Simulating Hospital Resource Management: Strategies and Challenges

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ABSTRACT

The efficient management of resources in hospital environments is critical for ensuring quality patient care while optimizing operational effectiveness. In this article, we explore the application of simulation techniques in modeling and optimizing resource management within hospitals. Through the integration of data-driven insights and computational methodologies, our research aims to address the complexities inherent in resource allocation, staffing decisions, and patient flow management. We discuss various strategies and challenges encountered in simulating resource management processes, including dynamic patient demand, resource constraints, and the impact of operational decisions on overall system performance. Furthermore, we highlight the potential benefits of simulation-based approaches, such as improved resource utilization, reduced waiting times, and enhanced patient satisfaction. By elucidating the intricacies of resource management in hospital settings, this article contributes to the ongoing discourse on healthcare optimization and offers valuable insights for healthcare administrators, policymakers, and researchers alike.

1. Introduction

In today's healthcare landscape, the effective management of resources within hospital settings is paramount to delivering high-quality patient care while navigating operational constraints and financial pressures. The dynamic nature of patient demand, coupled with resource limitations and ever-evolving healthcare needs, underscores the importance of adopting innovative strategies to optimize resource utilization and enhance operational efficiency. In this context, simulation emerges as a powerful tool for modeling and analyzing complex systems, offering insights into the intricate interplay between various operational factors and their impact on overall performance.

This article delves into the realm of simulation-based approaches for managing resources in hospital environments. By leveraging computational modeling techniques, healthcare administrators can simulate and evaluate different scenarios, allowing for informed decision-making and proactive resource allocation. Through a comprehensive review of existing literature and case studies, we explore the diverse applications of simulation in addressing key challenges such as capacity planning, staff scheduling, and patient flow optimization. Moreover, we discuss the potential benefits of simulation-based strategies, including improved patient outcomes, enhanced resource utilization, and cost savings for healthcare institutions.

As we embark on this exploration of simulation in hospital resource management, it is imperative to recognize the complexities inherent in healthcare delivery and the need for interdisciplinary collaboration to develop robust solutions. By bridging the gap between theory and practice, our research endeavors to contribute to the ongoing discourse on healthcare optimization, offering actionable insights for healthcare practitioners, policymakers, and researchers alike.

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2. Methods

This section contains artifacts about the state of the art and the research made about the topic in study, as well as the PRISMA methodology.

2.1. State of the Art

As the name implies, a simulation system aims to simulate an existing system that has been implemented using the same procedures with the same resources under the same conditions during its execution [2].

A simulation system can be implemented in a variety of scenarios and in a variety of contexts, from communications to education, health, entertainment and transport, where studies are used to optimize work processes and methodologies that can range from inventory management to human resource planning and manufacturing strategies. More specifically, in the restaurant sector, a certain restaurant can use simulation studies to manage its inventory, human resources and the layout of furniture within the establishment.

As mentioned above, the aim of this article is to explore the use of simulation systems in a hospital setting in terms of resource management.

According to Liu, Li, Triantis, Xue and Wang, they identified 483 journal articles which referred to this approach and which were published in 230 journals between 1981 and 2014. They state that this type of system has spread from the evaluation of operational research in health services to the evaluation of interventions in various other areas of health. They also say that there is a growing number of authors publishing articles on this subject, which means that the number of articles is also growing, concluding that there is a wide dissemination of this type of system [7].

Discrete event simulation (DES) models the functioning of a system as a discrete sequence of events in time, i.e., in this type of system a finite number of states can be found and each event occurs at a specific instant in time, with each event marking a change of state in the system [17][14].

The original idea of using EDS in the management of health service operations, health service resource planning, medical decision-making processes, etc. dates back to the early 1980s [13].

Since 1981, there has been a rapid diffusion of DES simulation in health research at different levels, which include, among others, national health care capacity planning; process reengineering in clinics, pharmacies and local hospitals; patient flow and waiting time reduction; recruitment and scheduling of staff in emergency services and outpatient clinics; logistics of medical supplies (e.g., blood, vaccines); the evaluation of disease screening; the evaluation of disease prevention and treatment and the impact of health on the economy [16] [11] [8] [15].

As reported by Karnon and colleagues, DES has been used in a variety of health care applications. In the most early applications, they had the job of analyzing the systems with constrained resources, where the general objective was to improve the delivery service in hospitals, clinics, and pharmacies. But in recent times, DES was employed to assess specific technologies in the context of health technology assessment [12] [10].

DES has advantages over other techniques due to its flexibility, ability to handle variability and uncertainty, and its dialog interfaces that facilitate communication among researchers, health professionals and policy makers [9].

DES has the capability of modeling complex patient flow through health care clinics [5].

2.2. PRISMA

A systematic review of the literature was conducted to describe the history behind Enterprise Information Systems and it's evolution and possible future trends. The systematic review was prepared according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a methodology used to conduct and register systematic reviews. Several databases were used to carry out the various searches, such as IEEE, ACM, GOOGLE SCHOLAR, Research Gate and Elsevier. A database aggregator called b-on was used to help with the search. It has information on the various databases mentioned above, i.e. it is possible to access articles from these databases on a single platform, but it is also possible to use this site to facilitate the search, since the platform identifies and eliminates repeated publications that may exist, since several articles may have been published by various publishers.

2.2.1. Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established to validate article selection

Inclusion criteria	**Exclusion criteria**
Articles focusing on simulation techniques for optimizing hospital resource management.	Articles not related to hospital resource management or simulation techniques.
Research discussing strategies for improving efficiency and effectiveness in hospital resource allocation through simulation.	Studies lacking empirical evidence or not discussing practical implications.
Papers exploring challenges, limitations, and future directions in simulating hospital resource management.	Review articles without original research or studies unrelated to hospital resource management.

Table 1: Inclusion and Exclusion Criteria table

2.2.2. Research questions

1. How do different simulation techniques contribute to optimizing hospital resource allocation in the context of varying patient populations and healthcare demands?
2. What are the key challenges and limitations faced in implementing simulation models for hospital resource management, and how can these challenges be addressed to enhance effectiveness?
3. What strategies can be employed to improve the accuracy and reliability of simulation-based predictions in hospital resource management, considering factors such as data quality, model complexity, and uncertainty?
4. How do simulation-based decision support systems influence decision-making processes among healthcare administrators and clinicians in managing hospital resources effectively during crises such as pandemics or natural disasters?

2.2.3. Screening phase

For the initial part of the research on the history of enterprise information systems in a more general sense, the following query was used:

- Simulation Systems AND Hospital AND Resources Management AND Waiting time

2.2.4. Selection process (eligibility phase)

Data extraction was performed independently by two reviewers using a standardized data extraction form. The following information was extracted from each included study:

- Research questions addressed by the study.
- Methodology employed for simulating hospital resource management.

- Key findings and outcomes related to hospital resource optimization.
- Challenges encountered during the simulation process and proposed solutions.

Any discrepancies between reviewers were resolved through discussion.

2.3. Quality assessment and risk of bias

The quality of included studies was assessed using appropriate tools depending on the study design. For primary research studies, we utilized tools such as the Newcastle-Ottawa Scale (NOS) for observational studies and the Cochrane Risk of Bias Tool for randomized controlled trials. For systematic reviews, the Assessment of Multiple Systematic Reviews (AMSTAR) tool was employed.

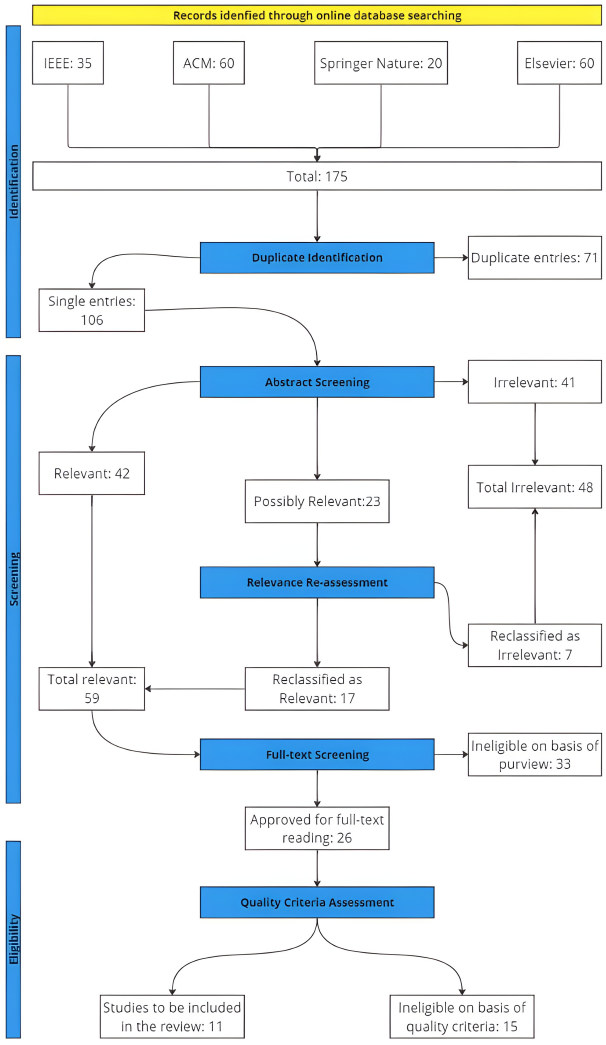

Figure 1: PRISMA flow diagram illustrating the article selection process.

2.3.1. Data collection process

A narrative synthesis approach was used to summarize the findings from the included studies. Themes and patterns identified across the studies were synthesized to provide insights into the landscape of recommendation systems in social media.

3. Research

3.1. Research 1

In the article, "A management analysis tool to support healthcare resource planning in public hospitals during the Covid-19 pandemic: A case study", published by Abid, Tlili, Maaroufi and Korbaa, they describe the use of modeling and simulation systems, particularly in a hospital setting, more specifically, they describe their implementation, as well as the advantages that the application of this type of technique can bring. The article describes a study carried out during the Covid-19 pandemic, in which the aim was to assess the effectiveness of these units in providing effective and timely responses to people that wanted to use the hospital's services. In this study, a real Covid-19 unit at SAHLOUL University Hospital in Sousse, Tunisia, was modeled and simulated using ARENA simulation software, which analyzes the performance of the actual Covid-19 healthcare unit by providing relevant statistics on patient flow and resource utilization rates.

The Covid-19 unit has various facilities, such as a waiting room, inpatient rooms and a care room for serious cases. The unit's staff includes a receptionist, a nurse, a doctor and a stretcher-bearer responsible for transporting patients. Patients are greeted by the medical receptionist, who collects their personal details. After checking in, the patient undergoes a screening procedure carried out by the nurse, who assesses symptoms related to Covid-19. Patients with two or more symptoms are referred to the Covid-19 unit for further testing and given a severity level. Most of the patients who arrive are healthy people or those with flu-like symptoms that are not related to Covid-19.

The Covid-19 unit operates 24 hours a day, every single day. In the start, patients are greeted by a medical receptionist, who collects their personal detail, then they are then screened by a nurse, who assesses the patient's symptoms and does various tests such as the COVID-19 rapid test, SpO2 readings and laboratory tests such as the COVID-19 rapid test, SpO2 readings and laboratory tests. If they show two or more symptoms of Covid-19, they are admitted to the unit for further testing and put in isolation, with priority given to critical cases. Around 20% of patients arrive in serious condition, requiring immediate intubation.

In the Covid-19 unit, resources are limited, because they are shared with other departments in the hospital. Patients awaiting test results for imaging tests to detect lung or chest problems have to wait with stretcher-bearers. This same results are crucial for the doctor's decision regarding hospitalization and treatment. Patients with mild to moderate symptoms, who do not require emergency care or hospitalization, are sent home to quarantine if they are stable. However, critical patients with life-threatening respiratory failure are immediately transferred to the intensive care unit for life support and constant monitoring. On the other hand, stable

Covid-19 cases, particularly those with chronic illnesses, are indefinitely hospitalized for medical monitoring to prevent any functional deterioration.

In the article, it becomes clear that the allocation of resources in the Covid-19 unit is inefficient and that there is poor management in adjusting human capacities to meet real demand. This Covid-19 unit is characterized by an unbalanced healthcare chain, since only one nurse is responsible for multiple tasks, such as patient triage, oxygen therapy, PCR tests, blood draws and other medical diagnostic tests [1].

3.1.1. Research 1 - Proposed alternatives for staff distribution

In the Table 2 is represented the proposed alternatives for the staff distribution.

Table 2: Proposed alternatives

Scenarios	Staff distribution				
	Receptionist	Nurses	Stretcher	Doctor	X-ray technician
Scenario 1	1	1	1	1	1
Scenario 2	2	2	2	2	2
Scenario 3	1	2	1	1	1
Scenario 4	1	2	1	2	1
Scenario 5	1	2	2	1	1
Scenario 6	2	3	2	2	1
Scenario 7	1	3	2	1	1
Scenario 8	2	4	2	2	1
Scenario 9	2	3	2	1	1
Scenario 10	2	3	1	1	1

The study described in the aforementioned article compares different medical care scenarios and their effects on patient flow and waiting times. The alternative scenarios are proposed based on the initial configuration of the staff distribution in the Covid-19 unit, presented in Scenario 1. In the scenario 2, by increasing the capacity of human resources, the percentage of fully attended patients increased by 9.6% and the average waiting time decreased from 179 minutes to 76 minutes. However, this waiting time was still considered long and unacceptable, since it represents 91% of the total patient time in the simulated system. In the scenario 3, with the addition of one more nurse, there was a notable improvement in patient flow rates, with an increase of 15.3%, and a slight reduction in average waiting time of 14.5%. In the scenario 4, although more patients were not seen and the waiting time for oxygen therapy and triage increased, the addition of two doctors was not effective, resulting in a significant queue for medical consultation. In the scenario 5, the results were similar to those of the scenario 3 and the increase in stretcher capacity had no impact on waiting times or patient flow. In scenario 6, there was a significant reduction in waiting time (22 minutes compared to 178.3 minutes in the original scenario) and an improvement in average daily throughput, but waiting times at the registration desk and treatment by nurses remained high. In scenario 7, an average of 404 patients arrived, and 383 were released, leaving 21 patients in the system, with an average waiting time of 36.6 minutes for treatment. However, the longest waiting time was at the registration desk, with an average of 24.5 minutes per patient. In scenario 8, there was a slight increase in the average daily throughput, but the patient's time in the system decreased from 2 hours to 1.65 hours. The average waiting time in front of the registration desk, diagnostic tests and PCR test was also reduced. However, the average service time for other medical activities is less than 1 minute per patient, which makes this alternative unfavorable due to the high associated costs. In scenario 9, the additional allocation of staff resulted in a significant increase in patient flow and a considerable reduction in waiting times. The improvement in resource utilization was attributed to the increase in human resource capacity and the elimination of bottlenecks, allowing patients to avoid long queues. In scenario 10, the results were similar to those of the previous scenario, with an increase in patient flow and a reduction in average waiting times [1].

3.2. Research 2

Healthcare systems worldwide face challenges in meeting the increasing demand for medical services while maintaining quality and efficiency. As the population grows and medical technologies advance, hospitals must find innovative ways to manage resources effectively to provide timely and high-quality care. This research, conducted by Khodakaram Salimifard, Dariuosh Mohammadi Zanjirani, and Leyla Keshtkar, focuses on utilizing simulation techniques to enhance hospital resource management, with a particular emphasis on the Emergency Department (ED). By simulating different scenarios, as outlined in their article titled "Using Simulation to Improve Hospital Resource Management," this study aims to identify strategies that optimize resource utilization, reduce waiting times, and improve patient outcomes [6].

3.2.1. Simulation Methodology

Simulation offers a powerful tool for modeling complex systems and testing various scenarios without disrupting real-world operations. In this study, as detailed by Salimifard, Zanjirani, and Keshtkar, Arena software was employed to simulate the dynamics of the ED, considering factors such as patient arrivals, resource availability, and staff allocation. The simulation ran for 10 replications, each spanning 365 days, ensuring robustness and reliability in the results.

The primary focus of the simulation, as described in the research conducted by Salimifard, Zanjirani, and Keshtkar, was on three key resources: beds, general practitioners (GPs), and nurses. These resources are critical for delivering efficient care in the ED and directly impact patient length of stay and waiting times. By manipulating resource levels in the simulation, the study sought to identify optimal configurations that enhance resource utilization and patient outcomes [6].

3.2.2. Scenario Analysis Summary

The results of the simulation scenarios were summarized to identify the most effective strategies for improving resource management and patient outcomes in the ED. Adding

one GP and three beds emerged as the best scenarios, showing significant reductions in waiting times and improvements in length of stay for both outpatients and inpatients.

These findings underscore the importance of strategic resource allocation and highlight the potential benefits of simulation in optimizing healthcare operations. By identifying and implementing effective strategies, hospitals can enhance patient satisfaction and overall quality of care. In the Figure 3, is provided a detailed overview of the improvements observed as a result of the simulation, offering quantitative evidence of the impact of strategic resource allocation on key performance indicators within the Emergency Department (ED) [6].

Table 3: Simulation Results

Key Perfomance		Current System	Adding One Bed	Adding Two Beds	Adding Three Beds	Adding One Nurse	Adding One GP	Adding Two Beds And One GP	Adding Three Beds And One GP
Resource Utilization (%)	Bed	0.86	0.80 6.9%+	0.75 12.7%+	0.71 17.4%+	0.86 -	0.86 -	0.75 12.7%+	0.71 17.4%+
	Nurse	0.52	0.52 -	0.52 -	0.52 -	0.49 5.7%-	0.52 -	0.52 -	0.52 -
	GP	0.74	0.74 -	0.74 -	0.74 -	0.74 -	0.48 35.1%+	0.48 35.1%+	0.48 35.1%+

3.3. Research 3

Simulation-based studies have emerged as indispensable tools in healthcare resource management, offering invaluable insights into complex operational processes and enabling effective optimization strategies. In particular, reducing patient waiting time stands as a critical objective in enhancing healthcare delivery and patient satisfaction. In this context, the article "A Simulation-Based Study for Managing Hospital Resources by Reducing Patient Waiting Time" by JAWAD AHMAD, JAVAID IQBAL, IMRAN AHMAD, ZUBAIR AHMAD KHAN, MOHSIN ISLAM TIWANA, AND KHALID KHAN, presents a comprehensive exploration into the development and validation of a simulation model aimed at addressing this pressing issue.

By leveraging sophisticated simulation software and interdisciplinary collaboration, the authors meticulously construct a simulation model tailored to the unique dynamics of hospital resource management. Through integration of patient flow patterns, departmental interactions, and resource utilization data, the model serves as a powerful tool for understanding and optimizing hospital operations [4].

3.3.1. Development and Validation of Simulation Model

Central to the study is the meticulous development and validation of the simulation model, which encapsulates the intricacies of hospital operations with precision. The research team combines empirical data with advanced simulation techniques to construct a robust model that accurately mirrors real-world scenarios. Validation procedures rigorously compare simulated outcomes with observed data, ensuring the model's reliability and effectiveness in informing decision-making processes [4].

3.3.2. Implications and Conclusion

The successful development and validation of the simulation model hold significant implications for healthcare management. By providing actionable insights into patient flow dynamics and resource utilization patterns, the model empowers healthcare administrators to implement targeted interventions aimed at reducing patient waiting time and enhancing overall operational efficiency. Moreover, collaboration with stakeholders ensures the model's relevance and applicability, fostering a collective approach towards continuous improvement in healthcare delivery. In conclusion, the study underscores the transformative potential of simulation-based approaches in driving meaningful advancements in hospital resource management and patient care outcomes, advocating for their widespread adoption in healthcare settings [4]. In the Figure 4 is shown the simulation results of the study.

Table 4: Simulation Results

Department	Resource State	Effect	
		Utilization	Average waiting time (minutes)
Lab	Increased by 25%	Decreased by 7.55%	Decreased by 22.2
X-Ray	Increased by 50%	Decreased by 8.6%	Decreased by 30.90
Ultrasound	Increased by 50%	Decreased by 29.7%	Decreased by 26.68
ENT	Decreased by 50%	Increased by 10.6%	Increased by 0.985
Eye	Decreased by 50%	Increased by 11.48%	Increased by 1.981
Skin	Decreased by 50%	Increased by 18.8%	Increased by 1.30

3.4. Research 4

The research conducted by R. M. Aguilar Chinea, I. Castilla Rodríguez, and R. C. Muñoz González, titled "Hospital Resource Management", sheds light on the complexities surrounding hospital operations within the context of evolving societal demands and advancements in healthcare. Hospitals, regarded as social systems, have witnessed a slower evolutionary pace due to the absence of a definitive product definition. However, recent developments underscore the growing importance of hospital management, poised to escalate further in response to burgeoning societal needs and healthcare advancements [3].

3.4.1. Challenges in Healthcare Systems

In navigating the intricacies of healthcare systems, significant challenges emerge. These include the escalating expectations placed upon healthcare facilities, driven by demographic shifts, improved living standards, and medical progress. Simultaneously, the finite nature of healthcare resources juxtaposed with ever-increasing demand underscores the necessity for efficient resource allocation strategies to maintain optimal service delivery [3].

3.4.2. Conceptual Model

A pivotal aspect of the study involves delineating hospitals into three distinct subsystems: patient flow, resource availability, and hospital management. Each subsystem plays a critical role in sustaining hospital operations and ensuring the delivery of quality patient care. By elucidating the functionalities of these subsystems, the research provides

a foundational understanding of hospital dynamics. Furthermore, the study employs a conceptual model, visually represented through a diagram, to illustrate the interrelationships and dependencies among these subsystems [3]. The Figure 2, serves as a valuable tool for comprehending the intricate workings of hospital management, facilitating strategic decision-making and resource allocation efforts.

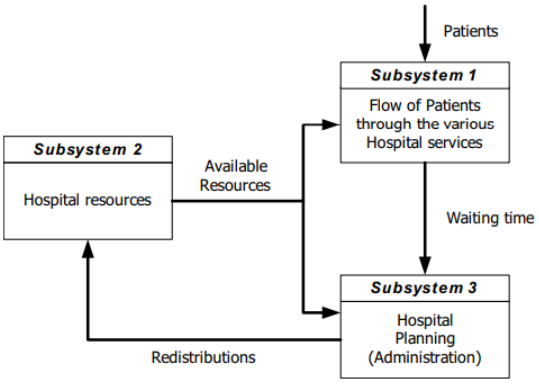

Figure 2: Hospital block diagram

3.4.3. Microsimulation in Healthcare Management

The research underscores the utility of microsimulation as a sophisticated modeling technique in healthcare management. Through microsimulation, virtual environments are constructed, enabling the exploration of diverse scenarios and their implications on patient care, waiting times, and overall system efficiency. By leveraging microsimulation, healthcare professionals can make informed decisions, strategically allocating resources to optimize patient outcomes and enhance healthcare delivery [3].

3.4.4. Findings

The findings of this research underscore the critical role of effective hospital resource management in navigating the complexities of modern healthcare systems. By employing microsimulation methodologies, healthcare administrators can gain invaluable insights into resource allocation dynamics, thereby enhancing operational efficiency and patient care delivery. Ultimately, this research contributes to the ongoing discourse surrounding healthcare management, providing actionable insights for policymakers and healthcare practitioners alike [3].

4. Conclusion

Based on the analyses presented on the use of simulation systems, it is clear that this type of system is crucial for decision-making in any institution and, in particular, in the field of hospital management. In this specific case, it was possible to observe a study carried out in a Covid-19 unit within a hospital, in which a problem was identified in the distribution of human resources that affected the waiting times and so various alternatives to the current one were considered that allowed for the comparison of different staffing distribution scenarios in order to carry out a simulation with them to reach an informed decision.

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