Capacity Utilisation Modelling and Patient Flow Intelligence: AI-Based Frameworks for Healthcare Resource Allocation and Management Optimisation

Dr. Aisha Hassan, Professor of Computer Science, University of Khartoum, Sudan

1. Introduction

The planning and allocation of staff, equipment, and facilities in hospitals have grown increasingly complex due to a growing demand for specialized staff and resources, as well as the need for hospitals to accommodate specific patient needs and requirements. With access to few ideal databases and restricted samples due to the lack of a mandated ratio, these calculations are not always grounded in empirical proof. As a consequence, this key metric of a well-run hospital is often subjective. The elimination of hospital beds contributes to excessive congestion and leads to long wait periods in emergency centers. Furthermore, there will be more contaminated waste and a population of more than 70,000 people. Consequently, hospitals need to focus on continuously replenishing staff, beds, and recovery to keep up with patient loads by improving operations. Using machine learning to anticipate useful assistance is a potential approach.

However, any AI-enabled or AI-driven project should be evaluated in terms of value, and machine learning on its own cannot offer knowledge or decision-making because machine learning applications are not a source of usable data to guide decision-making on employment and staffing. This essay illuminates the multiple applications of AI in forecasting patient flows and staffing choices, as well as the uncertainties and constraints. Rationale: Forecasting patient flows and making informed future alternatives for staffing have many advantages. Larger, well-established AI systems are expected to have a significant effect. This system assesses the potential AI system through a broad examination of the mechanisms of injury evacuation, given a variety of objectives. Furthermore, this paper lays the groundwork for focusing on a potential AI device that allows hospitals to forecast and use real-time patient data. Goal: AI for patient flow forecasting and staffing assignment. The purpose of this essay is to provide

an objective assessment of whether patient flow forecasting and staffing allocation are practical applications for managing operational resources by forecasting patient flow. This topic discusses options available for future care.

1.1. Background and Significance

Healthcare resource management has evolved in modern hospitals as their operations have become increasingly complex. Changes in medical practice and the exponential growth in attending larger populations have created increasingly larger and more complex hospitals controlling budgets of multi-billion dollars, employing thousands of employees, and occupying millions of square feet. Hospitals in the U.S. delay or turn away tens of thousands of patients annually, and insufficient high-skill labor is an ongoing problem. Many hospitals are turning away high-margin patients while those patients are willing to pay. This calls for enhancements in strategic as well as operational decision-making processes in hospitals in order to maximize the value of services offered by them in the face of increased and firming demand.

Several interdisciplinary bodies of research have emerged to make healthcare operations more efficient. In recent times, automation that characterized hospital operations in the 20th century has entered the decision-making realm of hospital operations. Decision-making support to hospital managers and executives is accomplished through the use of management information systems. These systems can be used to support strategic as well as tactical decisions. A topic that has received considerable attention in literature is the use of decision support technology in supporting strategic and operational workforce scheduling. Healthcare experts believe that the potential gain of AI-based manpower scheduling can be as high as 10%. As a result, conceptual developments have positioned machine learning as a tool that can help improve the workings of management information systems by combining with classical procedures to develop more robust scheduling solutions. Pilots at hospitals have also supported the seamless entry of AI tools. Staffing and scheduling are issues that are on the minds of hospital administrators in the U.S. Published literature consists only of three papers. Staffing and scheduling are also a concern for top management. Marginal increases in productivity and surgical capacity may mean millions of additional profits every year for a hospital. The healthcare industry in the U.S. spends over 1.4 trillion dollars every year. Spending of more than one-third of this total expenditure happens in hospital care. Inappropriate

utilization of beds, patient flow, information systems, staffing, and suboptimal emergency department operations are the principal causes of inefficient operation of hospitals. Data on responses from hospital administrators to a multi-dimensional efficiency survey also supports this conclusion.

2. Fundamentals of Healthcare Resource Management

The manner in which a hospital allocates and utilizes its resources can greatly influence the quality and cost of its services. One major source of expense in a hospital is staffing, which accounts for almost half of operating costs. Healthcare facilities must also manage physical resources, including facilities and technologies, such as imaging and laboratory services that demand skilled personnel and, in many cases, a high level of fixed capital investment. Clinical support activities and functions also require resources, and they may have separation from costs due to the need for specialized nursing or other professional staffing. Centralized hospital operations are often driven by economies of scale or shared management opportunities, which decrease overhead and reduce staffing requirements by expanding spans of control. Finally, nursing and other clinical ancillary staff provide direct patient care and support.

A core motivation in healthcare resource management is the idea that increased operational efficiency and good hospital resource allocation will lead to better patient outcomes. Resource-constrained settings, such as a hospital, may suffer frustration from different patient and stakeholder groups if resources are "eliminated" for the patient. Staffing appreciation for performance and cost is fundamentally related to the allocation of only one of the cost centers in hospital operations. The application of this value maximization practice makes hospital functions not for revenue maximization, but rather to access a network of strategic economic constraints. Effectively, the hospital works to "trade off" different operating outcomes to reduce friction in the business model while maintaining high clinical quality standards. The main cost centers to run a hospital operation typically are personnel, supply, and facility. This operations management paradigm did not exist prior to the deep infrastructure in more advanced data-supported management algorithms faced today.

2.1. Challenges in Hospital Operations and Staffing

Efficient hospital operations and effective staffing are the keys to healthcare. Hospitals' necessary resources are perennially short. There usually are not enough beds available

to accommodate the number of patients showing up for care. Hospital staffing for nurses, clinicians, and allied health professionals can be so onerous that an 18% annual staff turnover across the nation is in the best-case scenario. Scheduling conflicts are common, while human resources and staffing budgets are exceeding their respective bounds. The consequences of operational and staffing challenges do not only create an obstacle in delivering care but also stack patient response times and crowding, particularly in the Emergency Department area. These factors can, in turn, decrease the emergency patient arrival rate, inevitably lowering hospital revenue. Staff shortages can lead to a degradation of the quality of patient care, possible malpractice claims from poor patient outcomes, and decreased morale among remaining staff due to the additional burden placed on them.

To further compound the problem, the hospital-wide services have given rise to a reduced net operating margin per bed. Some of today's medical institutions are in high distress, edging towards bankruptcy. A hospital performance expert attributes this trend to aging physical infrastructures and outdated medical technologies. Another reason is the inability to financially maintain a high-standard facility. Despite these operational and financial barriers, the quality of care delivered remains an obvious criterion. As such, the need remains for solutions to remedy the challenges in operational and scheduling-related care within the hospital walls. A survey of hospital-based alumni indicates that the need to optimize resources through analytic-driven interventions is necessary in the special hospital-to-ED corridor.

3. Role of Artificial Intelligence in Healthcare

Artificial Intelligence (AI), through its role in transforming data into strategically informed decision-making, is having a profound effect in the healthcare industry. By managing and integrating huge data sets in real time, AI can revolutionize how healthcare organizations run hospitals and other operations. AI has the potential to enhance the efficacy of hospital administration, leading to an improvement in the quality of patient care and the bottom line. As concerns the patient, AI can advance healthcare administrators' ability to monitor patient outcomes, establish treatment protocols, and evaluate their success. By leveraging sophisticated machine learning tools, hospital leaders will become better adept at understanding how to use resources to maximize patient care delivery within their operations. Human capital investment –

the hiring and management of healthcare professionals, primarily nurses – makes up the largest line item in any hospital's budget. AI-based management practices will offer substantial operational efficiencies in the recruitment and retention of the nation's largest workforce, nurses. Finally, and importantly, AI streamlines medical errors.

The use of AI is broad and pervasive; it has been applied in areas from drug discovery to patient diagnostics and administrative tasks. Specifically, for this whitepaper, AI has practical applications in addressing the needs and challenges of the healthcare sector. This is important to underscore because AI has been hyped as a tool that is too costly and elaborate for all but the largest hospital systems in the nation. Some applications in the medical field are quite narrowly focused, such as the use of robots to conduct minimally invasive surgeries; others are broad and cross-cutting and can greatly help healthcare administrators manage and run efficient, fiscally responsible hospitals. AI is especially beneficial in addressing some of the issues identified in the previous sections. As AI becomes more common in healthcare settings, the relationship patients have with medical professionals will change. Personal interactions will not diminish; rather, the work experience of the healthcare worker will become more efficient, replacing many of the issues discussed in the previous section – supporting the work experience and simultaneously streamlining much of the work. Ultimately, discussing how AI will benefit the administrative side of a hospital is important in order to elucidate the benefits and importance of AI-based predictions. Nearly 60 percent of hospitals that discharge fewer than 100 patients each day do not use AI-based systems. Likewise, only one in six hospitals with 1,000 or more discharges make use of any AI-based systems. However, daily detection of such errors and swift action on itemized AI-based solutions will avoid problems or quicken the resolution of operational issues. Healthcare organizations must roll out AI systems. Hospital AI systems paint a powerful picture. Every single patient event and multiple data points can be reviewed and used in continuous process improvement and patient outcome management and analysis. AI-based systems will soon make predictions on patient discharge data, patient flow through the emergency department, and in a multitude of other areas where patients intersect inpatient and outpatient hospital systems.

3.1. Machine Learning and its Applications in Healthcare

Machine learning is a subset of artificial intelligence (AI) that creates algorithms to recognize patterns in data and make decisions based on them. It has found wide applications in the healthcare industry. A rapidly increasing amount of data available in the form of electronic health records, patient reports, and medical reports, among others, has pushed the adoption of machine learning techniques in the healthcare sector. By applying different machine learning techniques, informaticians are able to go through a large amount of data and develop applications and data analysis to improve patient outcomes.

There is a wide range of practical implementations of machine learning techniques. One of these is in medical imaging analyses. Machine learning models are able to identify patterns in scanned images and come up with conclusions based on their findings. Another area where machine learning has been applied to healthcare data is predictive analytics. One of the important aspects of big data in healthcare is predictive analytics. Machine learning models are able to predict disease development for a patient using different statistics from the electronic health records. Machine learning models learn the statistics from the different cases and predict when a new incoming patient is showing symptoms similar to those in the data. Although machine learning in healthcare has a wide range of applications, there are some challenges in building and training an effective machine learning model. Data quality is one of the critical factors that directly influence the effectiveness of machine learning models. Poor data quality results in inaccurate models and, as such, predictive analytics based on the inaccurate models are less reliable. In healthcare, data must comply with a wide range of regulations, and the sharing and transfer of data may be difficult. With healthcare patient data being sensitive, such information should be stored following regulations and local laws that govern data access. Technical challenges include transferring interpretation from an individual case to generalize knowledge, automating large data manipulation, and scalability and maintenance concerns with the systems used. The model interpretation also faces challenges from retaining and maintaining the models and policies over time.

One area of healthcare that is blossoming is hospital operations and resources management aimed at improving staff schedules and hospital operations. This is aimed at ensuring that hospitals make more patient-focused efforts, allowing them to

consolidate care for different patients, as caregivers are mandated to balance different activities during a work shift. While caregivers are equally important in patients' care journey, patient safety and satisfaction during hospitalization largely depend on the healthcare professionals working around the patient. Consequently, this precludes hospital management from having access to reduced costs and process optimization. Cognitive computing technologies help analyze staffing and other operational as well as patient streaming data to deliver a new model for patient-based staffing practices that can support hospital operations with intuitive, AI-driven staffing options with the help of quality data. It is important to note that any solution serving diagnostics or hospital operations must be trained by highly relevant quality data in order to achieve the best results.

4. AI-Based Solutions for Hospital Operations

The recent technological advances have provided various tools and techniques powered by artificial intelligence (AI) that can assist hospital managers in hospital operations such as resource management, including hospitals and workforce. In hospital management, resources can be divided into four groups: physical, financial, informational, and biological resources. Operations refer to the series of processes after the operations strategy has been determined as input from the strategy functions. Managing operations refers to the implementation of hospital business operations. AI can help enhance the performance of healthcare operations functions and resource management through scheduling and discharge planning, demand prediction and forecasting, resource allocation and sequencing, and inventory management. These improvements may lead to better patient care, lower readmission rates, lower infection rates, and a reduced number of adverse events.

AI can leverage real-time access to hospital data to assess patient loads over time and allocate resources accordingly. AI has been used to predict patient cancellations in surgical cases. The proposed model showed promising improvement. Similarly, an urgent care center uses machine learning to improve the predictive model of demand. Demand forecasting has been explored in medical cases. There are still open issues that AI advancements in hospital resource management and operations need to be further studied and researched. Barriers in AI implementation include limited budgets devoted

to AI projects, staff training and skill development, and problems in integrating AI with existing systems.

4.1. Predictive Analytics in Staffing

A specific application of predictive analytics in healthcare is in the context of staffing levels. Mainly, these models take into consideration the number of patients in a hospital that can be expected during specific hours, days, or months. Thus, they can provide information on the resources to be allocated to properly manage patient flows while minimizing the hospital's waiting times and ensuring the best possible service with limited human resources. In general, such models are able to assess the weekly and/or daily scheduling policies, identify possible shortages in the workforce, and make short-term predictions about the number of patients expected the next week or during certain weeks of the year.

Predictive staffing methods have been proven to be beneficial in improving scheduling efficiency, reducing payroll costs, and improving the quality of care provided in some cases. Most of these methods have been or are currently being implemented to some extent in practice by using software solutions and working with various algorithms, making certain assumptions, setting up fixed schedules that forecast the number of staff required per day or per week, and scheduling the workforce in a less informed way. Many challenges have been identified in this field, one of which is the difficulty of eliminating forecast inaccuracy. One way to deal with these issues is to identify methods where the predictive models are updated on a regular basis and where the workforce management is as flexible as possible.

5. Case Studies and Success Stories

In this section, a few case studies are provided to show real-world applications in the management of healthcare, as well as areas of success where improvements were made possible only through the implementation and optimization of AI/ML technology.

1) e-ICU: e-ICU is an example where ML models are employed by doctors to predict patients who might later decompensate, thereby reducing rescue time and improving patient outcomes. In general, AI has been employed in an array of tasks, ranging from prescribing probabilities for stroke based on image diagnosis, better patient flow through emergency departments, aiding in the treatment of infectious diseases, and

more. Greater detail about a selection of these AI-based healthcare solutions can be found below in case studies and success stories.

2) Sydney Local Health District Offers a Glimpse into the Future of AI in Healthcare: MonitorAI. Sydney Local Health District was challenged by the need to improve hospital efficiency. This was particularly necessary in the emergency department, with the hope of reducing wait times. In a bid to resolve this issue, an AI hub was established to handle initiatives that improve patient outcomes through AI. MonitorAI was created in 2018 to address the problem with the emergency department. It utilized machine learning to predict how many people were expected in the emergency department. Not only does it predict hospital admissions, but it also predicts the length of stay for a patient.

3) New York University: At New York University, the hospital had difficulty with staff rostering. Employees of the hospital had the opportunity to opt out of work. This led to a decline in staff morale. New York University was able to optimize rosters for operating rooms and clinics by using machine learning. Surprisingly, benefits expanded beyond the workplace. Staff were happier every time the clinic was overstaffed. Staffing changes also improved patient care. People did not have to wait in the emergency room for long.

Lessons Learned: Address more than patient care with interested stakeholders. This project has benefited patients, employees, and management. Staff morale was increased by rosters that took into account everyone's preferences. The urgency was reduced, which resulted in patient satisfaction.

5.1. Real-world Implementation Examples

Several hospitals have implemented AI-driven solutions to optimize their operations. A New York-based academic medical center worked with a vendor to combine predictive analytics solutions with robotic process automation in order to improve staff scheduling, reducing the need for contract or agency workers. The algorithm predicts patient needs and adjusts medical staff, administrative staff, housekeeping, respiratory therapy, and all other incremental support staff. The system also resolves scheduling problems that would previously require the admissions staff to pull together multiple interfacing systems.

Another hospital has gotten more granular. A large Michigan health system partnered with an AI software company and built its own business intelligence tool within the EHR system to help improve operations. The predictive model uses patient symptoms in real-time to determine a range, rather than a specific number, of hours from immediate patient readiness to leave the emergency department, but it makes an estimate. It also uses algorithms to look at providers' wait times and would alert staff if a surgeon was consistently early or late or if there was burgeoning capacity that could be filled. Operational insights within seven months saved nearly 1,500 lost hours of patient time from waiting for a bed. They saved more than 3,200 unnecessary post-anesthesia care visits. From the patient experience standpoint, the care team reduced the estimated wait time to get to an exam room within the ortho express care clinic by half. Within a three-month period, the new OEC clinic cut their length of stay by three hours per patient. Tactics this health system used to produce results included reducing direct hours of patient wait time, reducing or eliminating steps that caused unnecessary waits, and optimizing patient flow within the operating suite. Leaders said some elements were quickly reduced from two hours to 30 minutes; other elements took more than a month to reduce from two hours to 90 minutes. In the last six months of one health system, operational reports indicated that overall 1,620 to 2,076 patients were pushed out to an alternative care location. Staff worked with the predictive model to reabsorb personnel in stages that included continuous monitoring of staff utilization down to 10%, 5%, and 2% at their peak shrinkage.

6. Future Direction

Currently, AI applications in HRM are still in the initial stages towards maturity, and we expect major advancements in the following few years. As the Internet of Things becomes more common in healthcare applications, it will help to create a better environment for patients, and more information will be available, which could also help to make hospital operations more efficient. In the future, with rising IoT in healthcare, hospitals will be able to provide more data about patient history and recovery that could help to further optimize staffing so that they are always ahead of the curve. Furthermore, if built-in AI features are added, it is possible that this will be one way to better control staffing levels.

In addition, ethical leadership and ethical guidelines will be set aside, which is important to continue. Regardless of the technology, AI with a healthcare focus will not be subject to technology like Skynet. Hospitals and others should continue to work closely to research and implement AI applications to optimize hospital operations and staffing. In the future, there will surely be new paradigms and opinions about the application of AI in healthcare resource management, and it may well be possible to outperform the approaches used. These guidelines offer collaboration in hospitals and other places, while some potential issues are addressed. Policymakers may pave the way by further reducing such barriers to implementation and possibly leading to the introduction of guidelines and laws in which AI can be executed in various formulations in the context of human decision-making.

7. Conclusion

In this paper, we have examined the prospects of AI-based solutions for resource optimization in healthcare, with a focus on staff workforce management and operational facility overheads in a hospital setting. Our goal was to present a review that brings into focus the promises and challenges involved in integrating machine learning and AI into more efficient healthcare resource management. We argued that AI-based resource optimization strategies can provide tremendous benefits to the population at large in terms of improved population health and well-being, as well as improved hospital efficiency. We discussed the challenge in detail and suggested some possible ways forward.

The main arguments in this paper have been: AI-based solutions have the potential to integrate large volumes of data sources and can extract unanticipated patterns and insights. Classic structured solution methodologies fail, and the techniques offer no explanation or limited explainability. While the final word is still out on these new-age techniques, significant research has been done in recent years, requesting improvements and continued studies. In particular, in our setting, a transition to AI and machine learning-based methods will mean a shift in focus for hospital operations researchers—it will imply a move from automating scheduling and load balancing decisions to a focus on the efficient and effective pairing of patient care complexity with workforce skills, in the face of real-world patient care operations and constraints. Collaborations with healthcare agencies and governing bodies will be needed to populate the seldom-

studied constraints and parameters deemed critical from a healthcare professional's point of view. Finally, as routine becomes reliant on improving technology, it becomes increasingly essential to think about the rigorous training of medical staff and potential displacements of those staff to alternative roles so that they stay in steady work environments where patient care remains paramount, possibly leveraging the information contained in training data to improve patient treatment outcomes.

Overall, the message reiterated is one of radical change; put simply, the future is inescapable. However, as a result of this summit, what remains to be seen is the future of this new-age data-driven optimization paradigm. Regarding the application of these techniques in hospital operations management, support for implementing those that show good early robust success should not go unchecked. Ultimately, as long as the patient's well-being is at the top of the priority list and a policy around ethical care is set in place, then the change may need to happen to further investigate the power of advanced AI and may perhaps be deemed unlikely. There is much scope for a re-evaluation of the benefits of tax-based employment after the successful implementation of some of these recommendations, and a case can be made to allocate additional funding to research into more effective workforce planning to tackle these issues. Human resources is the ultimate business asset; health is one of the most extensive government budgets that need to consider resourcing for maximal return on investment to improve the quality of life and the economy.