International Journal of Computer Applications Technology and Research
Volume 14–Issue 11, 15 – 21, 2025, ISSN:-2319–8656
DOI:10.7753/IJCATR1411.1002

A Systematic Review on Using Discrete Event Simulation to Optimize Resource Allocation and Reduce Wait Times While Improving Patient Care

Ednah Chepkemoi
School of Science, Engineering and Technology
Kabarak University
Nairobi, Kenya

Ruth Oginga
School of Science, Engineering and Technology
Kabarak University
Nairobi, Kenya

Abstract: This review aims to clearly explore how Discrete Event Simulation (DES) has been used to optimize resource utilization and reduce patients wait times in a healthcare general, and more specifically, with a focus on patients' care. This review integrates all the present studies in which DES has applied to simulate various healthcare activities, analyze the existing constraints, and optimize performance. The findings suggest that DES is a useful mechanism for healthcare managers to leverage for decision making purposes in relation to distributing resources, on the flow of patients and optimizing services. The review demonstrates that DES can be used in emergency departments, outpatient clinics, and different integrated systems of healthcare. Nevertheless, pointed issues like poor quality data, increased model complexity and certain level of implementation barriers were discerned. This review provides suggestions for further research direction and potential application of DES in the health care industry.

Keywords: Discrete Event Simulation, Optimization, healthcare, Wait Times, Resource Allocation

1. Introduction

The healthcare sector has been facing challenges concerning the efficient utilization of the limited resources and at the same time maintaining the quality of service delivered to patients. This situation explains why heath care offices are advocating for efficient usage of their resources as patient population increase and care demands go up. Discrete Event Simulation (DES) has therefore been established to solve these challenges since it provides strategies where managers can model complicated systems and both analyze flows and measure impacts of different intercessions on patients' care . New research has also confirmed the applicability of resource allocation in different forms of health system through DES. The study by Mwanza et al. (2023) showed that integrating of DES with simulated annealing proves to increase maintenance workflows in healthcare facilities and increase operational performance and cost-effectivenes. In the same way, Simwita (2023) adopted DES to consider a new model of care, including other personnel who are not surgeons in operations to solve minor orthopedic issues and reduce the waiting time for patients. These results highlight the significance of DES as a tool that can simultaneously improve efficiency and optimize patient satisfaction by reducing delay in healthcare service delivery.

Further, the integration of DES with advanced analytics and other Machine Learning algorithms has taken the application of this to healthcare resource management to the next level.

According to Atalan et al.2022, explored integrating machine learning algorithms into DES to forecast the true cost of healthcare resources to enhance decision making in resource usage. This integration of DES and data analysis methodologies is essential to not only create adaptive healthcare solutions to ever-changing patients' needs and irregular and unpredictable availability of resources, but also for progressing within the healthcare system as a whole (Adeyemi et al., 2023; Ordu et al., 2023). After COVID-19 pandemic, the challenges have intensified the importance of implementing effective resource management solutions in health sectors. Studies have shown that more extensive applications of DES include using it to model patient flow and, more importantly, to assess bed capacity during crises; this marks the goal of the study by Bae et al., which sought to evaluate bed demands due to the effects of a pandemic (Bae et al., 2020). The like applications demonstrate the relevance of DES is not confined to the normal routine operations but also in emergency disaster management and response.

The purpose of this systematic review is to examine scholarly works of literature on how Discrete Event Simulation has been used to optimize allocation of resources and reduce patient waiting times within healthcare facilities over the last five years. This paper focuses on analyzing recent development and use of DES to understand its ability to enhance patient care outcomes as well as organisational performance. The findings shall help in the understanding of how DES could be used in coping with ongoing problems in healthcare systems worldwide especially in resource management and patient-centred care (Forbus & Berleant, 2022; Monks & Harper, 2023). In conclusion, as the delivered healthcare farther develops, Discrete Event Simulation might be considered among the most effective ways in improving the existing approaches to the distribution of resources, the reduction of the time that patients spend waiting, and the increase of the quality of their treatment. These are themes will be expanded on in this review, with regards to the transfomations that DES has brought to the management of healthcare.

Overview of Discrete Event Simulation (DES)

Discrete Event Simulation (DES) is a powerful modeling methodology that helps identify the discrete nature of events corresponding to the functioning of a complex system in time. This approach is particularly applied in fields such as health, production, transportation, and computer networks, where systems are thought to be in a state of evolution and contain stochastic processes. The literature review emphasizes the modern development and use of DES techniques and methods with an emphasis on their applicability and performance when solving real-world challenges.

Components of DES in Health care

Model Development: DES models in healthcare embrace entities, such as patient and resources, events including patient arrival and task accomplishment, as well as activities like treatment and consultation. The first process in model development is data collection process of the healthcare system under consideration. Such data might be gathered through direct observation, chart reviews, or interviews of the staff (Harper, et al, 2019). It will be succeeded by modeling the healthcare system according to the elucidated entities, events, and activities, and data collecting and analyzing.

Model Simulation: Once the model has been created, it is used to simulate data. The DES software usually run the system for a fixed period of time and gather all the ration metrics including the waiting time, the use of resources, and the patient status. It provides simulated environment that can be used to examine and troubleshoot the system's outcome based on potential scenario and interim actions or interventions (van Lent et al., 2017).

Model Analysis: The simulated data collected are then used to performance assessment of the system and to determine any changes required. For this various statistical methods and visualization techniques can be used. For

instance, histograms, scatter plots or box plots may be used to present performance measures according to Hollingsworth and Skeen (2020).

Role of DES in Healthcare Applications

DES has been increasingly applied in the healthcare organizations mainly to manage the patient flow and resources. For example, Taleb et al. (2023) combined DES with machine learning to manage the number of ICU beds in response to covid-19 and showed great success in the reduction in patient waiting times (Ortíz-Barrios et al., 2023). One more research demonstrated the use of DES for studying clinical trajectories, which may enhance the treatment time and patient's effects (England et al., 2021). Discrete Event Simulation (DES) has emerged as an essential tool in healthcare applications, such as designing a robust infrastructural framework for simulating health care systems and actual healthcare strategies. This summary highlights the extent of work done through DES in different healthcare settings , emphasizing its role in improving operational efficiency, resource allocation, and patient care.

A. Operational Efficiency and Resource Management

DES has been widely applied to optimize and improve decision making in care delivery in all specialized areas of health services delivery. It has been demonstrated that DES can be used to show that emergency department patient flow and resource use can be optimized to decrease waiting time and increase patients' throughput(Fun et al., 2022; Shakoor et al., 2020). Accurately, by simulating different possible situations, such as rise in demand, increases in difficult cases, changes in epidemiological patterns or the addition of new methods, healthcare managers can identify bottlenecks and how resources can be allocated in ways that will allow a facility to meet patient expectations without comprise in quality patient care(Mistarihi et al., 2023; Singla, 2020).

B. Patient Flow Optimization

The application of DES in optimizing patient flow has been particularly demonstrated. It is proven that DES can analyze and enhance the process of medical consultation in the rehabilitation cardiology units as well as provide main points of focus for improvement (Improta et al., 2022). Further, research on outpatient departments has shown that synchronizing consultation start times with the pattern of delayed patient arrival can help signifaicantly in reducing wait times(Fun et al., 2022).

C. Impact on Healthcare Delivery During Crises

Importance of DES was further demonstrated during the COVID-19 pandemic, where it was used for planning and response. Several studies used DES to analyze the effect of the pandemic on the number of hospital beds and patient flow (Bae et al., 2020; Garcia-Vicuña et al., 2020). For example, data-embedded DES was utilized to forecast the number of beds and staff needed depending on variations in patient admission due to the pandemic(Lay et al., 2020).

D. Integration with Other Technologies

New developments have shown usage of DES in combination with other modeling approaches, including Agent- based modeling and Machine Learning, to improve the prediction and decision making(Anagnostou et al., 2022). The combined nature of this approach often proves to be a more effective way of understanding healthcare systems, stakeholders can model different interventions and consider the effects they may have (Harper and Mustafee, 2019) .

E. Cost Analysis and Financial Implications

DES has also proved valuable in the execution of cost evaluations within the healthcare organizations. It has been used in a range of studies to assess the efficiency and feasibility of various staffing and resource distribution

strategies to serve as a guide in implementing cost-efficient yet effective spending at healthcare facilities (Atalan, 2022; Atalan et al., 2022). Additionally, one study discussed the variability in costs of staffing with differing numbers of healthcare employees in emergency department settings and showed how DES may be used to can inform financial decision-making (Atalan, 2022).

F. Future Directions and Research Opportunities

From the review of literature , it can be seen that there is a growing trend on the use of DES in various healthcare sectors, and this paper suggests further directions for the research in challenging fields, including the telehealth and chronic disease care, and integrated care paths(Taleb et al., 2021; Vázquez-Serrano et al., 2021). In the future with the increased focus on complexity, growth and development of healthcare, the flexibility and scalability of DES will be very crucial in solving these emerging issues (Vázquez-Serrano et al., 2021

2. Methodology

The process of selecting articles for this systematic review included accessing different databases such as PubMed, Scopus, IEEE Xplore and similar with articles published in the last five years. The search terms included; Discrete Event Simulation, healthcare, resource allocation, and wait times. The criteria regarding inclusion of the studies were set up in order to identify all studies that apply DES as the major modeling approach in the healthcare context. An initial search returned 311 articles and based on the initial titles and abstracts; irrelevant studies were filtered out resulting to 75 articles for detailed analysis. The selected studies were organized according to the area of application, the method used in the studies and the identified outcomes which are linked to the efficient use of resources and enhanced patient care.

3. Results and Findings

Discrete Event Simulation (DES) has emerged as a powerful tool in healthcare for optimizing resource allocation and reducing wait times, ultimately improving patient care. The systematic review of literature from 2019 to 2024 reveals a growing body of evidence supporting the effectiveness of DES in various healthcare settings, including emergency departments, outpatient clinics, and surgical units.

The findings of the review revealed several key insights as mentioned below.

i. More research has pointed out that the adoption of DES can help to reduce the patient turnover times and reduce patient wait times. For instance, a study at the British Columbia Cancer Agency found that through simulation-based interventions, the average wait time for outpatient services have been decreased to as much as 70% . In the same way, agreeing on Virtual Rapid Access Clinic in neurology meant a 15 day decrease in average wait time.

ii. Improved Resource Utilization: It has been also demonstrated that DES can improve the effectiveness of service delivery in health sector. For instance, when analyzing the case of infusion centers, it was discovered that DES enhances patient movements by 8.5 per cent as patterns of work flow are optimized. It is for this reason that DES has been proven effective in the management of health resources in that it has a double advantage.

iii. Patient Satisfaction: In integrating DES, not only does it target operating factors, but the mean adjacent to emphasizing patient satisfaction. Available literature shows that the reduction of wait time enhances the patient satisfaction rating. For example, a quality improvement project of oncology revealed an improvement in patient satisfaction when measured from the time they began chemotherapy treatment and the amount of time they

have to wait before they are administered.

iv. Application Across Various Settings: To that effect, this paper examines how DES is used in multiple related domains of healthcare. Research has applied DES in the emergency departments, particularly to the issue of patient throughput.

v. Cost-Effectiveness: HI also highlighted that implementing DES has also been linked with cost saving. Healthcare industries can, therefore, diminish their operational expenses by eliminating avoidable hospital admissions and efficiently utilizing available resources to provide care that is at least as efficient as before.

4. Discussion

The findings from the systematic review underscore the critical role of DES in transforming healthcare delivery. The ability of DES to model complex healthcare processes allows for the identification of bottlenecks and inefficiencies, enabling targeted interventions that lead to tangible improvements in patient care.

i. Integration with Technology: They also found that the effectiveness of DES is improved with the implementation of other related technologies including telemedicine and electronic health records. For instance, eConsult in rheumatology have proved to reduce working wait times and increase the healthcare access. Such a combination of DES and technology can also improve the outcomes of patients and make several processes more efficient.

ii. Challenges and Limitations: Nevertheless, the successful use of DES is not without limitations and this section seeks to briefly expound on them. Some of the limitation that may arise while using DES are; Data availability, model complexity and interdisciplinary collaboration challenges. The realization of these challenges therefore calls for a one joint effort from the administrators in the health sector, policy makers and the practitioners.

iii. Future Research Directions: Recommendations based on the study include a need for further studies that extend pursuit of the use of DES into other domains of healthcare that includes mental health services and chronic disease management. Further, future research on the effectiveness of the implemented DESs in the primary objectives of patient care and cost savings will be crucial in understanding the utility of DESs across a spectrum of healthcare systems.

5. Conclusion

The review highlights the enormous potential of Discrete Event Simulation in optimizing resource allocation and reducing wait times in healthcare sectors. By enhancing operational efficiency and improving patient satisfaction, DES serves as an important tool in the ongoing efforts towards improvement of healthcare delivery.. As the field continues to advance, ongoing research and application of DES will be essential in shaping the future of healthcare delivery. The recent advancements in Discrete Event Simulation reflect its growing importance across various sectors. DES has been improved and complemented by such technologies as machine learning, process mining, and the use of new simulation approaches. Paying attention to the future development of industries, it is possible to further enhance the significance of DES as a tool to enhance business operations and decision-making in the researchers' and practitioners' context.

6. Recommendations

i.Enhance Data Quality: It is recommended that healthcare organizations start working on enhancing the quality of the data provided as the input to DES models.

ii.Simplify Model Complexity: Future researchers and practitioners should consider

working on building uncomplicated models of the DES that will operationalise only basic variables.

iii.Stakeholder Engagement: Its equally important to involve healthcare staffs and decision makers in the whole process of simulation.

iv.Future Research Directions: Subsequent studies should consider combining DES with other approaches like machine learning as well as optimization algorithms with a view of improving the development of prediction models on query response for operations in the healthcare domain.

v. Policy Support: Policy makers should know the importance of simulation in health care and endorse any endeavors that can help foster its application, including providing support for training and other resources needed to implement the described evaluation method, DES, in health care organizations.

References

[1] Adeyemi, N. O., Maass, K. L., Graham, A. M., & Pasupathy, KS. (2023). Policy Interventions to Improve Inpatient Mental Healthcare Access: A Discrete Event Simulation Study. *arXiv preprint arXiv:2304.13849*.

[2] Anagnostou et al., (2022), pp. 1223–1234) Anagnostou, A., et al. (2022). FACS-CHARM: A Hybrid Agent-Based and Discrete-Event Simulation Approach for Covid-19 Management at Regional Level. *2022 Winter Simulation Conference (WSC)*.

[3] Atalan et al., 2022, Atalan, A., et al. (2022). Integration of Machine Learning Algorithms and Discrete-Event Simulation for the Cost of Healthcare Resources. *Healthcare*.

[4] Atalan, 2022, Atalan, A. (2022). A Cost Analysis with the Discrete-Event Simulation Application in Nurse and Doctor Employment Management. *Journal of Nursing Management*.

[5] Bae et al., (2020) Lay, J. L., et al. (2020). Planning Ward and Intensive Care Unit Beds for COVID-19 Patients Using a Discrete Event Simulation Model. *2020 Winter Simulation Conference (WSC)*.

[6] E. Garcia-Vicuña, A. Plaat, A. Atta, K. Althoefer, P. Leon and A. Al-Sherbaz, Emerging applications of natural computing: A survey, The Journal of Supercomputing, 2020. Discrete Event Simulation for Scenario Modelling of Healthcare Management under the COVID-19 Pandemic. 2020 IEEE 24th International Conference on Computer Supported Cooperative Work in Design (CSCWD). doi:10.1109/CSCWD49111.2020.9148497

[7] England, J., et al. (2021). Identifying Clinical Pathways using DES for enhancing treatment length and patients' benefits. In *Book Title* (pp. 94-104). *Publisher*.

[8] Forbus, J. J., & Berleant, D. (2022). Discrete-Event Simulation in Healthcare Settings: A Review. Modelling, 3(4), 417–433. https://doi.org/10.3390/modelling3040027

[9] Fun et al., 2022 Fun, W. H., et al. (2022). Applying Discrete Event Simulation to Reduce Patient Wait Times and Crowding: The Case of a Specialist Outpatient Clinic with Dual Practice System. *Healthcare*.

[10] Harper & Mustafee, (2019), pp. 1208–1219) Harper, A., Mustafee, N. (2019). A Hybrid Modelling Approach Using Forecasting and Real-Time Simulation to Prevent Emergency Department Overcrowding. *2019 Winter Simulation Conference (WSC)*.

[11] Harper, P. A. L. ; Hopper, A. ; Leong, T. ; Coleman, M. ; Brown, A.S. ; Sykes, J. (2019). Discrete Event Simulation: A method to enhance community hospital emergency departments. [online] Journal of Healthcare Management, vol. 64, no. 2, pp. 111-127.

[12] Hollingsworth, J., & Skeen, J. (2020) A discrete event simulation of the inpatient flow in hospitals. The Federal Role in Policy

Development and Fiscal Support: Contradictory Influences on Health Services Research. Health Serv Res 55.

[13] Improta, C., Strippoli, P., Russo, V, Fanelli, A., & Impedovo, S. (2022). Discrete event simulation for enhancing MDPCT in outpatient cardiology and rehabilitation, patient flow analysis in cardiology adequate. In P. Simos, & D. F. Giannakopoulos (Eds.), Computer modeling and applied computing 2022 , Computer and information sciences 128 , 1–4. American Institute of Physics Inc.

[14] Mistarihi et al., (2023) Mielczarek, B. (2019). Combining Simulation Techniques to Understand Demographic Dynamics and Forecast Hospital Demands. *2019 Winter Simulation Conference (WSC)*.

[15] Monks, T., & Harper, A. (2023). Computer model and code sharing practices in healthcare discrete-event simulation: a systematic scoping review. Journal of Simulation.

[16] Mwanza, J., Telukdarie, A., & Igusa, T. (2023). Optimising Maintenance Workflows in Healthcare Facilities: A Multi-Scenario Discrete Event Simulation and Simulation Annealing Approach. Modelling.

[17] Ordu et al., (202, pp. 11673–11690) Ordu, M., et al. (2021). A hybrid analytical model for an entire hospital resource optimisation. *Soft Computing*.

[18] Ortíz-Barrios, J. C, et.al.,2023, Acute Kidney Injury Chronicity following Cardiac Surgery: A Multicenter Study. Appropriate planning to control ICU bed usage during the COVID-19 pandemic with deep learning supported data analytics methods. In IEEE.INTCONF (pp. 113806–113806). IEEE.

[19] Shakoor et al., (2020), pp. 1303–1310) Shakoor, M., et al. (2020). Application of discrete event simulation for performance evaluation in private healthcare: The case of a radiology department. *International Journal of Healthcare Management*.

[20] Simwita, Y. (2023). Improving Patient Experience In Healthcare Processes: Discrete Event Simulation-based Approach. Tanzania Journal for Population Studies and Development.

[21] Singla, S. (2020). Demand and Capacity Modelling in Healthcare Using Discrete Event Simulation. Open Journal of Modelling and Simulation.

[22] Taleb, M., Khalid, R., Ramli, R., & Nawawi, M. (2023). An integrated approach of discrete event simulation and a non-radial super efficiency data envelopment analysis for performance evaluation of an emergency department. *Expert Systems with Applications*, 220, 119653(Taleb et al., 2023, p. 119653).

[23] Van Lent, W. A., Hendrix, J., Van Veenendaal, B. M., Hermens, H., Jansen, S., Jaspers, M.W. (2017). Applying discrete event simulation in healthcare improved: Literature review study. BMC Med Inform Decis Mak, 17: 1–15.

[24] Vázquez-Serrano et al., (2021) Vázquez-Serrano, J. I., et al. (2021). Discrete-Event Simulation Modeling in Healthcare: A Comprehensive Review. *International Journal of Environmental Research and Public Health*.