Emergency and Disaster Logistics Processes for Managing ORs Capacity in Hospitals: Evidence from United States

Mohammad Heydari[1], Yanan Fan[2], Mahdiye Saeidi[3], Kin Keung Lai[4], Xiaoyang Li[5], Ying Chen[6], Jiahui Yang[7], Xinyu Cai[8], Xin Zhang[9]

[1,5,6,7,8,9] Business College, Southwest University, Chongqing 400715, China

[2] Faculty of Earth Sciences and Environmental Management, University of Wrocław, Wrocław, Poland

[3] Payame Noor University, Department of Tehran West, Iran

[4] International Business School, Shaanxi Normal University, Xi'an 710062, China

Corresponding author: Mohammad Heydari, E-mail: MohammadHeydari1992@yahoo.com

ABSTRACT

Hospitals and the concept of a healthcare delivery system are practically synonymous. Surgical services, emergency and disaster services, and inpatient care are the three main services they offer. Outpatient clinics and facilities are also available at some hospitals, where patients can receive specialty consultations and surgical services. What challenges do hospital administrators face when attempting to balance the supply and demand for medical services while preserving service quality and maintaining low prices? In what ways and to what extent has OM literature contributed to the resolution of these issues? What are the current trends in practice? What additional opportunities and challenges do they present to OM students? This study is an attempt by the authors to answer the aforementioned questions. Although service capacity could be measured by the number of physical and human resources employed, we chose to focus on the three primary types of services provided by hospitals.

Keywords: *Emergency and Disaster Logistics; Healthcare; Capacity; Operating Rooms (OM); Hospital*

1. INTRODUCTION

We show how these services are interconnected and the issues that develop as a result of mismatches in one area having a cascading effect on all other hospital operations. Our goal is to bring essential concerns to light from practitioners' perspectives, use representative data to highlight difficulties that can be modelled utilizing OM techniques, describe state of the art in modeling such challenges, and recommend future research prospects.

Emergency logistics refers to the logistics actions triggered by emergencies, including restricting emergency logistics demand and emergency logistics supply activities to fulfill these logistics needs, all to improve time efficiency and reduce disaster losses. In emergency logistics, facility placement and material distribution are crucial components of emergency decision-making and rescue operations. Academics first proposed the concept of emergency logistics in 2004, defining it as *"logistics activities to deliver resources needed to respond to natural disasters, public health issues, catastrophic accidents, and other emergencies."* According to the Tomas and Fritz Institute's definition from 2004, Humanitarian logistics is the planning, execution, and control of the efficient and effective flow and storage of relief items and related information from the point of source to the point of consumption. Preparation, planning, procurement, shipping, warehousing, trucking and tracking, and customs clearance are examples of these services.

Healthcare expenditures are increasing as a percentage of GDPs in the 34 OECD nations with publicly available data (OECD, 2013). In 2012, ten countries spent between 10% and 11.8 percent of their GDPs on healthcare. With 16.9%, or nearly 2.8 trillion dollars, the United States (US) was an anomaly. Furthermore, inpatient care, the subject of this research, accounts for almost 30% of all healthcare spending (OECD, 2013; 2015).

Hospital beds have been steadily declining in the OECD countries over the last two decades, according to official data. It varies from country to country (e.g., McKee (2004) and from year to year (Roberge et al. 2010), but one major factor has been the control of hospital costs (Kroneman & Siegers, 2004). Based on Centers for Disease Control and Prevention, the average number of acute-care hospital beds per 100,000 people decreased from 410 in 2000 to 330 in 2012, and the average hospital stay decreased from 8.4 to 7.7 days. A similar increase in hospital discharges occurred during this time period, with the rate rising from 15,160 per 100,000 people in 2000 to 15,800 in 2010. (2015). (OECD, 2015). It is estimated that approximately 80 percent of inpatient beds are occupied on average. According to the Organization for Economic Cooperation and Development (OECD), Because of these trends, which include higher rates of bed utilization and shorter average lengths of stay, it has become increasingly important to match inpatient demand with available beds.

For five OECD countries, the data in Figures 1 and 2 summarize data on acute hospital bed supply, total hospital discharges, lengths of stay, and use of acute care beds (OECD, 2013; 2015). The top panel of Figure 1 depicts a decreasing supply of available beds. Aside from Canada, the discharges in the bottom panel of the same image are either flat or increasing in size (demand). Consistent or mixed patterns of acute care bed utilization are depicted in Figure 2 at the top, with decreasing average lengths of stay depicted at the bottom.

Specifically, the data in Figures 1 and 2 are significant because they demonstrate how lower bed supply, shorter periods of stay, and higher demand have all had an impact on bed occupancy rates in various countries. Despite the fact that the United States and United Kingdom have approximately the same number of acute care beds and discharges per capita, the average length of stay in the UK is approximately two days longer than in the US. These disparities are consistent with the United Kingdom's counted bed occupancy rate of 85 percent compared to the United States' 65 percent. It may appear that there is an excess of hospital beds in the United States, but because the OECD computation is based on the number of beds that a US hospital is licensed to staff, these figures are not accurate; instead, they are misleading (1, 2). Hospitals adjust their staffing levels on a daily basis to meet the demand for available beds. Because hospitals in the United States frequently staff fewer beds than are licensed to provide care, staffed-bed utilisation is frequently significantly higher than the national average. It is possible that the situation in the United States is comparable to that in other OECD nations. It is clear from these observations that it is critical to understand operational aspects even when interpreting aggregate data.

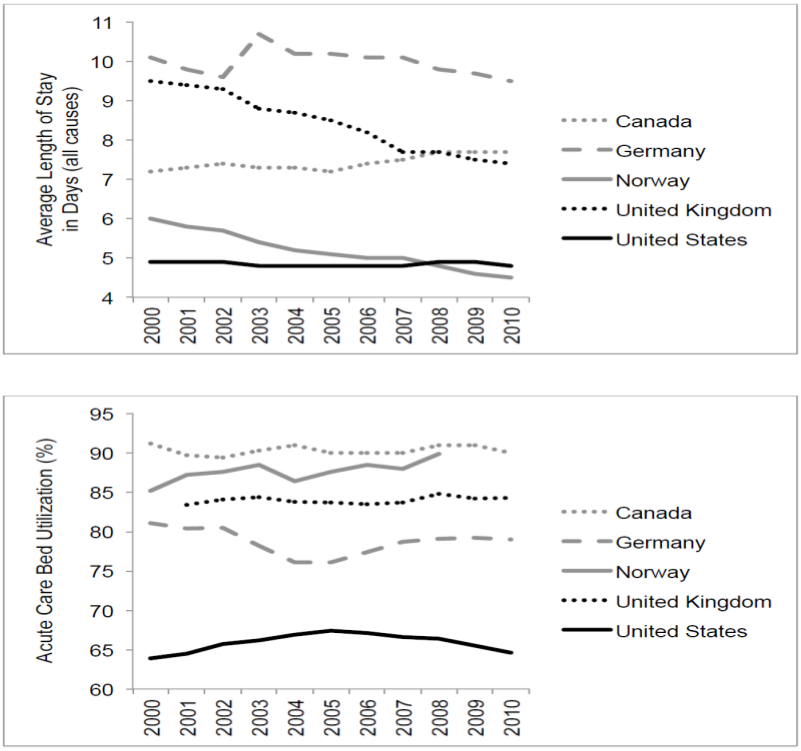

Fig 1: Supply and Discharges of Hospital Beds in Selected OECD Countries

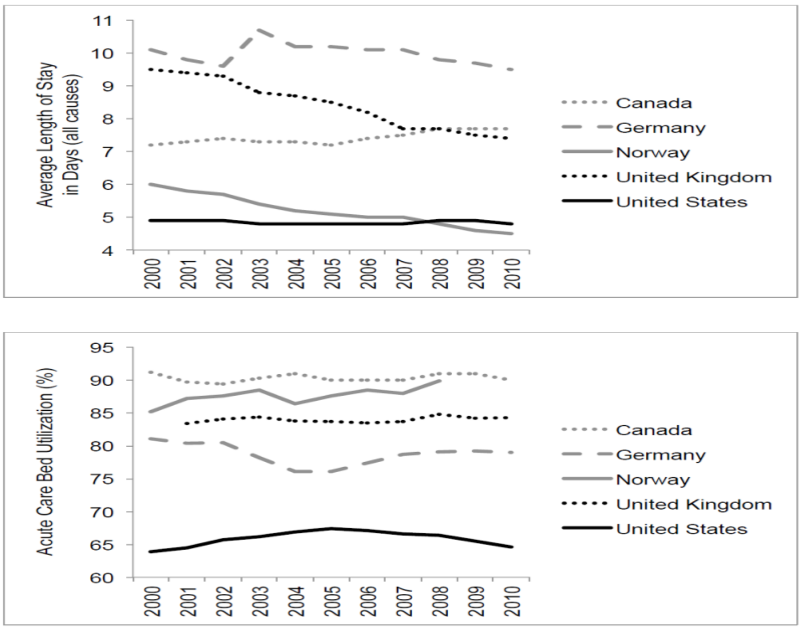

Fig 2: Hospital Stay Lengths and Bed Utilization in Selected OECD Countries

How many beds per 100,000 people is the correct number? This issue has sparked debate in several countries. Some people are concerned that the supply of beds has decreased too much, causing shortages (Cunningham & Sammut, 2012). Others think that the quantity of beds available is sufficient, and better bed management is required (Allder, Silvester, Walley, 2010). It is critical to comprehend, shape, and respond to the demand for acute care services, regardless of one's point of view. The fluctuation in demand and availability for such services is a significant problem for hospital executives.

2. LITERATURE REVIEW

The availability of hospital beds varies significantly depending on where you live in the United States (Dartmouth College, 2012). Discharge rates per 1,000 Medicare beneficiaries[1]. Payment innovations are intended to reduce or eliminate redundant or superfluous services from the payment landscape. After a cost-plus algorithm was implemented in the mid-1980s, the Medicare reimbursement for hospitalization was replaced with a Diagnosis-Related-Group (DRG) episode-payment mechanism. A decrease in the availability of hospital beds resulted in a reduction in the average length of hospital stay, while an increase in the use of post-acute transitional care was seen as a result (Qian et al., 2011; Fischer et al., 1989; Kosecoff et al., 1990). Medicare recently imposed payment penalties on hospitals that had a 30-day re-admission rate for patients with specific diseases that exceeded a predetermined threshold, according to a press release (Medicare Payment Advisory Committee, 2014).

Medicare and commercial insurers are also experimenting with new compensation systems in order to reduce the demand for hospitalizations and outpatient care even further. These approaches to compensation place a greater emphasis on quality than on quantity (Ryan & Press, 2014). Conrad et al. (2013) describes several reimbursement innovations that aim to promote integrated care by aligning clinical and financial incentives among all providers involved in a patient's episode of care (for example risk-adjusted global payments, Pay-for-performance, and bundled payments).

Numerous tactics used by healthcare delivery systems to improve their performance in response to reimbursement changes can be found outside of the hospital setting. These programs, which emphasize prevention and wellness in the outpatient setting, aim to reduce the use of emergency departments and hospitalizations. In the case of the patient-centered medical home (Schoen et al., 2011; Nutting et al., 2011), for example, interprofessional physician-led teams provide care to small groups of patients. Another example is the provision

[1] Medicare is a federally funded health insurance program for people over the age of 65 in the United States – for more information, see https://www.ssa.gov/medicare

of case management and care coordination services. A mid-level practitioner collaborates with patients ahead of time to ensure that they receive appropriate outpatient care at the appropriate time and location (Sutherland & Hayter, 2009; Lion et al., 2014; Mathews, 2014). Physician compensation models are also being implemented that place a greater emphasis on patient outcomes, such as specific biomarkers, rather than the number of patient contacts made by the physician (Latham & Marshall, 2015; Bailit et al., 2015).

Until all insurers transition to an outcome-based payment system, many health-care organizations will be forced to compete with one another for reimbursement. Value-based reimbursement accounts for only a small proportion of many systems' reimbursement streams; the vast majority are still fee-for-service. As a result, when companies use case management solutions, they run the risk of penalizing their bottom line (lower fees), while also incurring more extraordinary production expenses.

2.1 WHAT KIND OF SERVICES DO HOSPITALS PROVIDE?

The majority of acute-care hospitals offer at least three major service categories. Figure 3 shows a diagram of the three types of care available: emergency treatment (provided by emergency departments, also known as EDs), surgical services (provided by operating rooms, also known as ORs), and inpatient care (provided by inpatient beds).

Inpatient facilities that are specialized in a specific type of care are divided into hospital bed sections. A few instances contain intensive care units, step-down units, general-care units, surgical units, obstetric units, and neonatal units, to name just a few. Some hospitals are devoted solely to the treatment of specific medical conditions. For example, there may be intensive care units or step-down units dedicated to cardiac patients or people suffering from neurological problems, among other things. As an example, multiple operating rooms may be set up for different procedures, each with its own set of specialized equipment. The type of specialist care that can be provided (for example, some hospitals are designated regional trauma centers) and the diagnostic equipment available in EDs differ from institution to institution, as previously stated.

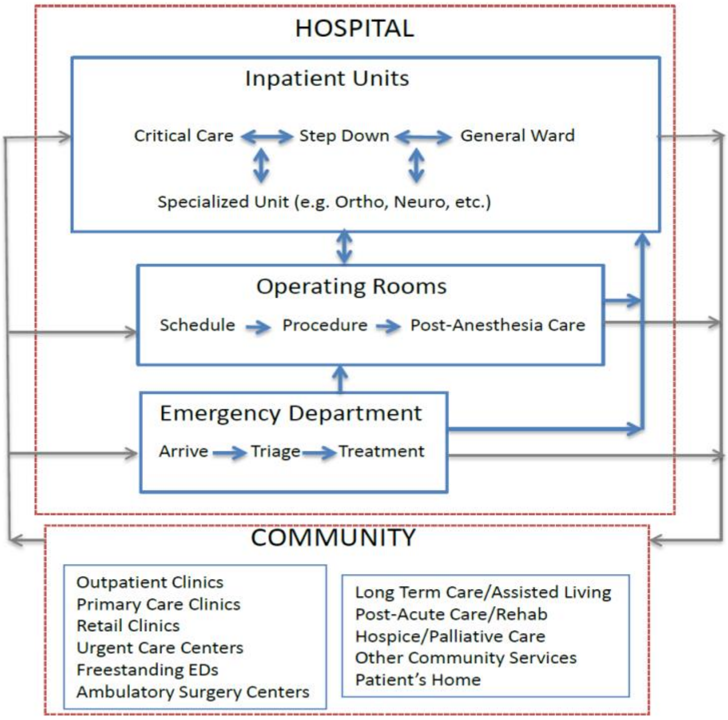

Fig 3: Patient flow

Throughout the rest of this section, we will discuss hospital beds in order to describe the institutional characteristics that make demand-supply matching difficult. Other types of services face challenges that are similar to these. The patient may be admitted to an inpatient bed following a visit to the emergency room or surgery, or following a physician's request for direct admission to the hospital, as illustrated in Figure 3. Patients are typically moved from one intensive care unit to another several times during their hospital stay, either to a lower-intensity unit if their condition improves or to a higher-intensity unit if it worsens. *PATIENT FLOW* is the term used to describe the movement of patients from emergency departments, operating rooms, or direct admission through one or more inpatient wards. There has been a lot of discussion about it in the occupational medicine literature.

2.2 Demand Variability

Because many patients require a combination of treatments, patient flow creates a random inter-based demand for ED care, ORs, and inpatient beds. ED visits requiring surgery, inpatient care, or both are typically unplanned and unpredictable. In addition to emergent cases, ORs must deal with urgent demand from hospitalized patients and deferred demand from patients who have scheduled surgery for a later date. Monday through Friday, starting at 7 AM, most

ORs are staffed for 8, 10, or 12 hours. After mid-morning, post-surgery patients begin to require hospital beds. The number of admissions through EDs tends to increase around the same time. Discharges, on the other hand, are more common in the afternoon. This results in a systemic imbalance of hospital bed demand and supply.

Figure 4 illustrates this phenomenon by showing the number of admissions and discharges in 24/h, for instance, in an acute-care hospital. Admissions activity picks up in the morning and stays quite consistent throughout the day. However, discharge activity increases in the afternoon (about 1 PM). Even if the hospital has adequate staffed beds on average, this mismatch can result in a scarcity of beds during particular day periods.

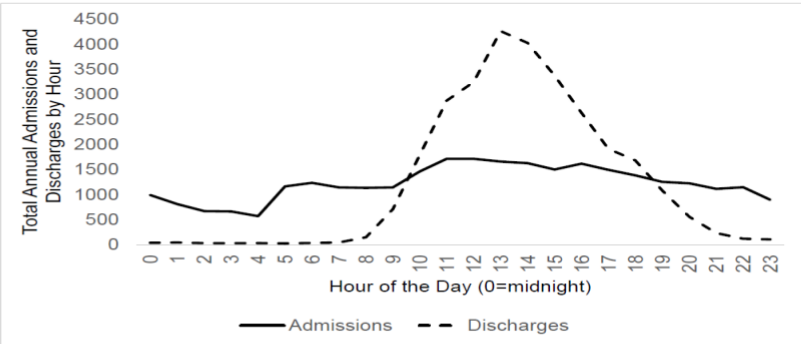

Fig 4: Patient Admission & Discharge Activity in 24/h

The term "census" refers to how hospitals keep track of the number of beds they have. Figure 5 depicts the typical census trend for a 500-bed hospital by the time of day and day of the week. Because the previous day's patients are still in the hospital and new patients arrive, the daily census peak shifts later in the day as the week progresses. The variability around the mean census increases later in the week. The goal is to discharge eligible patients by Friday afternoon to reduce the need for nurse staffing over the weekend, resulting in a lower weekend census. Many surgeons prefer to operate earlier in the week to avoid the need for weekend hospital rounds. On weekends, operating rooms only perform urgent or emergency surgical cases, resulting in a lower patient intake at inpatient units.

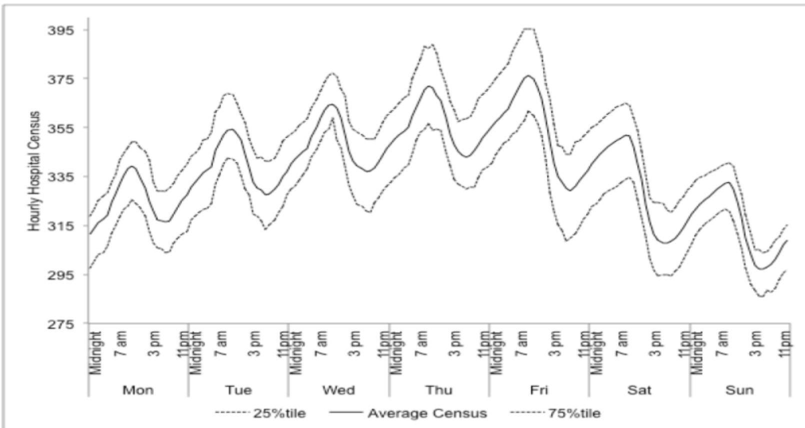

Fig 5: Hospital Population by Hour of Day and Weekday

Figure 5 demonstrates that some of the changes are natural, i.e., caused by the circadian cycle. Natural variability exists in need for emergency department or direct admissions beds. The natural variability depicted above contains predictable and unpredictable components (Allon et al., 2013). Emergency rooms, for instance, have predictable arrival patterns based on time of day and are busier on certain days of the week. Furthermore, ED-arrival ways are unpredictable (random), which may result in long wait times at certain times of the day.

The vast majority of surgical situations are not urgent or emergent, which means that patients can tolerate a short period of time before having their surgery without jeopardizing their overall health. The majority of variations in OR demand are driven by the surgical scheduling guidelines that are in place at a facility. This type of variability is referred to as artificial variability because it is caused by hospital policies, procedures, and practices, rather than natural variability. Artificial demand variability can be forecasted and smoothed out over time by using statistical methods (McManus et al., 2003). Learning about the different types of variability – such as natural or induced; predictable or unpredictable – can be beneficial in management (Van den Schrieck et al., 2014; Allon et al., 2013).

2.3 OPERATING ROOM (OR) CAPACITY MANAGEMENT

Operating Room (OR) capacity management falls under the purview of multiple stakeholders. The key players are (1) the OR directors, (2) the service line or surgical group directors, (3) the nursing directors, (4) the surgeons, (5) the anesthesiologists, and (6) the patients. As we explain later in this section, the objectives of these stakeholders are often not aligned.

The difficulty of matching supply and demand arises because of the natural variability of the service environment. E.g., the volume of different types of surgical procedures and surgery durations can be highly variable. Similarly, there is significant variability in case complexity and post-surgical resource requirements within and across surgical specialties, making planning difficult. In addition, prevailing capacity management practices and misaligned incentives give rise to a different type of variability that we call artificial variability. When we say this variability is artificial, we are emphasizing that it is caused by the actions of stakeholders such as block schedules and surgery booking practices, which can result in variable OR staffing requirements. It is difficult to argue whether natural or artificial variability has a more significant impact on OR operations. That depends, to a large extent, on the specific capacity management practices at the hospital in question. For example, some hospitals allocate almost all of their available OR time as blocks (in detail in the next section).

In contrast, others keep a significant proportion of their capacity unassigned. Typically, rules are in place to determine how unassigned capacity is allocated to arriving requests for OR time. The overall effectiveness of OR capacity matching depends on all these rules and policies.

A different way of thinking about variability is to consider the extent to which it can be anticipated or predicted. Common wisdom suggests that artificial variability should be more predictable because stakeholder actions are observable, often several days in advance. In practice, hospitals may not collect that information and/or may not leverage advanced knowledge of stakeholder actions to lower supply-demand matching costs.

The problem of matching supply and demand (red alert)[1] for OR time is sometimes viewed via the prism of time scales. Considerations such as the sorts of surgical operations performed,

---

[1] ***Major incident situation happened, how CCUs, and specialist staff act?*** Between (5 percent -15 percent) of patients presenting to hospital following a bomb blast or terrorist-associated mass casualty incident will need intensive care (Heydari et al., 2020; 2021; Adam & Osborne, 2005). (Heydari et al., 2020; 2021; Adam & Osborne, 2005). The demands on critical care sources for other incidents, like large fires or natural disasters, are less well recorded (Avidan et al., 2007). (Avidan et al., 2007). However, following the aftermath of Hurricane Katrina in New Orleans, the Charity Hospital had to manage enhanced demand without the opportunity to evacuate for many days (Rubinson et al., 2008). (Rubinson et al., 2008).

In 2007 the US Taskforce for Mass Critical Care offered that CCU plan to represent emergency mass critical care at three times the existing capacity for up to ten days (deBoisblanc, Bennett, 2005; Heydari et al., 2020). (deBoisblanc, Bennett, 2005; Heydari et al., 2020). However, CCU beds and specialists/staff are a limited source usually fully utilised; in a major incident, releasing beds or expanding the source needs good planning and organisation. As critical care sources will often represent the major limiting element encountering large numbers of casualties, it is also essential that early connections with different hospitals be made to transfer more stable the number of operating rooms (ORs), and how each OR is equipped are long-term decisions in this paradigm (typically made once every few years). Decisions concerning block allocations to surgeons, how many ORs to plan to staff each weekday, and staffed-OR start and end times are medium-term decisions (typically made annually). Finally, surgical-case booking decisions

---

patients in the most secure way possible. Based on this, critical care managers/leaders must be involved in planning (Heydari et al., 2020) for mass casualties along the healthcare communities.

The CHEST Task Force for Mass Critical Care has suggested different levels of capacity expansion needs via different levels of casualty (Christian et al., 2014; Hendrich et al., 2004).

Critical care sources require to enhance for:

(a) Conventional response-able to expand immediately via at least 20% above baseline incentive care unit Max capacity;
(b) Crisis response-able to expand via at least 200% above baseline incentive care unit Max capacity via regional, local, national, and international agencies;
(c) Contingency response-able to expand rapidly via at least 100% above baseline incentive care unit (ICU) Max capacity via accessing local and regional resources;

The Min requirements for critical care offered via the EMCC taskforce (Rubinson et al., 2008) are:

- Vasopressor administration
- Mechanical ventilation
- Sedation and analgesia
- Optimal therapeutics and interventions, like renal replacement therapy and nutrition for those patients who are not able to take food via mouth, if warranted via the hospital or regional preference
- IV fluid resuscitation
- Antidote or antimicrobial administration for special disease processes, if applicable
- Algorithms to decrease adverse consequences of critical care and critical illness.

It is offered that a tiered response shall be set up, allowing increasingly more high-risk management practices to be viewed as the effect of the incident enhances. Ultimately, triage of patients for accessibility to scarce critical care sources would also be included.

Predict and manage such an incident contains:

- Training and education of specialist/staff
- A level of stockpiling or recognition of alternative resources of equipment (e.g., use of anaesthetic ventilators to supply ventilatory support, and NIV machines)
- Recognition of Specialist/staff via transferable skills like recovery nurses, respiratory nurses and previous critical care nurses;

When people still coming in but there is no way to put them out, we go to the red alert; In this condition basically, the number of coming in patents is excessed the number going out, and there is nowhere to put them, and we haven't got any spare capacity (bed), we get to the point where we are genuinely thinking can we treat these sick people? A red alert demonstrates there is a significant risk to the patients safety. In this condition, all non-emergency surgeries should be canceled, and we need to search for a free bed to start to discharge the beds until the flow moves forward. Whenever the hospital is on the alert, all wards are under pressure to discharge the patients. What we require to do is follow the patients from inter to leave.

When all wards are full, and there is no bed in any wards; at the moment, the emergency admission system is running at its absolute limit; it is starched. The point where if one person, one key person doesn't turn on for whatever the reason, then whole things just can fall apart. Just like a real domino, just one person comes out the whole thing just collapses. Because the flow stops, you get blockage and back right away up to the front door. Everything just becomes impossible. Whenever the hospital is on alert, all of the wards are under pressure to discharge the patients (Heydari et al., 2020).

(including start times and planned case lengths), scheduling of urgent and emergent cases, and handling of either delays or cases that surgeons may add to their block schedules are short-term decisions (typically made either a few days prior or on the day surgeries take place). On the one hand, the hierarchical division of decision problems makes it possible to decompose a complex problem into tractable models to aid decision-making within each hierarchy. On the other hand, this decomposition may lead to sub-optimal decisions. Note that OR capacity-management decisions directly impact the need for staffed beds, which we discuss in the last section.

In this section and others that follow, we proceed as follows. We begin by providing an institutional background and a discussion of performance metrics. Some evidence from data follows this. Data analysis aims to reveal operational inefficiencies, which provide a natural segue into the next section focusing on operational challenges. After that, we describe the state of the practice and current OM approaches. Finally, we close the section with a discussion of opportunities for OM researchers to contribute to this aspect of hospital operations.

3. DATA ANALYSIS

This section aims to illustrate key drivers of OR performance with the help of data from typical community hospitals. We obtained data from three Hospitals. These hospitals are different in terms of the lengths of procedures performed and the relative volume of different types of procedures performed. We summarize procedure lengths in box plots shown in Figures 7, 9, and 11 and the relative frequency (in percentage) of different types of surgeries in Figures 6, 8, and 10. Hospitals 1 and 3 perform many more different procedures, and some of their procedures differ greatly in procedure lengths. The top four services in Hospital 1 are General, Orthopedics, Urology, and Neurology. The majority of surgeries in Hospital 1 are between 2 and 5 hours in duration. Hospital 2's major service is Ophthalmology, and most surgeries are short – between 30 and 60 minutes. Hospital 3's top four services are General, Orthopedics, Ophthalmology, and ENT (Ear, Nose, and Throat), and many procedures have short durations.

A few items are worthy of special attention. Some neurology and general surgery procedures performed at Hospital 1 have durations that exceed the usual shift length of 8 hours. This hospital uses two-shift lengths: 8 hours and 12 hours. Long neurology cases are scheduled in rooms where staff work for 12 hours. Hospital 2 has a few long cases, but they are quite rare.

Hospital 2 uses a single 8-hour staff shift. In contrast, Hospital 3 uses a 10-hour staff shift. Nearly all of the cases performed at this hospital finished within 10 hours.

The natural variability in volume and length of different procedures and the variability induced by the surgery booking process often result in a situation in which service lines with blocks may underutilize their block allocation and simultaneously use more than their allotted time for non-urgent cases. We illustrate this phenomenon in Figure 12, for the top five service lines, by total minutes of OR time used over 12 months at Hospital 1. The vertical axis in Figure 12 shows the OR minutes. There are three vertical bars for each service. The first bar, which is stacked, shows demand in OR minutes for non-urgent and urgent cases. Non-urgent cases are also referred to as scheduled demand. The second bar for each service line shows the allotted block minutes, and the last vertical bar shows the minutes of block time utilized.

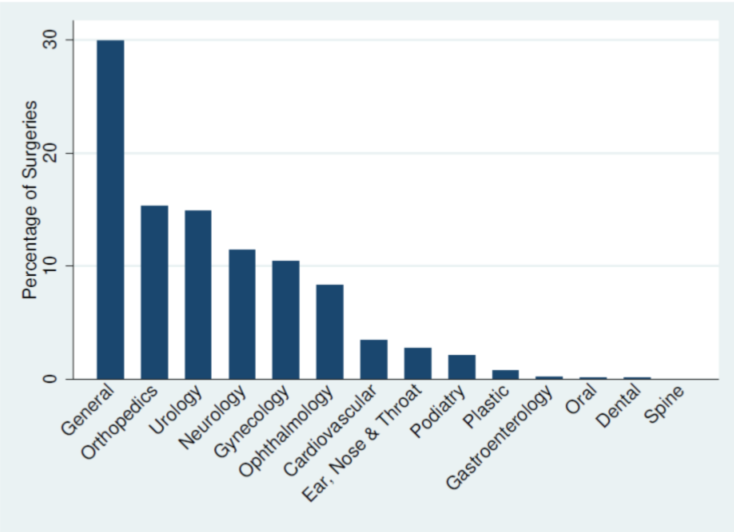

Fig 6: Hospital-1 Volume of Procedures by Service Type

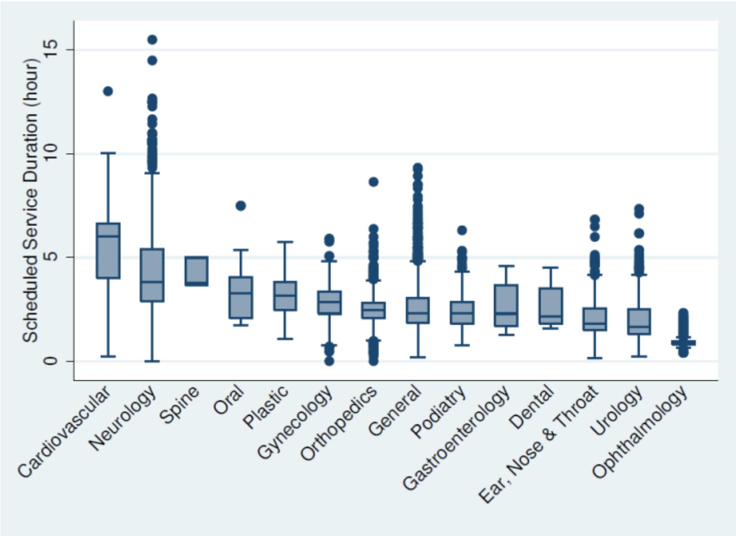

Fig 7: Hospital-1 Surgery Duration Distributions by Service Type

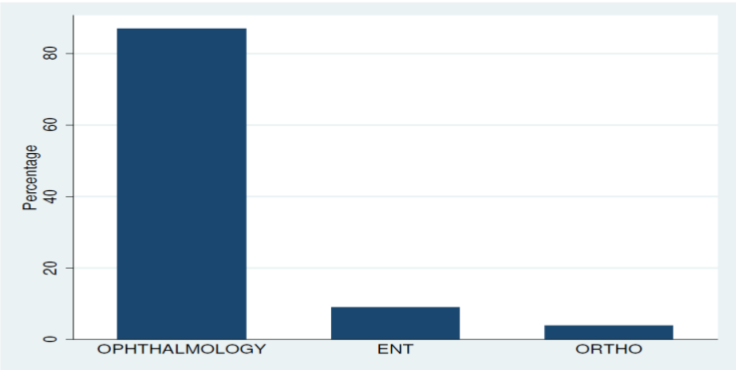

Fig 8: Hospital-2 Volume of Procedures by Service Type

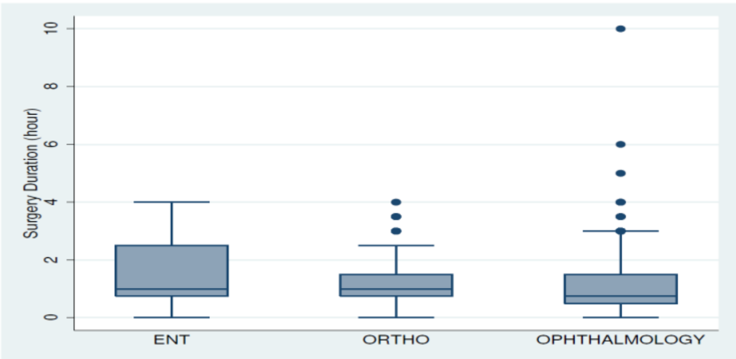

Fig 9: Hospital-2 Surgery Duration Distributions by Service Type

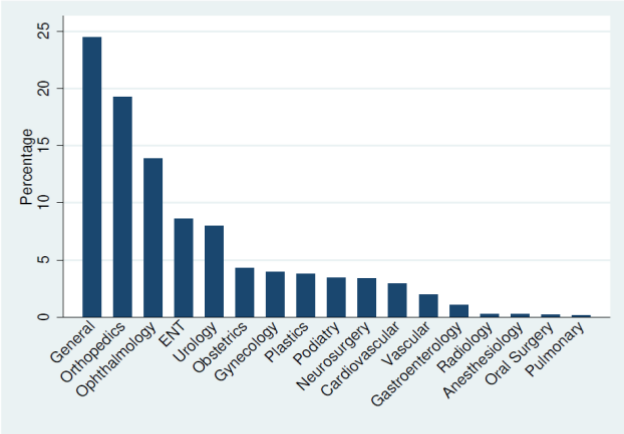

Fig 10: Hospital-3 Volume of Procedures by Service Type

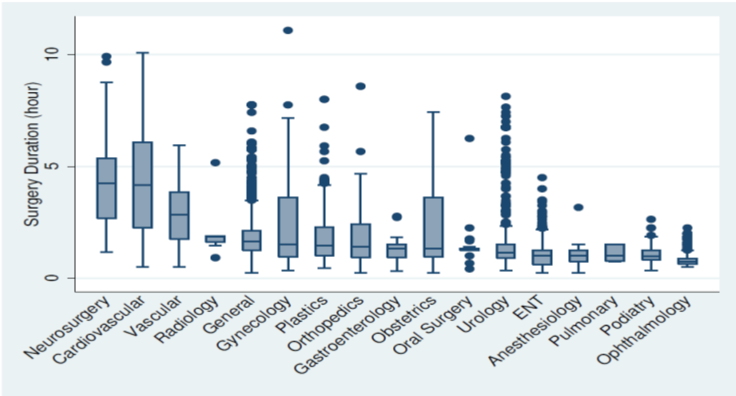

Fig 11: Hospital-3 Surgery Duration Distributions by Service Type

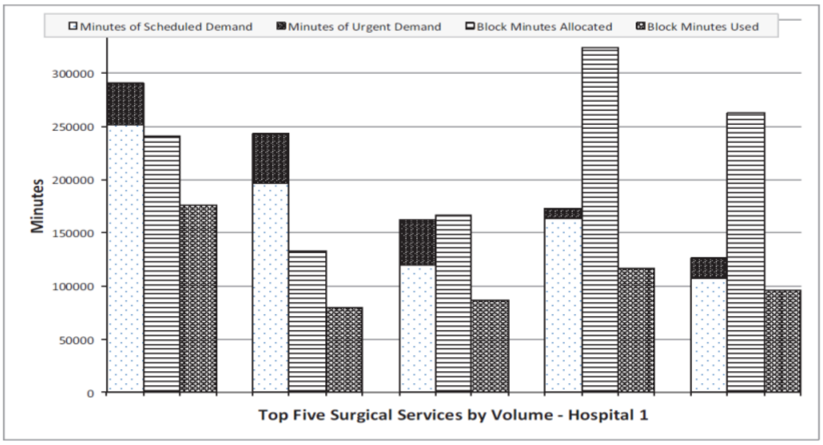

Fig 12: Demand, Block Allocation, and Block Usage

Observe that allocated block minutes are smaller than the scheduled demand for the first two service lines and greater than the demand for the last three. This can happen for a variety of reasons. For example, scheduled demand may have changed since block allocations were made. Some rooms may have been dedicated to the exclusive use of certain service lines, and block allocations may have been made based on the perceived importance of some service lines. More interesting to note is that none of the top five service lines fully utilizes its allotted block minutes. This is true even for the first two service lines; whose scheduled demand exceeds the allotted block minutes. This phenomenon reveals the complexities of OR capacity management.

In US hospitals, surgical procedures are booked one at a time and must fit into the length of the block. The underlying problem is an online bin-packing problem, which remains an open challenge. The authors also found that hospitals may not provide clear guidelines to schedulers about using non-block time by block surgeons, which can contribute to the issues exemplified in Figure 12.

We highlight a different problem in the following analysis, which focuses on staffed OR utilization. This analysis was performed using data from a hospital that uses two-shift lengths – 8 hours and 12 hours. The hospital staffed different numbers of ORs by day of the week. Moreover, more 8-hour shift ORs were staffed each day than 12-hour shift ORs. This may partly be because of the difficulty and cost of continuously staffing ORs for 12 hours. All shifts started at 7 AM, and the first half-hour was reserved for preparation. That is, ORs opened for surgery at 7:30 AM.

Figure 13 shows differences in utilization of staffed ORs between 7:30 AM and 3 PM compared to their utilization between 3 PM and 7 PM. We observe that staffed OR utilization regularly exceeds 100% after 3 PM. This happens because surgeries scheduled in rooms that are supposed to close at 3 PM do not completed by 3 PM. Staff who work 8-hour shifts and need to stay beyond 3 PM must be paid overtime, while they may have been idle earlier in the day. The annual costs for opening ORs longer than planned for the duration of this data were of the order of hundreds of thousands of dollars. This example shows that hospitals need to match the times better when the ORs are open and when the surgeries are typically performed to reduce both underutilization and overutilization of staffed OR time.

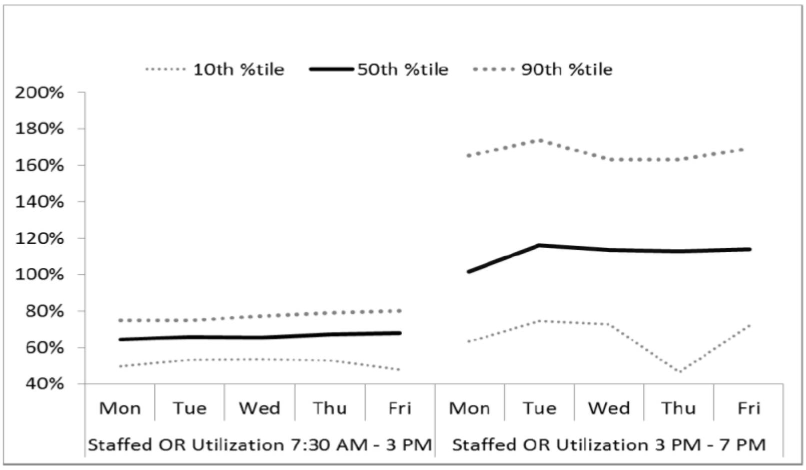

Fig 13: Staffed OR Utilization

Evidence from our analysis of data uncovers a series of problems that could potentially be modeled and solved using OM methodology. To summarize, the key issues are as follows:

1. there is significant variability in the volume of surgeries by type,
2. case length durations within each surgery type are also highly variable,
3. block utilization is often low, even when surgeons' total case lengths far exceed their allotted block size,
4. and ORs typically run in overtime, especially the 8-hour shifts, because cases are not finished by 3 PM.

In the next section, we describe the operational challenges different stakeholders face.

4. OPERATIONAL CHALLENGES

We propose four main decisions concerning nursing unit operations that affect supply-demand matching. These are (1) unit size and scope decisions, (2) choice of performance metrics, (3) choice of policies concerning assignment of shifts and time-off requests, which we call HR policies (HR stands for human resources), and (4) choice of policies concerning patient movement. Whereas the unit size and scope decisions are most easily recognizable as being relevant to OM topics, we will show that all four impact nurses' productivity and hospital costs. We justify our focus on nursing costs while ignoring other care providers because (1) an estimated 80% of the direct care costs in hospitals is payroll related (Heydari et al., 2021), and (2) nursing care plays a dominant role in care provision, and (3) the cost of available nursing hours is high relative to that of other care providers.

Staffed-bed capacity decisions lie within a continuum of choices that hospitals make. These choices fall into a natural hierarchy based on the frequency with which they are made (see Figure 14). At one end of this hierarchy are the least frequently changed parameters, such as the total number of certified beds, the amount of space per floor, and contractual agreements with employee unions. Unit size and scope choices are next in this hierarchy, and they are followed by the choice of the number of nurses and their skill levels. Next, hospital managers develop a work schedule for nurses for 2-4 weeks at a time posted 4-6 weeks in advance. Such staffing plans are also medium-term plans (Latham & Marshall, 2015). Finally, hospitals make start-of-shift nurse assignments (in response to realized nursing care needs and absent/sick calls) and real-time patient movement decisions as requests for beds are received. These decisions lie at the other end of the hierarchy. As shown in Figure 14, all of these decisions are affected by choice of performance metrics.

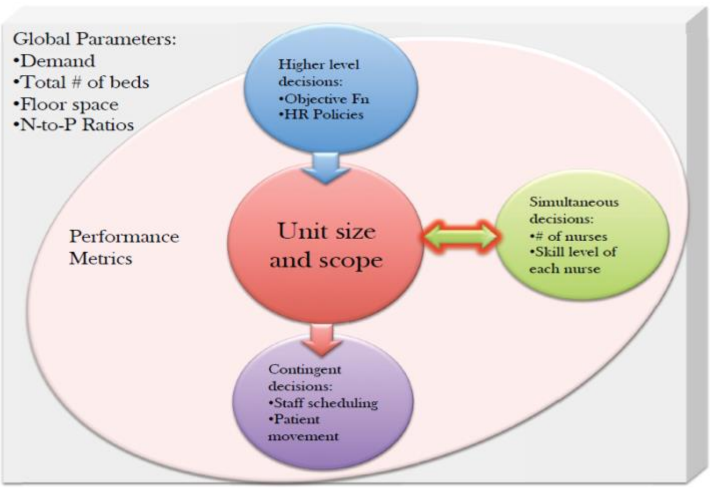

Fig 14: Hierarchy of Managerial Decisions.

Many hospitals have organized services for each acuity level into multiple nursing units such that these units have a significant overlap in capability. Each unit also specializes in taking care of a subset of patients who cannot be placed in other units. The overlap in the scope of services is not 100%. However, such units may be treated as interchangeable for many patient types.

Relevant questions are as follows. What should be the degree of overlap among units (defined in terms of types of patients that each unit can handle)? What should be the size of each unit? What should be the assignment order when patients could be placed in one of several units that have available staffed beds?

Some hospitals use swing units that open and close as needed to absorb census fluctuations. Others may distribute census variability across interchangeable units. The former can help the hospital maintain uniform core staffing in primary units, but hospitals need extra staff to staff swing units. The latter arrangement results in greater fluctuation in core staffing levels in primary units. The relevant questions in this context are as follows. When to open or close swing units? What should be the size of swing units, and how should they be staffed?

Along similar lines, some hospitals have invested in understanding adaptable (universal) beds that patients can occupy during their entire hospital stay. In contrast, others move patients to different units depending on their care-intensity needs. In the former arrangement, the level of nursing care is adjusted to match the acuity level of each patient during his/her sojourn. In the latter arrangement, which is the traditional approach, patients may start their sojourn in ICUs then move to step-down units, and finally to low-intensity medical-surgical units, depending on the need. The presence of adaptable acuity beds reduces the number of patient transfers. In some empirical studies, this approach has increased patient safety and decreased nursing hours required (Brown & Gallant, 2006; Chan et al., 2012). Acuity-adaptable beds cost more and require frequent adjustments to the level of nursing care provided. Specifically, nurse-to-patient ratios in such units vary across patients and across time. Relevant research questions are as follows. How many acuity-adaptable beds should a hospital invest in? How should it staff units that may have both acuity-adaptable and regular beds?

Because intensive care beds are costly to staff, the available ICU beds are often in short supply. In some cases, hospitals may move patients to lower care-intensity beds even though such patients will likely stay in the ICU if there is no shortage of beds. This phenomenon is called ICU bumping (Chan et al., 2012; Dobson et al., 2013). It is a part of a broader strategy of moving patients from one unit to another to balance the supply and demand for different types of beds. The authors are familiar with situations in which patients are moved to help hospitals close some units with a low census or help open a previously closed unit, which requires a minimum cohort of nurses for safe operation. Movements also occur to balance patient census across similar units. Thus, patient movements could occur across a care intensity or within a hierarchy. They serve a purpose similar to the cross-training of nurses and the availability of acuity-adaptable beds. Relevant operational decisions concern the determination of rules governing patient movement.

5. CONCLUSION

Spending on inpatient care across OECD countries accounts for almost 30% of overall healthcare expenditures, with outpatient care consuming another 33% (OECD, 2013). Although spending growth rates have slowed in recent years, spending is still increasing. It is anticipated that the cost pressures of GDP spending on healthcare will continue to grow as the world's population ages. Spending increases are counterbalanced by a global life expectancy increase of about six years in the last 20 years, which has been attributed to advances in healthcare (GBD *"The Global Burden of Disease Study"*); (Abubakar et al., 2015; The Henry J Kaiser Family Foundation. Distribution of National Health Expenditures, 2014).

Efforts to reduce healthcare costs have focused on cutting hospital beds, cutting salaries of healthcare workers, reducing reimbursement to healthcare providers, cutting the healthcare workforce, and increasing patient responsibility for covering their healthcare costs through co-payments (Cunningham & Sammut, 2012; Morgan & Astolfi, 2013). But trying to shape supply and demand for healthcare services using these approaches has its limits, and their unintended consequences can be counterproductive. The recent Medicare hospital payment penalties for 30-day hospital re-admission rates (see Matthews, 2014), for example, were implemented to incentivize improved hospital discharge planning and better patient handoffs from inpatient to outpatient care. What has happened instead is that many hospitals are readmitting patients for observation? Stays (Weaver et al., 2015). This reduces the hospital's readmission rate since observation status is not technically a hospital admission. But observation stays can result in higher out-of-pocket costs for patients, especially if they require nursing home care after hospitalization. This is because Medicare does not cover nursing home care unless a patient has been admitted to the hospital for at least 3 days.

Healthcare organizations face many challenges as they adjust to reimbursement changes evolving from fee-for-service to value-related payments. Current and future reimbursement policies will encourage healthcare organizations to focus on managing the care across the entire supply chain to reduce the need for escalation of care to the inpatient setting. These challenges highlight the need for OM models that help improve the efficiency and effectiveness of care for populations of patients across the entire supply chain of care, focusing simultaneously on throughput and outcomes and provider and patient perspectives. OM efforts to improve chronic care management highlighted earlier provide examples of ongoing work needed in designing and evaluating new care models.

Regardless of how care models evolve, there will always be a need for inpatient care. This monograph highlighted recent OM work that models the dynamic inter-related impact of demand-supply matching across the ED, OR, and inpatient units. Healthcare managers and clinicians tend to make staffing and scheduling decisions across these areas independently. Then, as demand unfolds in real-time, clinicians and managers reactively firefight as best they can to reallocate staffing to where it is most needed at a given point in time to alleviate bottlenecks in patient flow. As OM researchers, we need to develop models that enable healthcare managers to improve simultaneously OR scheduling policies, ED demand prediction, and medium- and short-term staffing plans that take into account the inter-relationship of how demand unfolds over time across the ED, OR, and inpatient units.

OM work has fallen short of its full potential in implementing and testing models for real-time decision support tools. In the medical field, major research funding agencies have focused on translational research to more quickly bring new medical knowledge from the bench to the bedside. Some funds are targeted to support such translational research specifically. We recommend a similar focus on the OM fields. Newly developed OM models have the potential to aid healthcare managers in better matching demand and supply. The increasing use of electronic medical records, staffing systems, and scheduling systems contain relevant data to feed these models to support real-time decision-making. To date, we have not systematically focused on the challenges of bringing OM models from bench to bedside and then testing the impact of the models on improving the efficiency and effectiveness of care delivery. To be more relevant, we need to understand and appreciate how to embed OM models for decision support into the computer systems used by clinicians and managers and work collaboratively with them to achieve the full potential that OM has to offer.

REFERENCES

Abubakar, I. I., Tillmann, T., & Banerjee, A. (2015). Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*, 385(9963), 117-171.

Adam, S. K., & Osborne, S. (2005). Critical care nursing: science and practice. *Oxford University Press.*

Allder, S., Silvester, K., & Walley, P. (2010). Managing capacity and demand across the patient journey. *Clinical medicine*, 10(1), 13.

Allon, G., Deo, S., and Lin, W. The Impact of Size and Occupancy of Hospital on the Extent of Ambulance Diversion: Theory and Evidence. *Operations Research*, 61(3):544–562, 2013.

Avidan, V., Hersch, M., Spira, R. M., Einav, S., Goldberg, S., & Schecter, W. (2007). Civilian hospital response to a mass casualty event: the role of the intensive care unit. *Journal of Trauma and Acute Care Surgery*, 62(5), 1234-1239.

Bailit, M. H., Burns, M. E., & Dyer, M. B. (2015). Implementing value-based physician compensation: advice from early adopters. *Healthcare Financial Management*, 69(7), 41-48.

Brown, K. K., & Gallant, D. (2006). Impacting patient outcomes through design: acuity adaptable care/universal room design. *Critical care nursing quarterly*, 29(4), 326-341.

Chan, C. W., Farias, V. F., Bambos, N., & Escobar, G. J. (2012). Optimizing intensive care unit discharge decisions with patient re-admissions. *Operations research*, 60(6), 1323-1341.

Christian, M. D., Sprung, C. L., King, M. A., Dichter, J. R., Kissoon, N., Devereaux, A. V., & Gomersall, C. D. (2014). Triage: care of the critically ill and injured during pandemics and disasters: CHEST consensus statement. *Chest*, 146(4), e61S-e74S.

Conrad, D., Grembowski, D., Gibbons, C., Marcus-Smith, M., Hernandez, S. E., Chang, J., ... & dela Cruz, E. (2013). *A report on eight early-stage state and regional projects testing value-based payment.*

Cunningham, P., & Sammut, J. (2012). Inadequate acute hospital beds and the limits of primary care and prevention. *Emergency Medicine Australasia*, 24(5), 566-572.

Dartmouth College. The Dartmouth Atlas of Health Care: Acute Care Hospital Beds Per 1,000 Residents, (2012). Available at http://www. dartmouthatlas.org/data/topic/topic.aspx?cat=24; Accessed: 10-21-2015.

deBoisblanc, B. P. (2005). Black Hawk, please come down: reflections on a hospital's struggle to survive in the wake of Hurricane Katrina. *American Journal of Respiratory and Critical Care Medicine*, 172(10), 1239-1240.

Dobson, G., Tezcan, T., & Tilson, V. (2013). Optimal workflow decisions for investigators in systems with interruptions. *Management Science*, 59(5), 1125-1141.

Fischer, L. R., & Eustis, N. N. (1989). Quicker and sicker: How changes in Medicare affect the elderly and their families. *Journal of Geriatric Psychiatry*.

Hendrich, A. L., Fay, J., & Sorrells, A. K. (2004). Effects of acuity-adaptable rooms on flow of patients and delivery of care. *American Journal of Critical Care*, 13(1), 35-45.

Heydari, M., & Lai, K. K. (2020). A study on risk and expense evaluation of agility supply management of machinery. *Discrete Dynamics in Nature and Society*, 2020.

Heydari, M., Lai, K. K., & Xiaohu, Z. (2021). How to Manage Red Alert in Emergency and Disaster Unit in the Hospital? Evidence From London. *Frontiers in Public Health*, 9.

Heydari, M., Lai, K. K., & Zhou, X. (2020). Creating sustainable order fulfillment processes through managing the risk: evidence from the disposable products industry. *Sustainability*, 12(7), 2871.

Heydari, M., Xiaohu, Z., Lai, K. K., & Yuxi, Z. (2020). Evaluation of Organizational Performance Strategies. *Proceedings of National Aviation University*, 82(1).

Kosecoff, J., Kahn, K. L., Rogers, W. H., Reinisch, E. J., Sherwood, M. J., Rubenstein, L. V., ... & Brook, R. H. (1990). Prospective payment system and impairment at discharge: thequicker-and-sicker'story revisited. *Jama*, 264(15), 1980-1983.

Kroneman, M., & Siegers, J. J. (2004). The effect of hospital bed reduction on the use of beds: a comparative study of 10 European countries. *Social science & medicine*, 59(8), 1731-1740.

Latham, L. P., & Marshall, E. G. (2015). Performance-based financial incentives for diabetes care: an effective strategy? *Canadian Journal of Diabetes*, 39(1), 83-87.

Lion, K. C., Mangione-Smith, R., & Britto, M. T. (2014). Individualized plans of care to improve outcomes among children and adults with chronic illness: a systematic review. *Care Management Journals*, 15(1), 11-25.

Matthews, W. A. (2014). Care coordination measures of a family medicine residency as a model for hospital re-admission reduction. *The American Journal of Managed Care*, 20(11), e532-4.

McKee, M., & World Health Organization. (2004). *Reducing hospital beds: what are the lessons to be learned?*

McManus, M. L., Long, M. C., Cooper, A., Mandell, J., Berwick, D. M., Pagano, M., & Litvak, E. (2003). Variability in surgical caseload and access to intensive care services. *The Journal of the American Society of Anesthesiologists*, 98(6), 1491-1496.

Medicare Payment Advisory Committee, (2014). Report To the Congress: Medicare Payment Policy. Technical report, MEDPAC, Washington, DC.

Morgan, D., & Astolfi, R. (2013). *Health spending growth at zero: which countries, which sectors are most affected?*

Nutting, P. A., Crabtree, B. F., Miller, W. L., Stange, K. C., Stewart, E., & Jaén, C. (2011). Transforming physician practices to patient-centered medical homes: lessons from the national demonstration project. *Health affairs*, 30(3), 439-445.

OECD. Health At a Glance (2013): OECD Indicators. Technical report, OECD Publishing, 2013.

OECD. Health Statistics (2015) - Frequently Requested Data, 2015. Available at http://www.oecd.org/health/health-data.htm; Accessed 10-21-2015.

Qian, X., Russell, L. B., Valiyeva, E., & Miller, J. E. (2007). *Medicare's prospective payment system for hospitals: new evidence on transitions among health care settings* (No. 2007-07). Working Paper.

Roberge, D., Pineault, R., Larouche, D., & Poirier, L. R. (2010). The continuing saga of emergency room overcrowding: are we aiming at the right target? *Healthcare Policy*, 5(3), 27.

Rubinson, L., Hick, J. L., Hanfling, D. G., Devereaux, A. V., Dichter, J. R., Christian, M. D., ... & Geiling, J. A. (2008). *Definitive care for the critically ill during a disaster: A framework for optimizing critical care surge capacity: From a Task Force for Mass Critical Care summit meeting*, January 26–27, 2007, Chicago, IL. Chest, 133(5), 18S-31S.

Ryan, A. M., & Press, M. J. (2014). Value-based payment for physicians in Medicare: small step or giant leap? *Annals of internal medicine*, 160(8), 565-566.

Schoen, C., Osborn, R., Squires, D., Doty, M., Pierson, R., & Applebaum, S. (2011). New 2011 survey of patients with complex care needs in eleven countries finds that care is often poorly coordinated. *Health affairs*, 30(12), 2437-2448.

Sutherland, D., & Hayter, M. (2009). Structured review: evaluating the effectiveness of nurse case managers in improving health outcomes in three major chronic diseases. *Journal of clinical nursing*, 18(21), 2978-2992.

The Henry J Kaiser Family Foundation. Distribution Of National Health Expenditures, By Type of Service (In Billions), (2014). Available at http://kff.org/health-costs/slide/distribution-of-national-healthexpenditures-by-type-of-service-in-billions-2012/; Accessed: 10-21-2015.

Van den Schrieck, J. C., Akşin, Z., & Chevalier, P. (2014). Peakedness-based staffing for call center outsourcing. *Production and Operations Management*, 23(3), 504-524.

Weaver, C., Mathews, A. W., & McGinty, T. (2015). Medicare Rules Reshape Hospital Admissions: Return-visit rate drops, but change in billing tactics skews numbers. *The Wall Street Journal.*