CHAPTER I
INTRODUCTION

1.1 Background

Over the past two decades, the healthcare industry has faced significant transformation. One of the most pressing global challenges of the 21st century is the aging population. The increasing proportion of individuals aged 65 and above has contributed to a worldwide surge in healthcare expenditure, driven by higher demand for both medical and long-term care services. This trend poses substantial threats to the sustainability of public health financing across countries (Lopreite & Zhu, 2020).

The COVID-19 pandemic has further disrupted global healthcare systems. Hospitals became overwhelmed with patients, while public health authorities focused on mitigating the virus's spread. As a result, non-urgent medical services, including elective surgeries, were postponed or canceled. Restrictions such as curfews, transportation limitations, and stay-at-home mandates prevented patients from accessing care, while many avoided healthcare facilities out of fear of infection. These disruptions severely affected elective surgical services, leading to extensive waiting lists and delays in nearly every country. Although concerns about surgical wait times are not new, the combination of limited operating room (OR) resources and growing demand has exacerbated the issue (Angelis et al., 2016).

The pandemic has worsened this already strained system. According to the COVIDSurg Collaborative, it would take a median of 45 weeks to clear the backlog of surgeries caused by just 12 weeks of peak pandemic disruption, assuming a 20% increase in normal surgical volume post-pandemic. However, with the pandemic persisting for over two years, this estimate likely underrepresents the true extent of the problem (Mehta et al., 2022). These delays increase both operational costs and the complexity of scheduling, as urgent and delayed procedures must be managed simultaneously.

Extended waiting times can lead to severe consequences. Prolonged delays in diagnosis and treatment may worsen patients' conditions, reduce recovery prospects, and even impact survival rates. The long-term effects include irreversible loss of function or poorer health outcomes, while short-term consequences range from worsened symptoms to decreased ability to work (Mehta et al., 2022). For example, patients awaiting elective procedures like joint replacements face prolonged pain and reduced quality of life. Delays in cancer surgeries or missed chemotherapy sessions can have life-threatening implications. Additionally, deferring appointments increases the likelihood of missed diagnoses and necessitates more expensive, resource-intensive interventions later. These delays impose not only a burden on the healthcare system but also broader societal and economic costs.

As COVID-19 transitions to an endemic phase, it is imperative that healthcare institutions address the backlog of elective surgeries and resume routine operations. Effective allocation of OR resources is now more critical than ever to ensure timely access to surgical care and restore normal system functionality.

1.2 Motivations and Significances

Resource allocation is a constant challenge for healthcare decision-makers. Whether prioritizing between services (priority setting) or among patients (rationing), the pandemic has highlighted the necessity for systematic, transparent, and equitable allocation decisions (Angelis et al., 2016). COVID-19 created a stark mismatch between demand and available resources. Hospitals and governments were forced to make urgent decisions regarding who would receive care, often without clear guidelines for admissions, discharges, or the use of limited resources such as ICU beds and protective equipment (Frank et al., 2020). Allocation protocols were rapidly developed to reduce bias and improve decision-making under uncertainty (Badalov et al., 2022).

Now, with the acute phase of the pandemic largely behind us, hospital administrators are under increasing pressure to reduce surgical backlogs and meet rising demand for elective procedures. The competition for limited OR blocks across departments has intensified, necessitating better planning and scheduling strategies. However, the challenges remain: hospitals continue to face resource shortages,

including limited surgical staff, operating theatre slots, beds, and ICU capacity. Uncertainties about future surgical demand and resource availability further complicate planning efforts.

In this context, effective OR block allocation is crucial. The number of blocks assigned to each surgical department directly affects hospital performance by influencing patient throughput, operating costs, and overall revenue. Different surgical specialties generate varying revenues, incur different costs, and require different postoperative recovery times and ICU stays. Moreover, the cost of waiting varies across specialties—some patients experience more severe health declines from delays than others.

Given these complexities, a strategic approach is required to optimize the allocation of OR resources and prioritize patients within each department in a fair and clinically informed manner. This research aims to address these challenges through a two-phase approach:

1.1 **Phase 1**: focuses on allocating OR blocks among surgical departments based on multiple performance and capacity considerations.

2.1 **Phase 2**: applies a multi-criteria decision-making (MCDM) framework to prioritize patients within each department, ensuring that limited surgical slots are used for those with the most urgent needs or the highest potential benefit. By improving planning and scheduling processes, hospitals can better manage surgical backlogs, enhance resource utilization, and ensure timely and equitable access to elective surgical care in the post-pandemic era.

1.3 Problem Definition

The Operating Theatre (OT) is a critical and resource-intensive component of the hospital system, where the coordination of various resources—operating rooms (ORs), surgical teams, intensive care units (ICUs), and inpatient wards—is essential to delivering timely and efficient elective surgical care. As demand for elective surgeries continues to rise across multiple surgical departments, hospitals face growing

challenges in optimizing the use of constrained OR capacity while minimizing patient waiting times and operational costs.

Hospitals typically adopt a Block Scheduling Strategy—allocating fixed time blocks within ORs to specific surgical departments over a planning horizon (e.g., a week). However, if these blocks are not optimally assigned, it can result in unfair access among departments, under-utilized ORs, prolonged patient waiting lists, and inflated hospital costs. Furthermore, uncertainty in surgery durations and patient length of stay (LOS) complicates planning, making traditional deterministic models inadequate for real-world applications.

The Block Master Surgery Scheduling Problem (BMSSP) arises from the need to allocate surgical specialties to OR blocks under such uncertainty, while balancing multiple, often conflicting, performance objectives. Despite its practical relevance, existing approaches often overlook the stochastic nature of surgical services or treat uncertainty in a simplified manner. To address these issues, this study proposes a two-phase decision framework:

Phase 1: OR Block Allocation – A mathematical optimization model is developed to allocate OR blocks to surgical departments while incorporating uncertainty in both surgery durations and patient LOS. The model aims to ensure fairness in access—by minimizing disparities in waiting list clearance time—and to reduce total incurred costs associated with surgery overtime, delays, and capacity overflow.

Phase 2: Patient Prioritization – After block allocation, an MCDM-based approach is applied within each department to prioritize patients for surgery based on multiple criteria, including clinical urgency, waiting time, and expected resource utilization, under limited OR time and stochastic conditions.

By integrating strategic-level OR block planning with tactical-level patient scheduling, the proposed framework contributes a comprehensive, uncertainty-aware solution to improving surgical service delivery. It aims to enhance OR utilization, reduce patient wait disparities, and contain hospital operational costs in a resource-constrained environment.

1.4 Problem features

1.4.1 Block Master Surgery Scheduling Problem (BMSSP)

Master Surgery Scheduling Problem (MSSP) is to schedule the surgical specialties (SSs) to the different operating rooms available, such that surgeries may be performed efficiently. MSSP determines the workload distribution, and the revision of the MSS is restricted by the capacity and demand constraint. The availability of the operating room is based on block scheduling strategies adopted. As a large body of literature is based on the block scheduling strategy, while relatively fewer studies follow the open scheduling strategy. In practice, the block scheduling strategy is applied more often than the open scheduling strategy in hospitals. Once a block time of an OR is allocated to one surgeon or surgical specialty, others cannot occupy the block even if that surgeon doesn't arrange any surgical cases in the block time.

In this study, we focus on BMSSP, the problem of allocating surgical specialties (SSs) to operating rooms over a given time horizon (one week). OR capacity is divided into blocks or slots with each OR for a specified duration of 8 hours.

1.4.2 Uncertainty

Uncertainty is an impacting issue due to the highly variable nature of surgical cases (Vancroonenburg et al. 2015). The literature on OR scheduling shows that the uncertainty of surgery duration is inherent to surgical services. Surgery duration refers to the processing time of the surgery. Duration uncertainty refers to the deviations between the actual and the planned durations of relevant activities during the surgical process. The uncertainty of surgery duration is mainly caused by the patient condition, the skill of the surgeon and any other factors that can make the surgery smooth or not (Molina-Pariente et al., 2015). Furthermore, the duration depends on the surgical specialty such as orthopedic, cardiac, or neurological. Uncertain actual surgery duration is a significant factor in surgery planning and scheduling problems, which makes the problems much more challenging. The consideration of uncertainty in surgery durations and emergency interventions can make the OR scheduling problems quite different from the deterministic ones. Such uncertainty or variability is commonly ignored in many OR planning and scheduling

problems which assuming deterministic surgery durations, while stochastic approaches try to incorporate it. In addition to duration uncertainty, the inherent uncertainty in surgeries such as the unforeseen arrival of an emergency patient also has an impact on the surgery schedule.

Although plenty of studies show that the uncertainty factors such as emergency requirements in OR planning are extremely important, researchers all use the deterministic optimization model in the existing OR planning methods, and the hospital is supposed to use dedicated ORs to serve emergency patients, or to use a fixed portion of the capacity to perform emergency operations (Lamiri et al., 2008). Moreover, in hospitals, balancing the operational costs and the service level is hard. In the problems of OR planning and scheduling, the constraints are mainly about the availability, applicability, and usability of resources, including facilities resources. A set of resource combinations is open to certain cases at certain times in certain places, while others may be unavailable or inapplicable. Only a few researchers pay attention to resource uncertainty that results from patient length of stay (LOS). Hence, this study aims to incorporate demand uncertainty, namely surgery duration and patient LOS.

1.4.3 Performance measures

Various performances criteria are used to evaluate operating room planning and scheduling problems. The structure and scope of an OR mathematical model may be limited to these criteria (Rahimi & Gandomi., 2020). According to Cardoen et al. (2010), they distinguished between eight main performance measures, such as, waiting time, throughput, utilization, leveling, make-span, patient deferrals, financial measures, and preferences. In this study, we focus on two critical healthcare performance measures namely: waiting list clearance time (waiting time and throughput) and total incurred cost (financial measures). Henceforth, operating room block planning and scheduling aims at minimizing the conflicting costs of operating room overtime, as well as patient waiting time for surgery while accounting for the penalty cost for exceeding operating room capacity.

1.5 Objectives

The following are the main objectives of this study:

1) To develop a mathematical model that minimizes both the total absolute deviation of the time required to clear the surgical backlog for all Surgical Specialties (SSs) and the overall costs associated with operating room (OR) block allocation over the planning period.
2) To allocate OR blocks across multiple SSs in a way that balances resource utilization and equity in patient access.
3) To prioritize patients within each surgical specialty using a multi-criteria decision-making (MCDM) approach that accounts for various clinical and operational factors (e.g., urgency, waiting time, expected surgery duration, ICU/ward resource consumption).
4) To analyze the trade-off between time-based and cost-based performance in OR block allocation decisions.

1.6 Scope of Research

This study focuses on improving elective surgery planning at the tactical and operational levels in a hospital setting through a two-phase framework:

1) **Phase 1 –** OR Block Allocation: A mathematical model is developed to allocate OR blocks to various Surgical Specialties (SSs) under demand uncertainty. The aim is to minimize the total absolute deviation in the time required to clear patient backlogs and reduce OR operational costs, while ensuring efficient and equitable use of critical resources (OR time, ICU beds, surgical ward beds).
2) **Phase 2 –** Patient Prioritization: Once blocks are allocated to each department, patients on the waiting list are prioritized using a multi-criteria decision-making (MCDM) approach to ensure that patients with higher urgency and greater need are treated first. This step addresses sequencing decisions within each specialty rather than detailed scheduling across the OR timetable.

The following issues are addressed to achieve these goals:

1) Develop a mathematical model to determine the optimal number of OR blocks allocated to each surgical specialty that minimizes operating costs and the deviation in backlog clearance time.
2) Use MCDM methods (e.g., AHP, TOPSIS, or similar) to prioritize patients for surgery within each specialty based on predefined criteria.
3) Perform scenario analysis to examine how different planning strategies affect the trade-off between time and cost.
4) Explore fairness scenarios where some specialties may be given priority access (e.g., life-threatening conditions) to evaluate equity in waiting list clearance.
5) Evaluate the proposed block allocation and patient prioritization framework using computational experiments and sensitivity analysis over a planning horizon to improve the operating room's performance in terms of time and cost.

1.7 Research Assumptions

The study makes the following assumptions:

1) Dedicated Pathway for Emergencies: Emergency surgeries are handled in separate resources and are excluded from this analysis. Outpatient procedures are also excluded as they typically do not strain ICU or ward capacities.
2) Homogeneous ORs: All ORs are identical, fully equipped, and capable of handling surgeries for any specialty. Surgical team constraints are not explicitly modeled.
3) Block Scheduling Policy: A block is defined as 8 hours (8:00–16:00). A maximum of two blocks per day per OR is allowed (i.e., 16 hours from 8:00–01:00). Overtime incurs a penalty cost.
4) Resource Constraints: The study focuses on OR blocks, ICU beds, and surgical ward beds. Other resources such as lab, radiology, or outpatient nursing capacity are excluded.

5) Static Waiting List: The number of patients on the waiting list at time t is known and fixed. The model does not consider new arrivals and aims to clear the current backlog to return the OT to business as usual operations.
6) Sequencing Rule Baseline: Although MCDM is used for prioritization, the default comparison assumes a first-come, first-served (FCFS) rule.
7) Post-Operative Resource Usage: Post-surgery ICU stays are modeled. Patients may be downgraded to lower levels of care if ICU capacity is exceeded, with associated penalty costs.

1.8 Expected Usefulness

1) The proposed models will provide a structured admission and block allocation plan for elective surgery that minimizes variation in actual versus target utilization of critical resources.
2) The proposed multi-stage optimization framework help the decision-making more transparently.
3) The study's results will help medical and administrative staff recognize the importance of effective OR planning and patient prioritization to ensure timely care delivery and efficient resource use.

1.9 Organization of the Thesis

1) **Chapter 1** outlines the background, problem definition, objectives, scope, assumptions, and significance of the study.
2) **Chapter 2** presents a review of related literature in OR scheduling, block allocation, and patient prioritization methodologies.
3) **Chapter 3** formulates the mathematical models for OR block allocation and describes the MCDM approach for patient prioritization, along with the case study context.
4) **Chapter 4** provides computational results and scenario analyses to evaluate model performance and robustness.
5) **Chapter 5** concludes the study with key findings, contributions, limitations, and directions for future research.