ICU-level care (with high certainty) and who is currently in the queue for imagining (e.g., MRI or CT), when is the patient ready to transfer? Currently, there are separate queues for patients who require imaging depending on if the order is placed from the ED or if the order is placed from the ICU. The queue for orders placed from the ED is fast, while the queue for orders placed from the ICU moves much slower. Once the patient reaches the front of the imaging queue, a nurse from their current unit (e.g., ED or ICU) must escort the patient to the emergency imaging department. Unit directors incur costs when bedside nurses must perform this task, as the nurses are usually busy with other patients and responsibilities. As a result of this system, ED clinicians typically place imaging orders from the ED to get results sooner, regardless of whether the imaging is necessary to determine the appropriate destination unit, the patient is ready to transfer or the patient is currently assigned to a ready bed. For patients transferring from the ED, the high end of the distribution of historical transfer processing wait times (see Section 3.3.1) suggests that ED clinicians may continue to order imaging for patients even after they have been assigned to a ready (i.e., clean and available) bed. Fully characterizing this process and clearly defining ED patient readiness to transfer is a significant opportunity for further study. A preliminary solution approach could be:

1. If the imagining exam is required to determine the patient's destination unit, then the patient is *not* ready to transfer and ED clinicians order the exam from the ED. The patient departs from the ED for the exam and returns to the ED after the exam. Once ED clinicians receive the imagining results, they determine the appropriate destination unit, declare the patient ready to transfer and place a bed request.
2. If the imagining exam is *not* required to determine the patient's destination unit and the patient would *not* be next up in the imaging queue, then the patient is declared ready to transfer. ED clinicians order the exam from the ED and place a bed request. The patient transfers from the ED to the ICU. Eventually, the patient departs from the ICU for the

exam and returns to the ICU after the exam. The exam results are sent to the ED and the critical care clinicians.

3. If the imagining exam is *not* required to determine the patient's destination unit but the patient would be next up in the imaging queue, then the patient is declared ready to transfer. ED clinicians order the exam from the ED and place a bed request. The patient departs from the ED for the exam, but transfers to the ICU after the exam. The exam results are sent to the ED and the critical care clinicians.

Finally, the simulation of neuroscience patient flow under the JIT Policy scenario reveals additional opportunities for further research. Under the JIT Policy, 4.0%[106] of all patients experience bed wait times more than 30 minutes longer than their historical bed waits. For OR-to-ICU transfers with nonzero historical bed waits less than or equal to one hour, the 95th percentile of the distribution of predicted bed waits is higher than the 95th percentile of the distribution of historical bed waits. Similarly, for OR-to-Floor transfers with nonzero historical bed waits less than or equal to one hour, the 95th percentile of the distribution of predicted bed waits is higher than the 95th percentile of the distribution of historical bed waits. The simulation also predicts that almost 20% of ED patients transferring to neuroscience floor beds would still experience bed waits of over two hours (i.e., the desired AWL) under the JIT Policy.

The model of neuroscience patient flow provides valuable data on the state of the system when these long intraday patient wait times occur. In some instances, these long waits would occur regardless of the bed assignment polices due to sudden increases in demand for highly utilized and capacity-constraints units. In other instances, trends emerge. For example, the patients who experience the longest 10% of ED-to-Floor bed wait times are usually clinically ready to transfer

[106] Sources: Patcom, EDIS, Perioperative Case Data, CBEDs. Timeframe: January 1, 2012 to June 30, 2013. N=270.

between 12 a.m. and 6 a.m. In other words, the ED patients who wait the longest for floor beds are typically those who accumulate in the ED overnight. The longest OR-to-ICU transfer delays tend to occur on Wednesdays. The surgical patients who wait the longest for ICU beds are most often those who finish their procedures between 10 a.m. and 4 p.m.; the surgical patients who experience the longest bed waits for transfers to inpatient floors typically finish their procedures between 12 p.m. and 2 p.m. An opportunity for further research is to develop a more dynamic bed assignment algorithm that adaptively assigns beds based on environmental factors, such as the current state of the system.

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Appendix A: Bed Assignment and Patient Transfer Process: ED-to-ICU

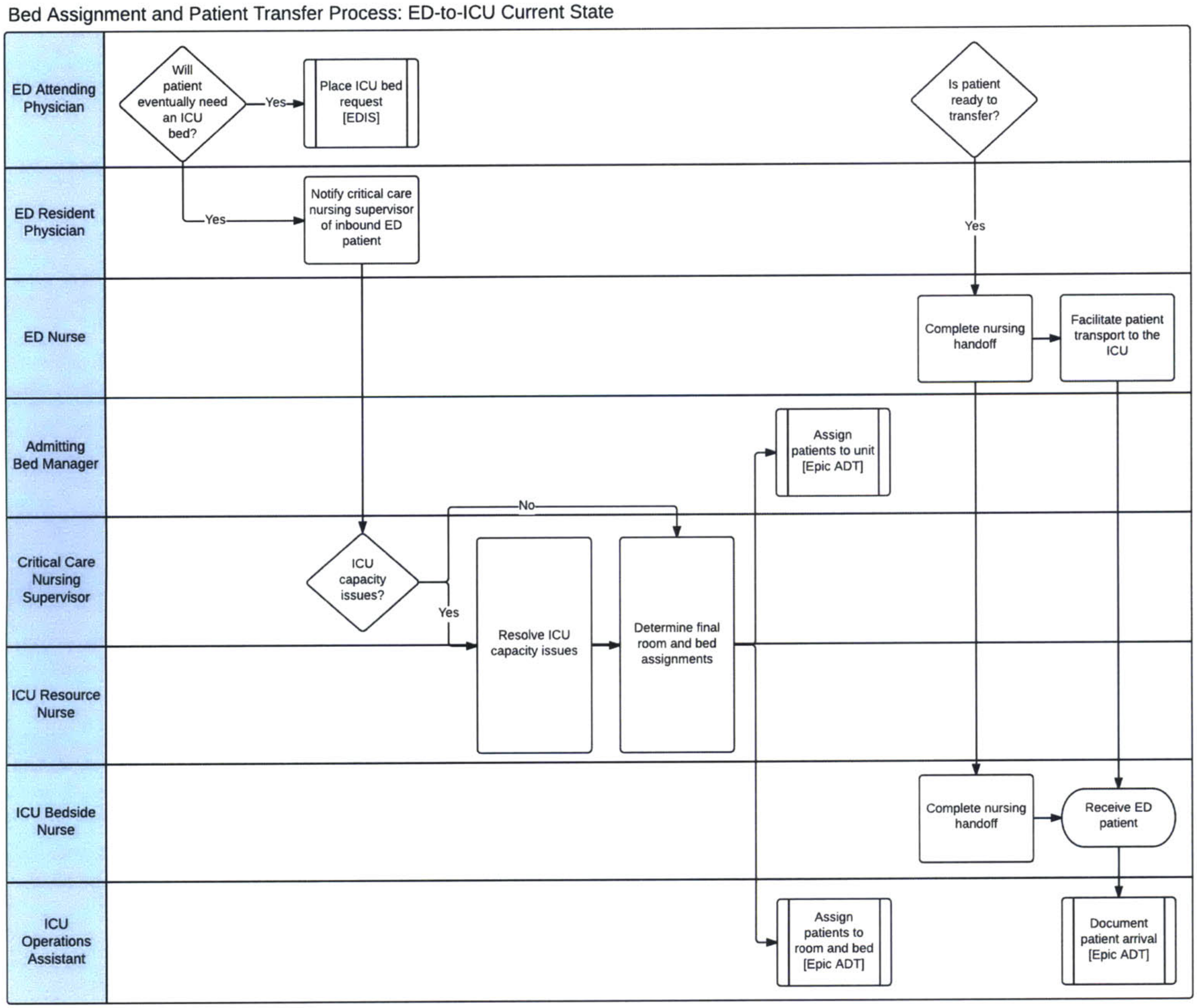

Figure 18: Bed Assignment and Patient Transfer Process: ED-to-ICU Current State

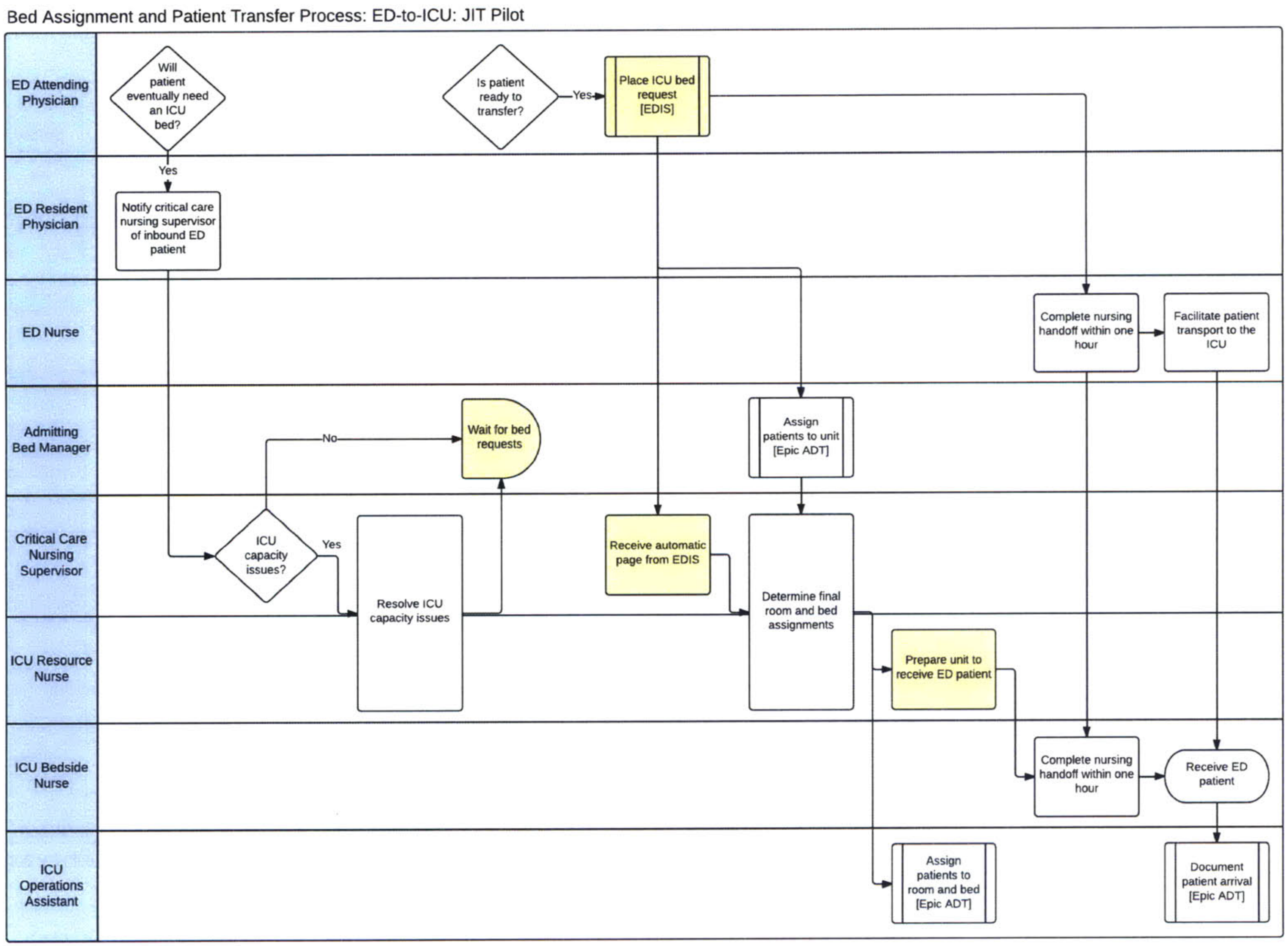

Figure 19: Bed Assignment and Patient Transfer Process: ED-to-ICU JIT Pilot

Appendix B: Bed Assignment and Patient Transfer Process: OR-to-ICU

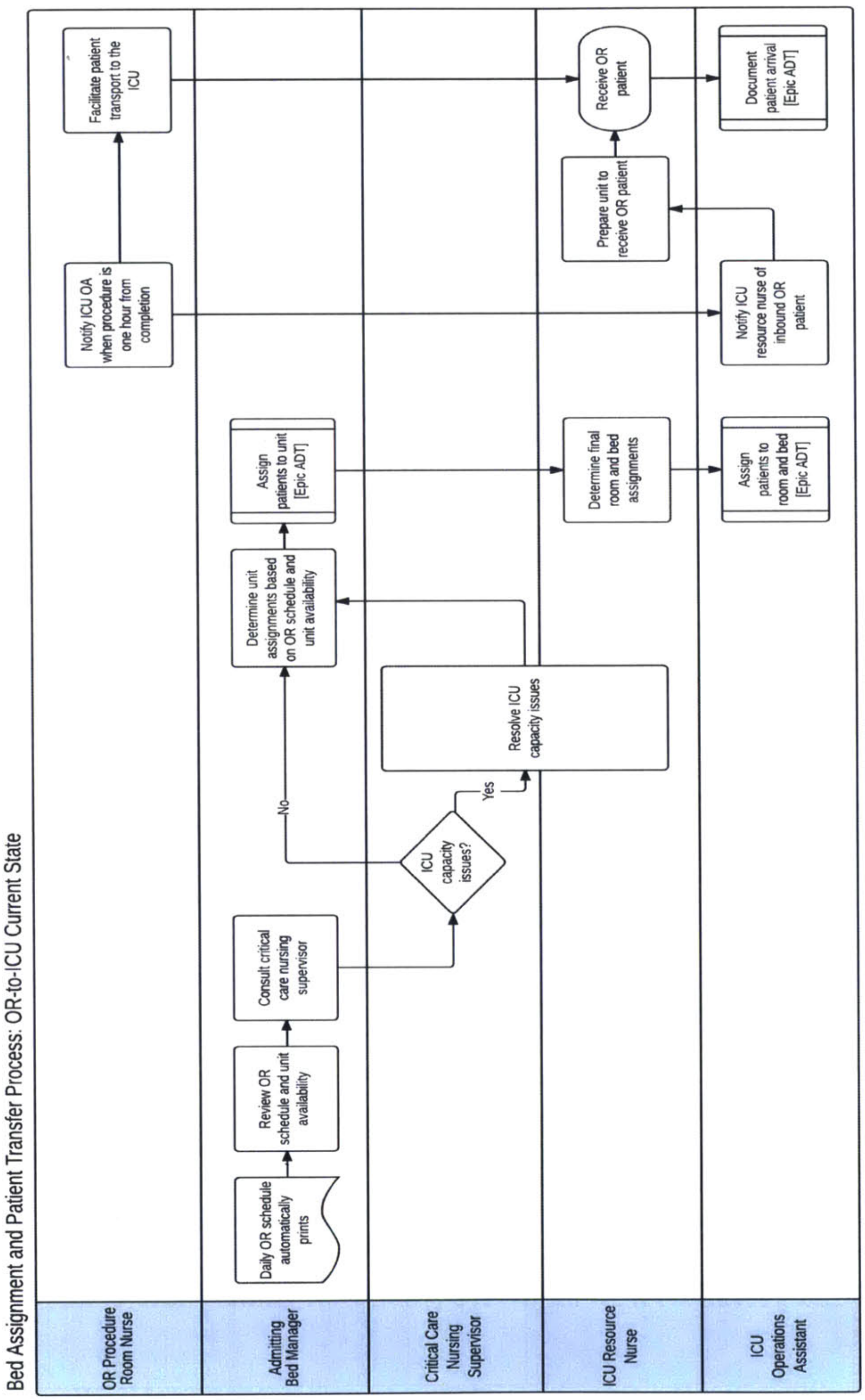

Figure 20: Bed Assignment and Patient Transfer Process: OR-to-ICU Current State

Bed Assignment and Patient Transfer Process: OR-to-ICU: JIT Pilot

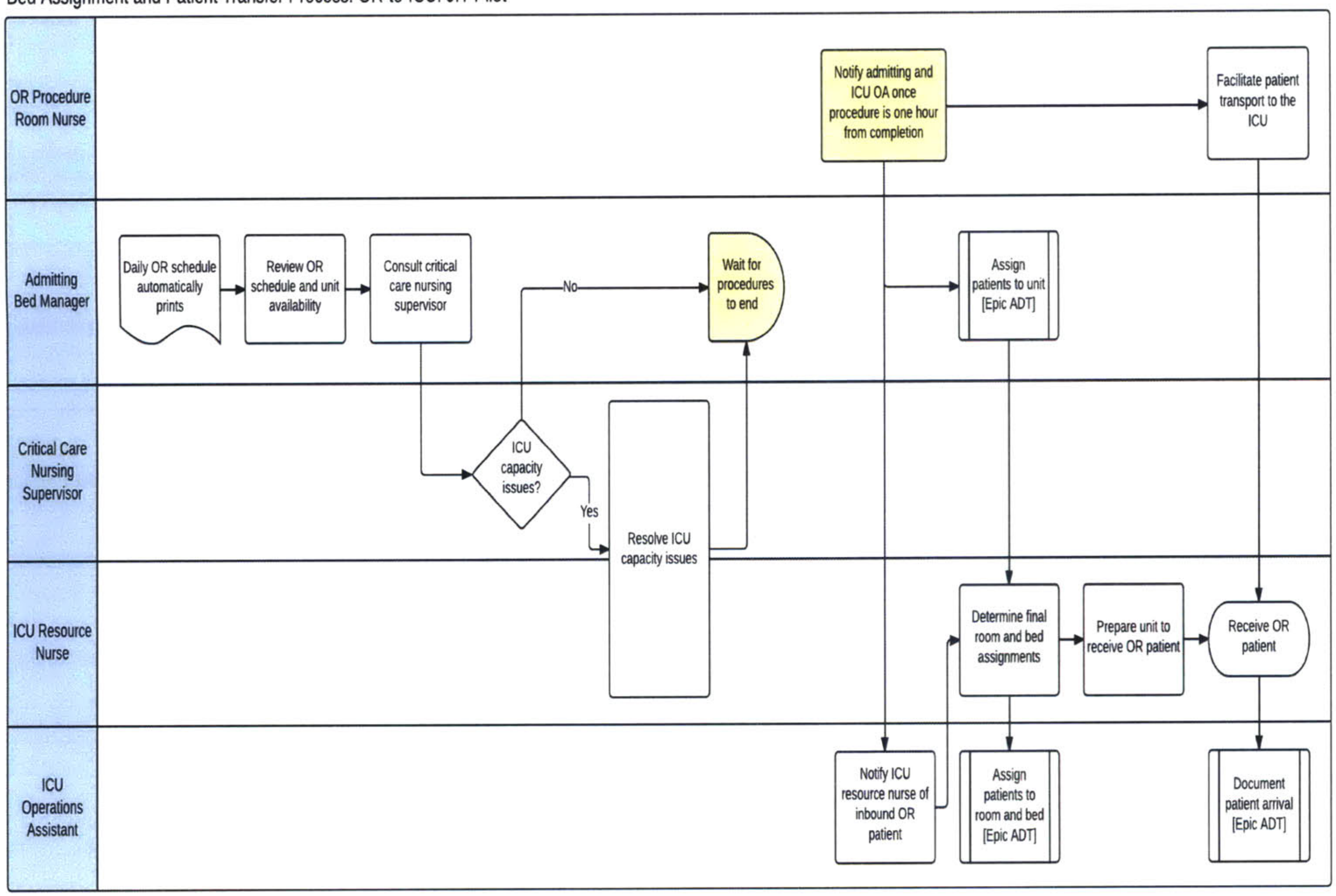

Figure 21: Bed Assignment and Patient Transfer Process: OR-to-ICU: JIT Pilot

Appendix C: Bed Assignment and Patient Transfer Process: ED-to-Floor

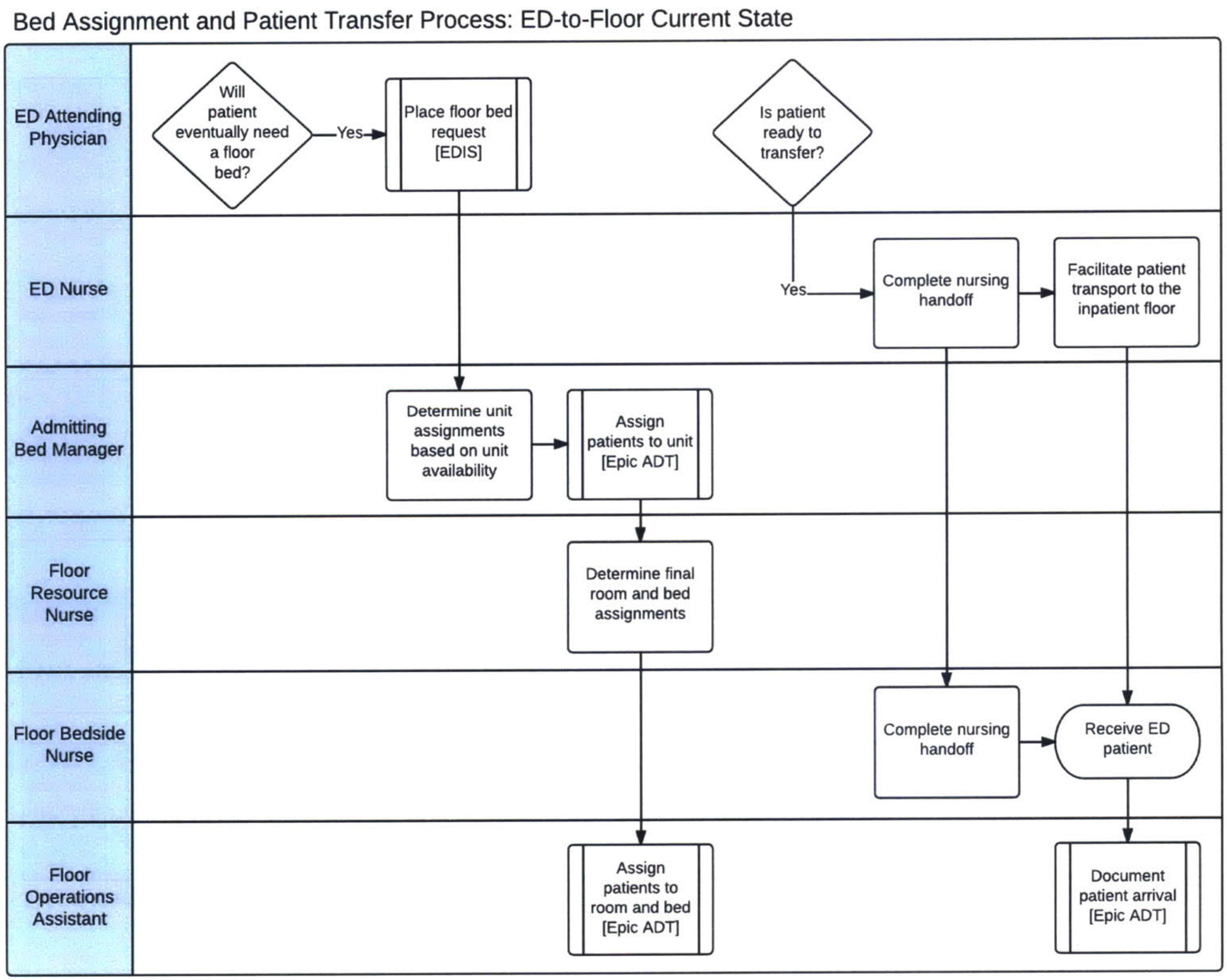

Figure 22: Bed Assignment and Patient Transfer Process: ED-to-Floor Current State

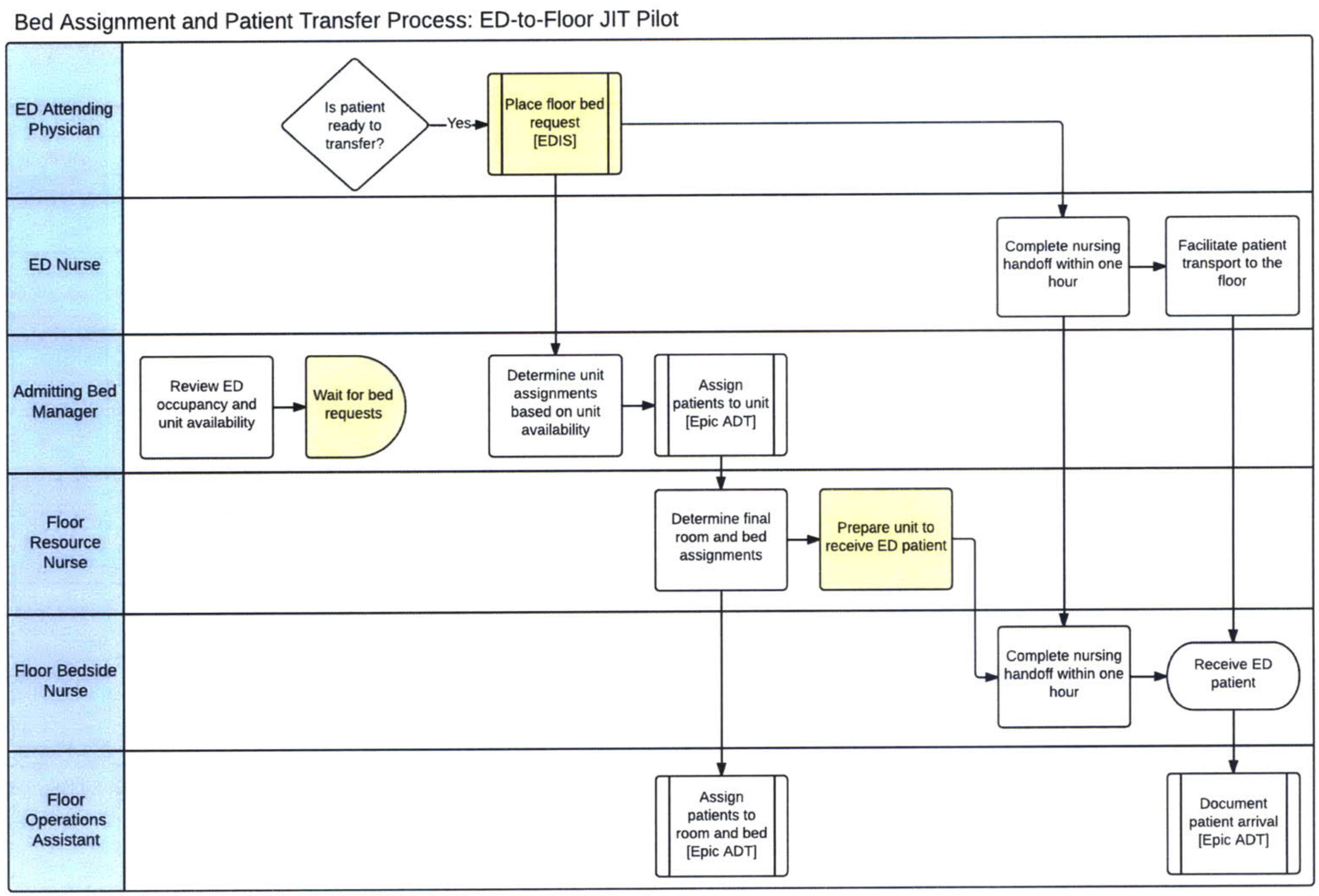

Figure 23: Bed Assignment and Patient Transfer Process: ED-to-Floor JIT Pilot

Appendix D: Bed Assignment and Patient Transfer Process: OR-to-Floor

Bed Assignment and Patient Transfer Process: OR-to-Floor Current State

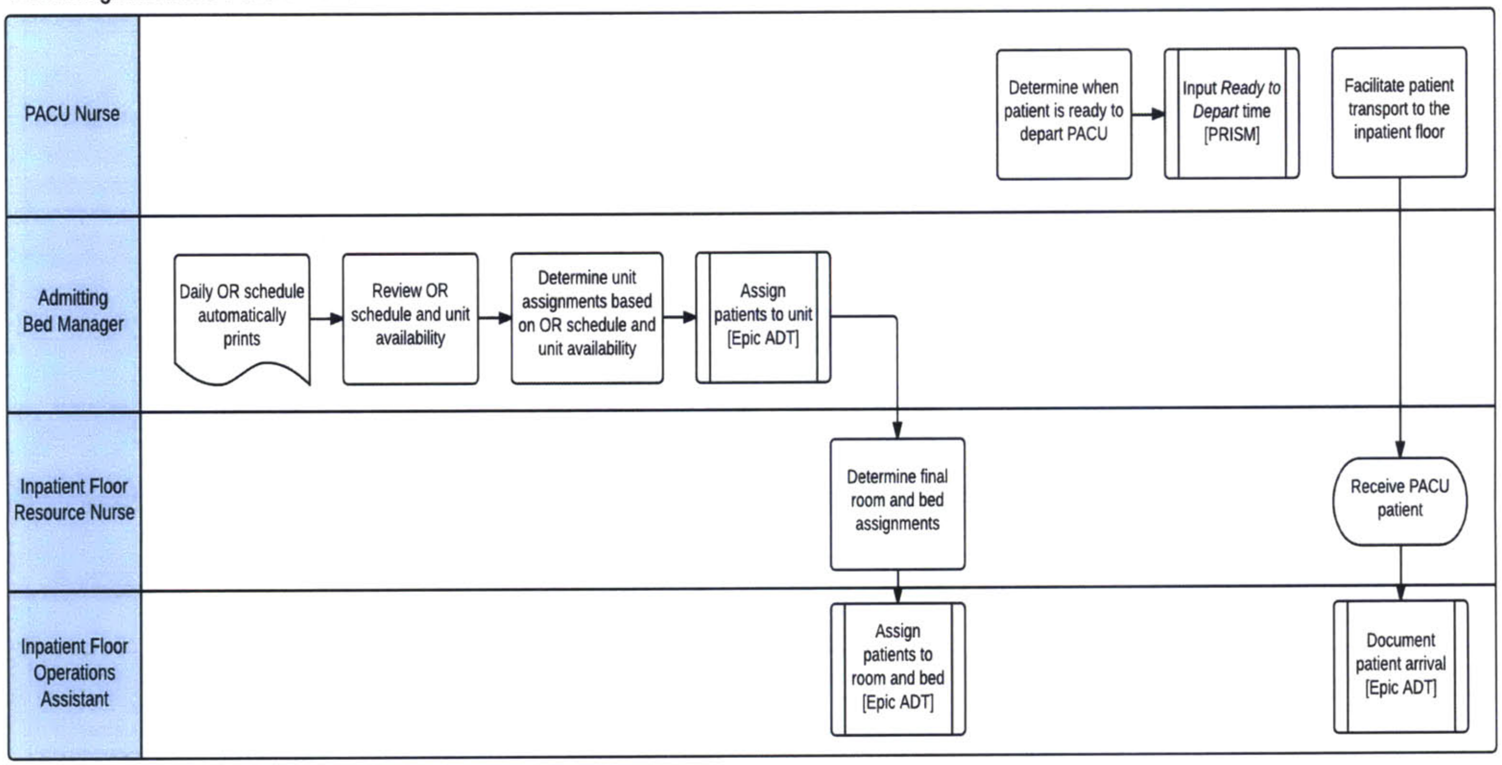

Figure 24: Bed Assignment and Patient Transfer Process: OR-to-Floor Current State

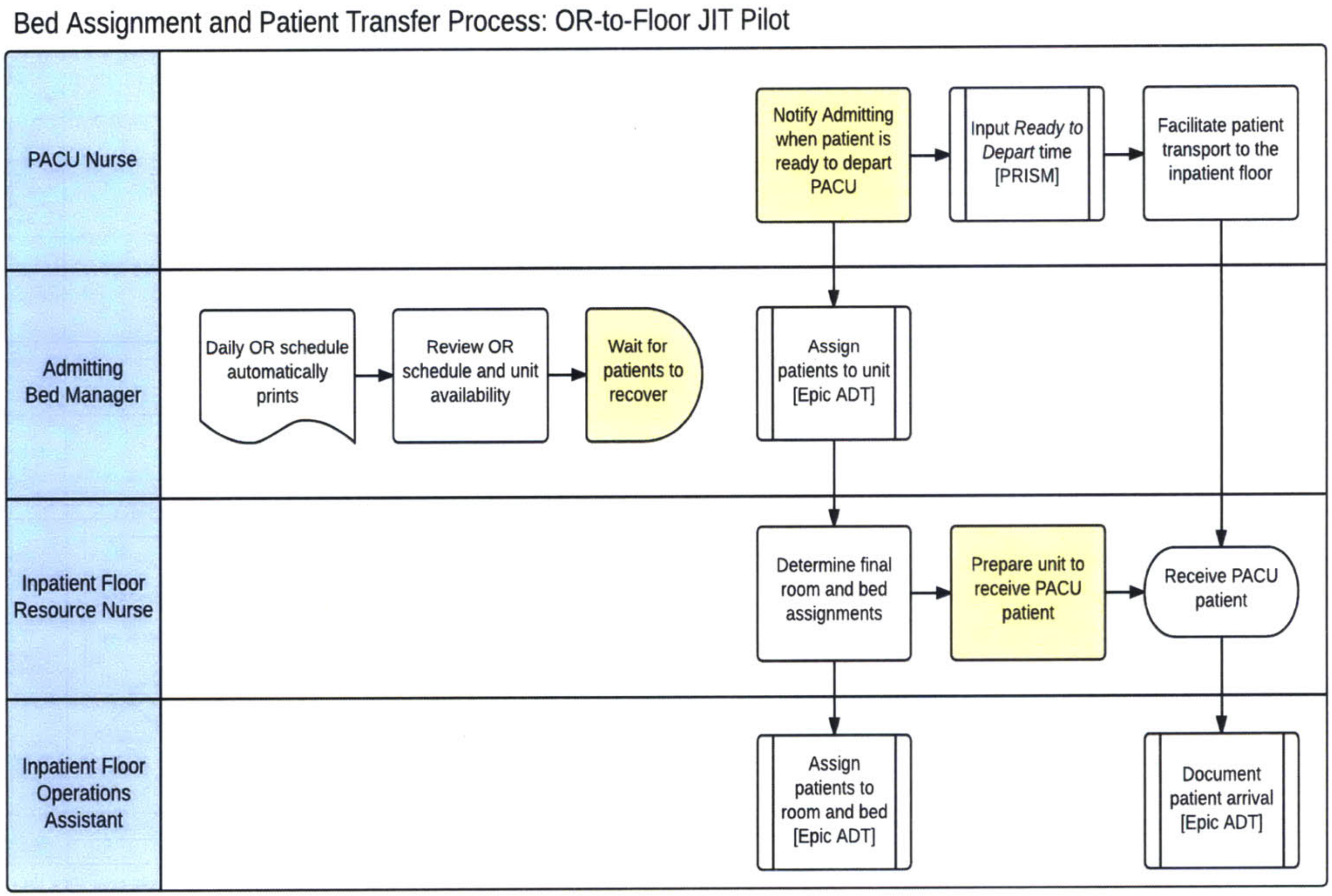

Figure 25: Bed Assignment and Patient Transfer Process: OR-to-Floor JIT Pilot

Appendix E: Small-Scale Early Discharge Intervention Processes

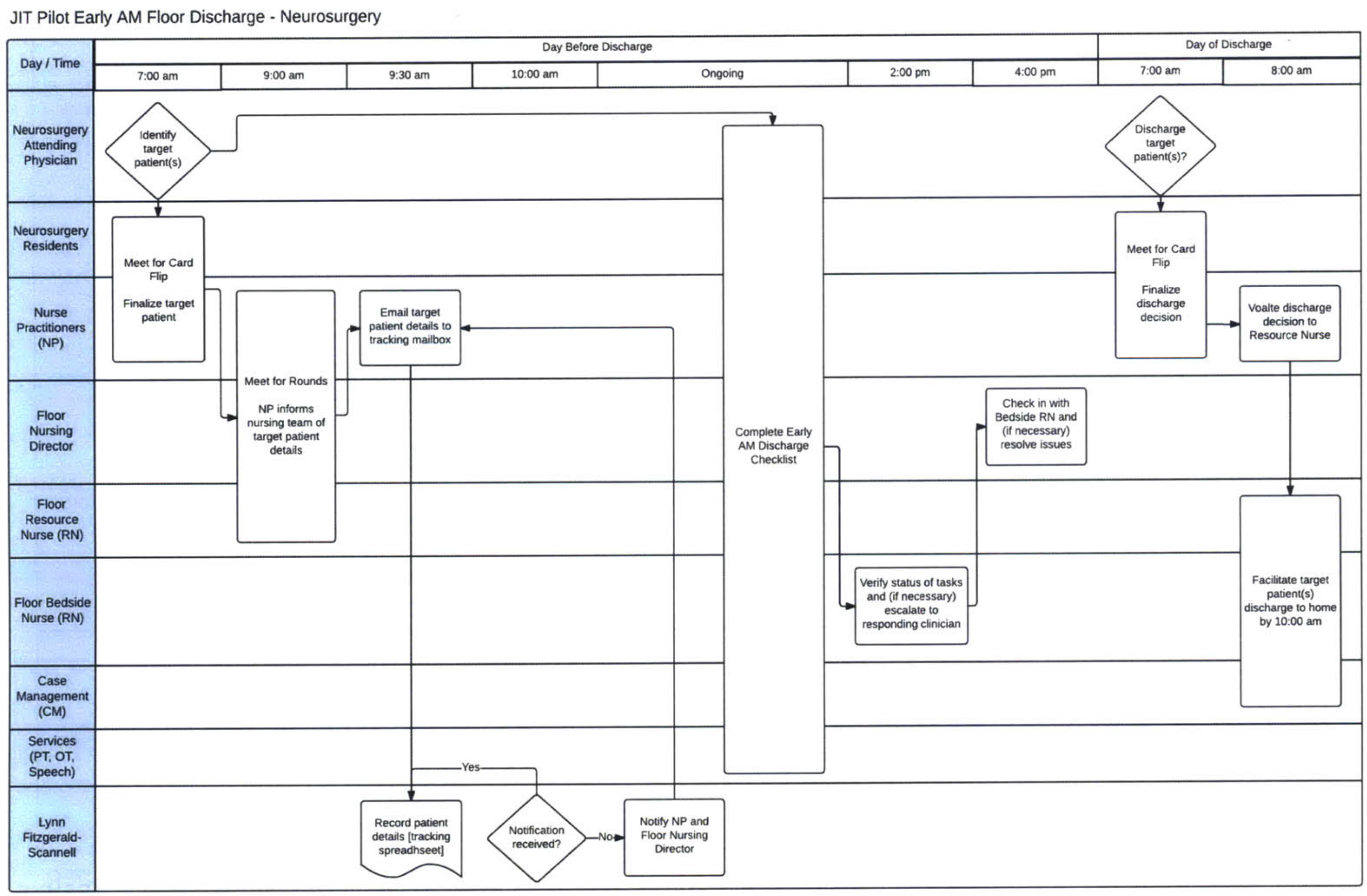

Figure 26: Small-Scale Early Discharge Process: Neurosurgery

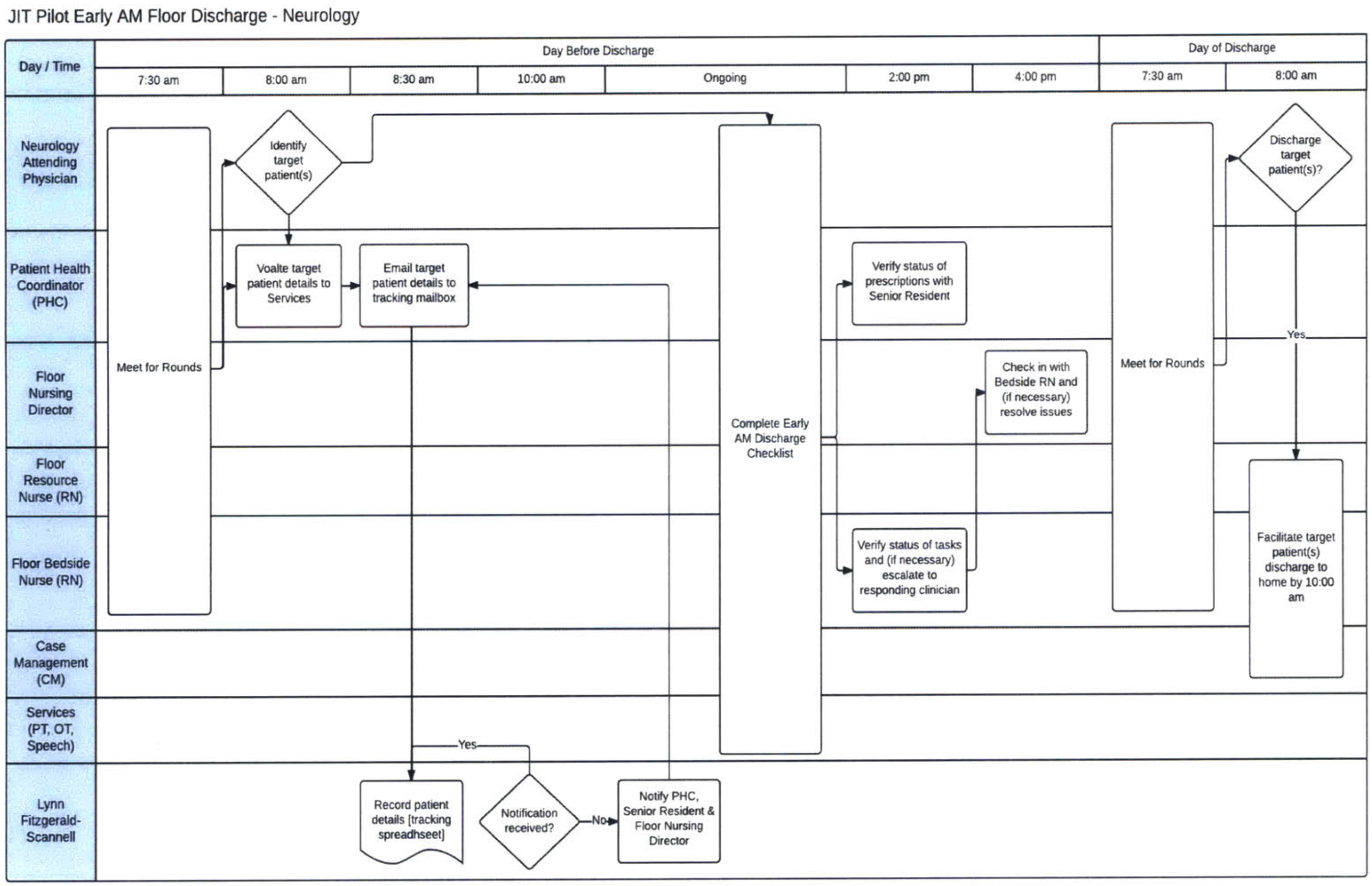

Figure 27: Small-Scale Early Discharge Process: Neurology

Appendix F: Early Morning Discharge Checklist

Early Morning Discharge Checklist

Patient Name	
Patient MRN	
Target Discharge Date	

Physician / NP:

- ☐ **Discharge Plan** → Communicate discharge plan to patient, family and PCP
- ☐ **Electronic Notes** → Add Order to CAS and update EDD in Apprentice
- ☐ **Prescriptions** → Prescribe medications and inform bedside RN by 2:30 p.m.
- ☐ **Discharge Orders** → Write discharge orders
- ☐ **Discharge Summary** → Write discharge summary

Bedside RN:

- ☐ **Discharge Time** → Inform resource nurse of expected discharge date and time
- ☐ **Discharge Note** → Write discharge note
- ☐ **PDML** → Review Post Discharge Medication List
- ☐ **Prescriptions** (If necessary) → Send prescriptions to appropriate pharmacy
- ☐ **Discharge Instructions** → Communicate discharge instructions to patient and family
- ☐ **Transport** → Coordinate early morning transportation from MGH with patient and family

Services:

- ☐ **PT** → Complete final PT evaluations
- ☐ **OT** → Complete final OT evaluations
- ☐ **Case Management** → Schedule home services and inform patient by 3:30 pm
- ☐ **Care Coordination** → Schedule outpatient appointments and inform patient

Figure 28: Early Morning Discharge Checklist

Appendix G: Small-Scale Early Transfer Intervention Process

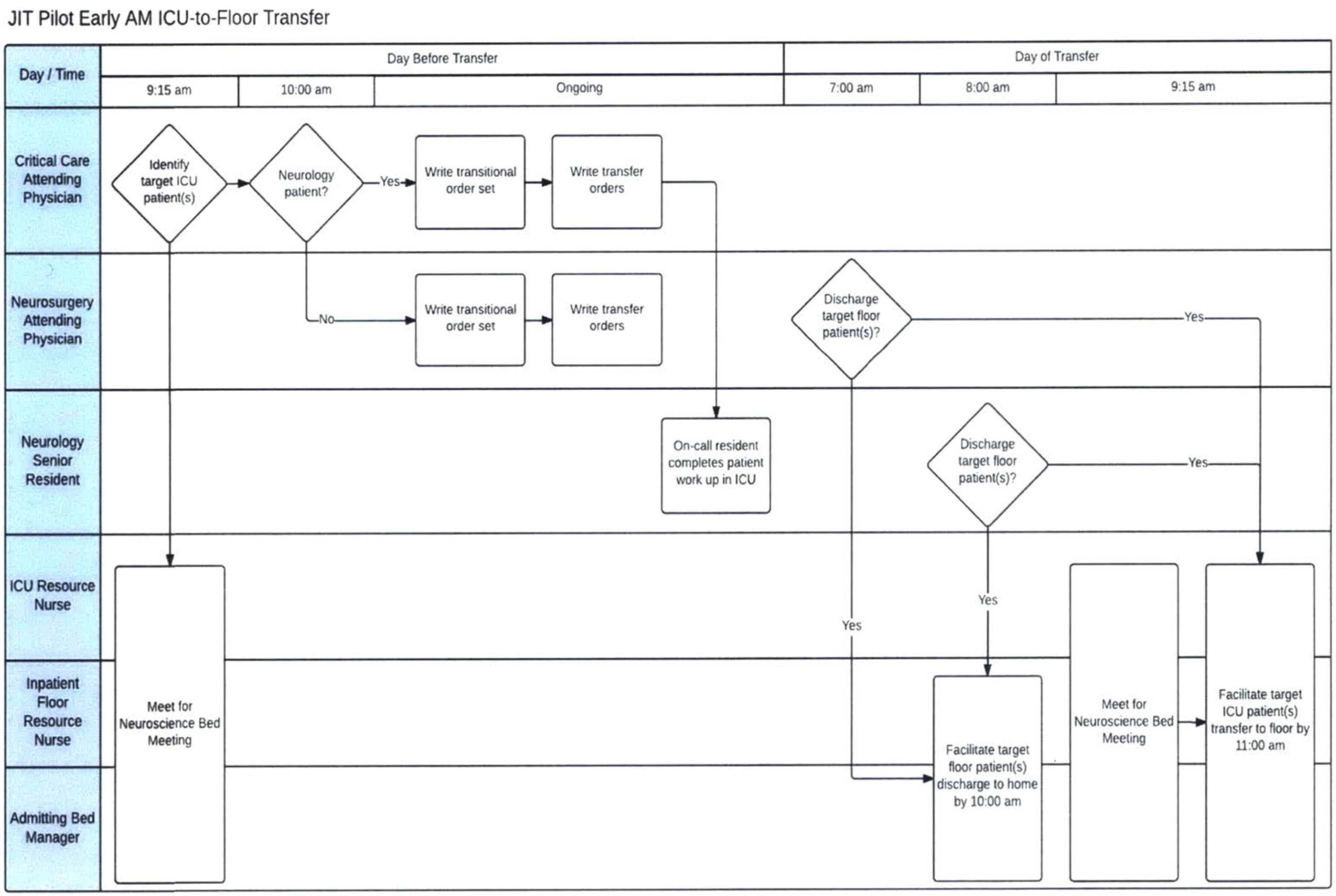

Figure 29: Small-Scale Early Transfer Process: Neuroscience ICU to Floor

Appendix H: Simulation of Small-Scale Early Discharge Intervention

This section describes technical details of the simulation of neuroscience patient flow under the conditions of the small-scale early discharge intervention. In the intervention, neuroscience patients are discharged from the neuroscience inpatient floor units to home early in the morning on Tuesday through Saturday. If the historical first daily neurosurgery discharge occurred before 10 a.m., then the simulation discharges that neurosurgery patient at their historical early discharge time. If the historical first daily neurosurgery discharge occurred any time after 10 a.m., then the simulation discharges that neurosurgery patient at 10 a.m. The simulation applies an identical algorithm to the first daily neurology discharges too. Although the small-scale early discharge intervention calls for each neurology team (i.e., RDA and CMF) to identify a candidate for early morning discharge, the simulation only ensures that one neurology patient is discharged by 10 a.m. This is a conservative assumption that allows for days when one neurology team cannot identify a patient that is a good candidate for an early discharge the following morning.

Appendix I: Simulation of Small-Scale Early Transfer Intervention

This section describes technical details of the simulation of neuroscience patient flow under the conditions of the small-scale early transfer intervention. In the intervention, neuroscience patients transfer from the neuroscience ICU to the neuroscience inpatient floor units early in the morning on Tuesday through Saturday. The small-scale early discharge intervention ensures that at least two neuroscience inpatient floor patients are discharged by 10 a.m. on these days. Once a floor bed becomes available, the simulation uses the 'first-due' ranking methodology (described in Section 6.2) to select from among all non-ICU patients in the queue waiting to transfer to the capacity-constrained inpatient floor units. For ICU to floor transfers, the simulation executes these patient movements at the end of the day (i.e., after all other pending transfers to floor units are processed) on the day of historical transfer, given available floor capacity. This effectively deprioritizes ICU patients relative to all other patients competing for floor beds, which reflects MGH's current and desired protocol. In the small-scale early transfer intervention, however, an algorithm places one ICU patient who is clinically ready to transfer at the top of the queue each Tuesday through Saturday. This ensures that one ICU patient moves to a neuroscience inpatient floor unit by at least 11 a.m.