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ORIGINAL RESEARCH

Evaluation of Services in MRI Department of University Hospital with Discrete Event Simulation Technique: A Case Study

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ABSTRACT

With the advancement of technology, radiological imaging examinations are vital in clinical diagnosis and treatment processes. Patients with chronic conditions often require diagnostic imaging procedures such as MRI, X-ray, CT scans and Ultrasound. Timely access to these services is critical, especially in situations requiring urgent medical attention. Assessing and improving the performance of radiology departments is critical to optimize patient care. Simulation techniques, especially discrete event simulation, have emerged as an effective tool for optimizing workflow, resource allocation and patient flow in MRI departments. This study aims to contribute to strategic planning and operational decision processes in radiology departments to ensure more efficient use of resources. Using Arena Simulation, recommendations for efficient use of resources and balancing patient flows were developed and modeled. The main bottlenecks identified in the current situation analysis require strategic measures to be taken to improve the efficiency of MRI service processes. The recommended steps, such as procurement of new MRI equipment and staffing, are critical to meet the increasing demand for services in the future. As a result, this study provides concrete recommendations to increase the effectiveness of MRI service processes of the university hospital and serves as a guide to improve operational performance.

Introduction

As technology has advanced, radiological imaging examinations have emerged as vital aids in clinical diagnosis and treatment (Gong et al., 2022). Patients with chronic conditions often require diagnostic imaging procedures such as Magnetic Resonance Imaging (MRI), X-ray radiography, Computed Tomography (CT) scans, and Ultrasound to investigate potential side effects and determine appropriate medical interventions (Shakoor et al., 2017). Timely access to these services is crucial for prompt medical treatment and intervention. Delays in receiving these imaging services can cause disruptions for patients in need of urgent medical intervention. Therefore, the efficiency of the radiology department plays a critical role in enabling healthcare professionals to make timely diagnostic and treatment decisions (European Society of Radiology 2009). Assessment of equipment utilisation and patient waiting times in the radiology department is crucial in optimising patient care. Simulation techniques are valuable tools for assessing and improving the performance of radiology departments and assist in informed decision-making processes to improve overall healthcare delivery (Jun et al., 1999). Significant transformations and barriers in the healthcare sector, including advances in medical technologies, have reshaped the role and importance of hospitals. These changes underline the critical need for rigorous and effective planning and management of healthcare facilities (Su & Shih, 2003).

Providing radiology services is a complex and technologically demanding endeavour where the use of operations management tools can contribute significantly to the management and improvement of processes (Ondategui-Parra et al., 2004). Well-structured and efficiently managed radiology practices have a competitive advantage characterised by rapid decision-making, decisive actions in line with established policies and a collective responsibility for practice development among group members (Muroff, 2004).

The use of discrete event simulation in the MRI department can be highly advantageous to optimise workflow, resource allocation and patient flow. DES (Discrete-event simulation) has been widely used in healthcare settings to improve operational efficiency and patient care delivery (Zhang, 2018). In healthcare delivery processes, DES has been used to evaluate alternative resource allocation strategies, resulting in improved patient care and operational efficiency (Günal & Pidd, 2010). Furthermore, DES has played an important role in optimising workflow for multimodal imaging procedures such as combined X-ray and MRI-guided interventions in radiology departments (Fernández-Gutiérrez et al., 2016).

The radiology department plays a critical role in the healthcare delivery process at the university hospital. However, it faces several challenges due to fluctuating demand that is not aligned with capacity. The purpose of this study is to identify factors that predict demand variability and opportunities for improvement. By analysing current performance and benchmarking methods, key performance indicators have been established from various perspectives. Through discussions, observations and literature review, the variability and bottlenecks with the greatest potential for improving MRI services were identified.

Interventions were designed and their effects modelled using Arena Simulation. In our study, how existing resources (modalities, personnel) can be used more efficiently in the short and long term and how patient flows can be balanced is addressed. In this context, using the Discrete Event Simulation Technique, the service processes in the MRI department were analysed and potential improvement areas were identified. The research findings aim to provide important contributions to strategic planning and operational decision-making processes in order to ensure more efficient use of resources in radiology departments.

Literature Review

The use of DES in healthcare has increased significantly in recent years with the aim of increasing operational efficiency and improving patient flows. This literature review focuses on the application of DES in healthcare and in particular in radiology departments. Existing studies show that DES is an effective tool in various healthcare processes and reveal how it is used to improve service quality under different scenarios. Studies demonstrating the effectiveness of DES in modelling and optimising system performance in various healthcare settings highlight its ability to assess resource allocation, patient flow, service planning and system interventions (Günal & Pidd, 2010; Landa et al., 2013; Woodall et al., 2013; Zhang, 2018; Moretto et al., 2019; Zouri et al., 2019; Vázquez-Serrano et al., 2021). The importance of DES in healthcare design, resource optimisation and system performance evaluation has been emphasised by researchers (Duguay & Chetouane, 2007). In particular, DES has been used to simulate and analyse complex healthcare systems to identify bottlenecks, improve patient flow and enhance quality of care (Duguay & Chetouane, 2007; Pongjetanapong et al., 2019; Durmuş & Özdemir, 2023).

DES has also played an important role in assessing the impact of staffing levels, turnaround times and service configurations in healthcare settings (Günal & Pidd, 2010; Pongjetanapong et al., 2019). Simulations under different scenarios have provided insights into patient outcomes, resource utilisation and operational efficiency (Günal & Pidd, 2010; Pongjetanapong et al., 2019; Özdemir et al., 2023). For example, Shakoor, evaluated the effectiveness of proposed strategies for resource management in radiology departments. The study revealed that the newly implemented strategy was more effective, but emphasised the need for improvement in services (Shakoor, 2015). Similarly, Suthihono and Kusumastuti investigated alternative solutions that can reduce the waiting time of patients in MRI services during the COVID-19 pandemic period and showed that it is possible to significantly reduce the length of stay of patients using DES (Suthihono, & Kusumastuti, 2021). Oh et al. formed a project team to reduce waiting times for X-ray patients in a tertiary hospital and showed that the implemented strategies accelerated patient access (Oh et al., 2011). Such studies demonstrate the effectiveness of strategies to improve hospital processes.

Nickel and Schmidt focused on analysing patient flow and device utilisation in the radiology department and showed that by modelling and evaluating different scenarios, device utilisation was increased and waiting times were reduced (Nickel & Schmidt, 2009). Similarly, Johnston et al. used DES to reduce patient flow in hospital emergency departments, identifying areas for improvement and supporting the decision-making processes of hospital staff (Johnston et al., 2009). Torabigoudarzi used DES to model patient flow in emergency radiology units and showed that adding additional staff for a shift improves performance (Torabigoudarzi, 2019). Similarly, Luo et al., showed that emergency booking policy can improve hospital performance and shorten patients' waiting times (Luo et al., 2018). Idigo et al. modelled and analysed the workflow process in a radiology department and showed that they can improve the operation planning and control process

(Idigo et al., 2020). Felicitas et al., showed that by analysing the workflow in the radiology department, patient flow can be managed by adopting an optimal scheduling system (Felicitas et al., 2021).

Finally, Singla identified the planning intentions of National Health Service (NHS) radiology services to maintain and improve MRI capacity. His research, which aimed to examine and plan the utilisation of hospital resources for the radiology department using DES, showed positive improvements in reducing patient waiting time and improving resource utilisation (Singla, 2020).

This literature review highlights the benefits and effectiveness of the use of DES in healthcare in a variety of areas. Studies show that DES is an important tool in healthcare design, resource optimisation and system performance evaluation. In particular, DES has been used to simulate and analyse complex healthcare systems, identifying bottlenecks, improving patient flow and enhancing quality of care. Simulations under various scenarios have provided valuable insights into patient outcomes, resource utilisation and operational efficiency. These studies emphasise the importance of developing strategies to increase efficiency and improve quality of care in healthcare. In conclusion, the use of DES as an effective tool in healthcare management can contribute to making healthcare services more efficient and accessible in the future.

Material and Methods

This study uses the discrete event simulation technique to evaluate and improve the service processes in the MRI (Magnetic Resonance) department of a university hospital. Discrete event simulation is an effective method to analyse system performance by modelling the dynamic behaviour of complex systems and interactions between individuals. Within the scope of this methodology, firstly, the existing workflows and processes in the MRI department were analysed in detail. Data were obtained from hospital record systems, observations and interviews with staff.

The first step of the study is to map the service processes in the MRI department and identify key performance indicators. These indicators include the number of shots, shooting time, appointment waiting time, report writing time, personnel and device utilisation. Using the collected data, a simulation model of the current processes was created. The model was designed to cover all steps from the entry of patients to the MRI department to the delivery of reports.

The simulation model was developed using Arena simulation software. In order to verify and validate the model, comparisons with real data were made to ensure that the model accurately represents the actual functioning in the MRI department. This validation process is an important stage to increase the reliability of the model.

The data obtained from running the model were analysed to determine the efficiency of existing service processes and bottlenecks. In addition, various scenarios were simulated and the potential effects of different capacity planning and production methods were evaluated. These scenarios included interventions such as increasing the number of staff, optimising device utilisation rates and improving the appointment system. It is emphasised that process simulation is a powerful tool for visualising the dynamics of workflows, analysing the behaviour of business processes and helping to plan a complex workflow. In this context, the study advocates the use of process simulation methods to make workflows in the radiology department more effective (Teichgraber et al., 2003).

The DES model was developed to simulate the patient flow process receiving MRI services in the radiology department of a university hospital. This involves outlining the patient flow, defining performance measures, establishing model assumptions, collecting and analysing data and validating the model. Ultimately, the study aims to identify optimal programming rules and perform sensitivity analysis.

Patient flow process; The patient flow process for an MRI scanner is shown in Figure 1. The scanner serves three categories of patients offering routine scans. In the event of new emergency patients arriving, these patients are placed in the earliest available non-emergency slots, holding until all previous emergency patients have been serviced. This flow diagram illustrates the process of magnetic resonance imaging of various types of patients and the steps that follow. The process starts with the referral of three different patient groups for MRI imaging: emergency patients, outpatients and inpatients. The first step is to refer the patient to the imaging centre for MRI imaging. After the imaging procedure is completed, the images obtained are interpreted by a specialised doctor. After the doctor's interpretation, a detailed report is written based on these interpretations. The report is reviewed and approved by a second doctor. In the final stage, the approved report is sent to the patient. This process follows a standardised procedure regardless of the type of patient and each stage is carried out on the basis of medical accuracy and reliability.

The flow diagram shows in detail the patient service processes for the MRI (Magnetic Resonance) department of a university hospital (Figure 2). The process starts with the patient arriving at the hospital and being examined. As a result of the examination, it is decided whether an MRI scan is necessary for diagnosis and treatment. If MRI is not deemed necessary, the process ends. However, if MRI is necessary, the patient is referred to the radiology unit.

After the patient is referred to the radiology unit, an appointment is made with the secretariat for MRI. The patient's MRI scan is performed on the appointed appointment day. After the MRI scan is completed, the patient's images are read and evaluated by specialised doctors. After the evaluation phase, the patient's MR report is written.

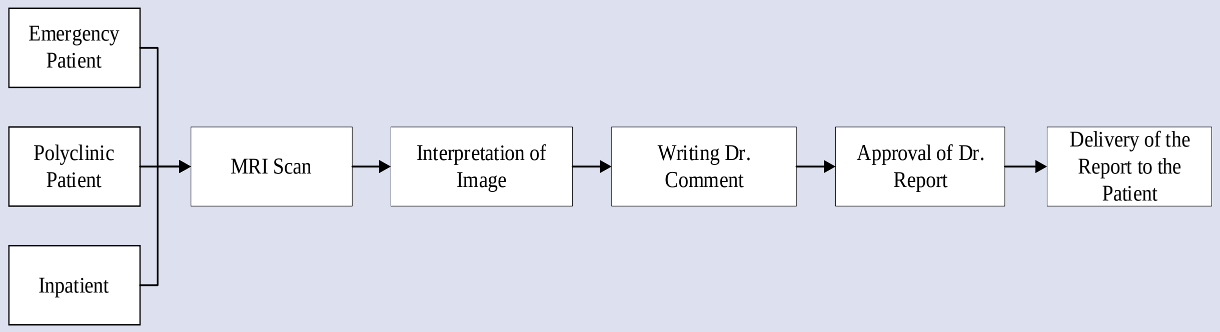

Figure 1. Patient flow process in the radiology unit

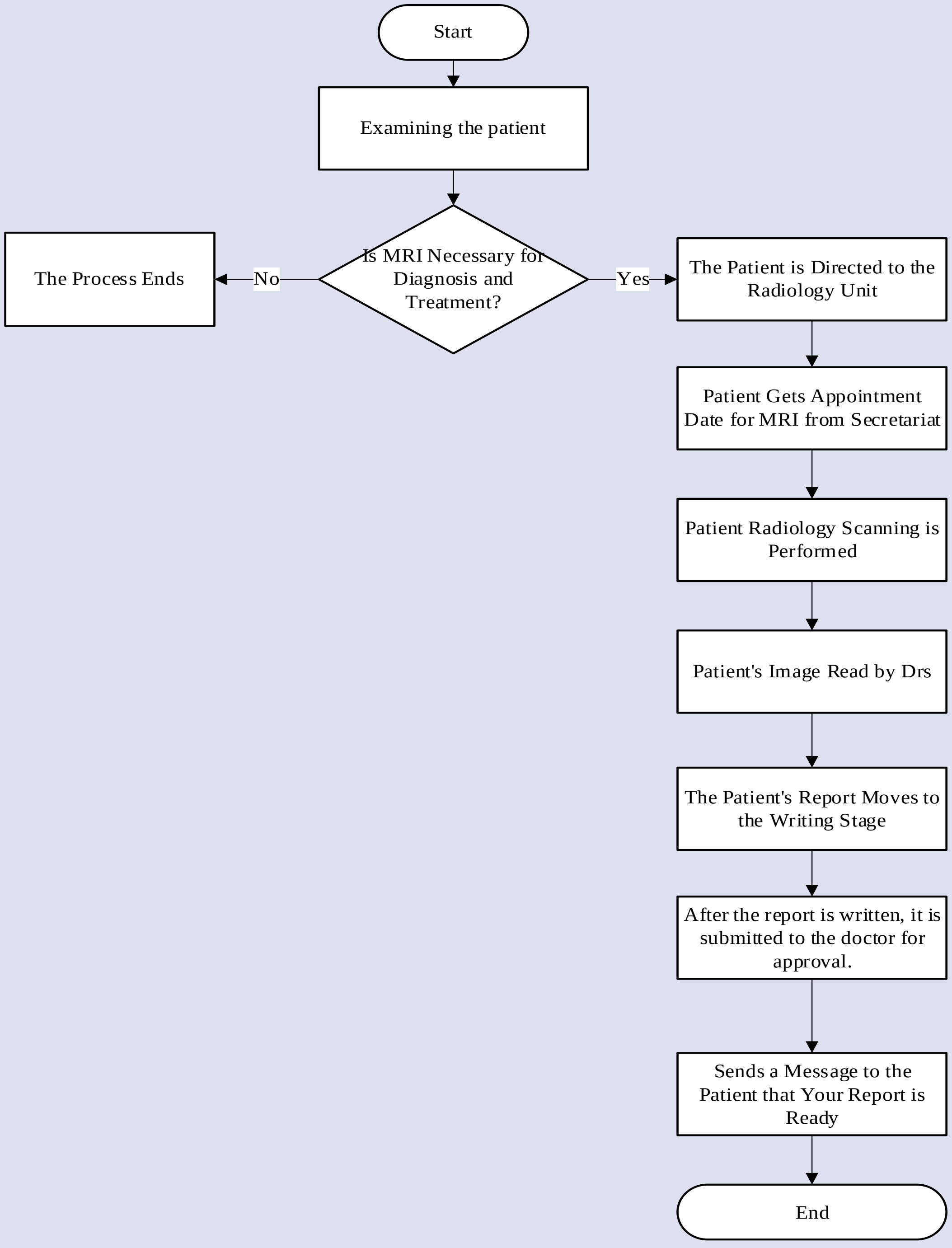

Figure 2. Patient Flow diagram in the radiology unit

The written report is submitted to a doctor to be checked for accuracy and completeness and is subject to the doctor's approval. When the approval process is completed, the patient is notified that the report is ready. The process ends with the patient receiving the report. This comprehensive process is designed to ensure efficient management of patient flow and minimise delays in diagnosis and treatment.

In the study, it is considered that the discrete event simulation model developed to evaluate the service processes in the MRI department of the university hospital is based on certain assumptions. Firstly, the patient flow is assumed to have a statistically random but estimated distribution based on historical data. This assumption aims to accurately reflect the frequency and probability of patient admissions and MRIs in a given time period.

In the model, the possibility of failure of MRI devices is neglected, i.e. it is assumed that the devices operate continuously and without interruption. This assumption reduces the variability and complexity in the system, making the simulation more focussed and manageable. It is also assumed that staff availability is constant and shift changes do not affect the service process. This was done to minimise the impact of staff scheduling and task allocation on the simulation. It is also assumed that the appointment system is efficient and patients keep their appointment times. This implies an arrangement that assumes that the system works regularly and there are no unexpected delays.

Finally, it was assumed that the transition of patients to the next step after completing each step in the MRI process was instantaneous. In other words, it is assumed that at the end of each procedure step, the patient moves to the next step without delay. This assumption is critical to isolate and analyse the impact of procedure times on total patient waiting time. These assumptions are intended to increase the analysability of the model while maintaining its simplicity, and although they do not accurately reflect real-world conditions, they ensure that the results obtained are valid and useful in identifying general trends and potential for improvement.

Sample Selection and Data Collection

In this study, discrete event simulation technique was used to analyse the service processes of the MRI (Magnetic Resonance) department of a university hospital and to identify areas for improvement. The MRI department of the university hospital was selected as the sample. Since this department is an intensively used and critical component of the hospital in terms of service continuity, it constitutes an ideal sample for studies aimed at increasing operational efficiency. A high number of patients are processed in the MRI department on a daily basis, which reveals the need to increase the efficiency of the department.

The collected data were used to create a discrete event simulation model and to analyse the operational performance of the department. Patient confidentiality and ethical rules were observed throughout the data collection process, thus ensuring the accuracy and reliability of the data obtained. This study aims to provide improvement suggestions to increase service efficiency and patient satisfaction in the MRI department, and the findings will provide important contributions to strategic planning and operational decision-making processes for hospital management and other stakeholders.

The data in Table 1 shows the number of MRI scans of the university hospital on a monthly basis in 2021, 2022 and 2023. These data can be used to analyse the changes and trends in the demand for services in the MRI department of the hospital. In 2021, the service demand started with 1849 MRI scans in January, peaked with 2787 scans in March, and closed the year with 2924 scans in December. During this year, fluctuations were observed in the number of MRIs; especially in June, the number of MRIs decreased to the lowest level with 1733, and then entered an upward trend.

Table 1. Number of MRI scans

Year	**2021**	**2021**	**2021**	**2021**	**2021**	**2021**
Month	**January**	**February**	**March**	**April**	**May**	**June**
Number of Shots	1849	2366	2787	2508	2092	1733
Month	**July**	**August**	**September**	**October**	**November**	**December**
Number of Shots	2025	2539	2805	2694	2809	2924
Year	2022	2022	2022	2022	2022	2022
Month	**January**	**February**	**March**	**April**	**May**	**June**
Number of Shots	2758	1894	3098	2980	2589	3108
Month	**July**	**August**	**September**	**October**	**November**	**December**
Number of Shots	2340	2976	3132	2903	2093	2690
Year	2023	2023	2023	2023	2023	2023
Month	**January**	**February**	**March**	**April**	**May**	**June**
Number of Shots	3351	3236	3479	2970	3393	2833
Month	**July**	**August**	**September**	**October**	**November**	**December**
Number of Shots	2844	3076	3155	2865	3121	3325

In 2022, a significant increase was observed in January with 2758 withdrawals compared to the same period of the previous year. The highest level was reached in March with 3098 shots. Fluctuations in the number of shots continued throughout the year, and the year ended with 3108 shots in June and 2690 shots in December. Throughout this year, significant increases and some decreases were observed in the number of shots. The year 2023 started with 3351 MRI scans in January and showed a significant upward trend compared to previous years. In March, the highest level of the year was reached with 3479 MRI scans. Throughout the year, the number of MRI scans generally remained at high levels, and the year was completed with 3325 scans in December. These data indicate a continuous increase in the hospital's capacity and service demand. In general, a significant upward trend in the number of MRI scans was observed between 2021 and 2023. This increase demonstrates the increasing demand for the hospital's MR department services and the need for planning and capacity increase to manage this demand. Increasing number of MRI scans may require more detailed analysis and improvement studies on patient flow management and resource optimisation. In this context, the importance of strategic planning to increase efficiency and patient satisfaction in the MRI department services of the university hospital is emphasised.

Variables

In this study, various variables were analysed in order to evaluate the service processes in the MRI (Magnetic Resonance) department of a university hospital with the discrete event simulation technique. The variables were determined by considering the factors affecting patient flow processes and operational efficiency. The main variables are categorised as number of shots, shooting time, appointment waiting time, report writing time, number of personnel, device usage.

The number of scans refers to the total number of MRI scans performed in the MRI department each month, indicating the level of demand for the department. The scan duration covers the time between the start and end of an MRI scan, directly reflecting the efficiency of device utilization. The appointment waiting time represents the period patients wait between scheduling an MRI appointment and undergoing the scan, impacting both patient satisfaction and access to healthcare services.

The report writing time refers to the period required for doctors to review and document the findings from MRI scans after their completion. The staff count includes the number of doctors, technicians, and support personnel working in the MRI department. The device utilization variable measures how effectively and efficiently the available MRI machines are used.

These variables were used as key inputs in developing the simulation model and played a critical role in analyzing the current performance of the department and evaluating potential improvement scenarios. The results provide a basis for making strategic decisions aimed at enhancing service efficiency and improving patient satisfaction in the MRI department of the university hospital.

Methodology

Discrete Event Simulation, a computer-based modeling methodology, is characterized as an intuitive and adaptable approach capable of simulating the dynamic behaviors of complex systems and the interactions among individuals, populations, and their environments (Karnon et al., 2012). DES is widely used across various fields and serves as a highly suitable tool for modeling and analyzing complex systems (Cihangir et al., 2021). It has been effectively employed in domains such as manufacturing enterprises, healthcare systems, transportation, and logistics (Atalan et al., 2018; Yıldırım et al., 2021). For instance, DES is recognized as an effective tool for modeling the impacts of constraints in health technology assessments (Salleh et al., 2017). Additionally, it is utilized in the application of dynamic simulation modeling methods in healthcare service delivery (Marshall et al., 2015).

These simulations enable the unbiased prediction of performance outcomes, regardless of the system's initial state (Uncu, 2017). Discrete Event Simulation is a widely used technique for modeling complex systems and serves as a critical tool for analyzing and improving system performance. Furthermore, DES has been noted for its applicability in the probabilistic verification of complex systems with real-time features (Younes et al., 2002).

Simulation techniques are widely used in learning processes. For instance, in nursing education, simulations help students develop clinical decision-making skills by replicating clinical environments, thereby reducing the likelihood of errors (Uslusoy, 2018). Similarly, simulation applications in emergency departments are utilized to improve patient treatment processes and enhance the quality of healthcare services (Koçyiğit & Yıldırım, 2022).

The use of DES in the MRI department can provide significant benefits in optimizing workflow, resource allocation, and patient flow. DES is widely applied in healthcare settings to improve operational efficiency and the delivery of patient care. By modeling the MRI department as a series of discrete events over time, DES helps evaluate different scenarios and identify potential bottlenecks or inefficiencies within the system (Raunak et al., 2009; Vieira et al., 2019). In the context of healthcare delivery processes, DES has been used to assess alternative resource allocation strategies in emergency departments, leading to improvements in patient care and operational efficiency (Vieira et al., .2019). Furthermore, DES has been applied to model patient flow in emergency departments, enabling the simulation of various process improvement alternatives to reduce patient length of stay and enhance overall departmental efficiency (Hoot et al., 2008). In this regard, DES is a critical technique employed by researchers across different disciplines for modeling, analyzing, and improving systems. It has been effectively utilized in various fields, including healthcare, transportation, physics, and computer science.

Simulation Model

Based on the data obtained from the Hospital Information Management System, patient arrival distribution was analyzed using Arena Input Analyzer, and it was determined that patient arrivals followed a POIS (0.0152)/day distribution. Additionally, approximately 10% of the daily scheduled patients were emergency cases requiring MRI scans, and these patients were incorporated into the system with a POIS (0.152) distribution. The MRI scan duration was found to follow a NORM (30.5, 4.78)/minute distribution. Interviews with medical secretaries, assistants, and doctors in the MRI department revealed that report review takes 1-10 minutes, report writing takes 8-15 minutes, and report approval takes 8-10 minutes. These processes were incorporated into the model with distributions of UNIF(1,10) minutes, UNIF(8,15) minutes, and UNIF(8,10) minutes, respectively. Currently, the hospital operates with two MRI machines. The model developed using the obtained distributions is shown in Figure 3. The simulation results representing the current state were obtained by running the model for 365 days and are presented below.

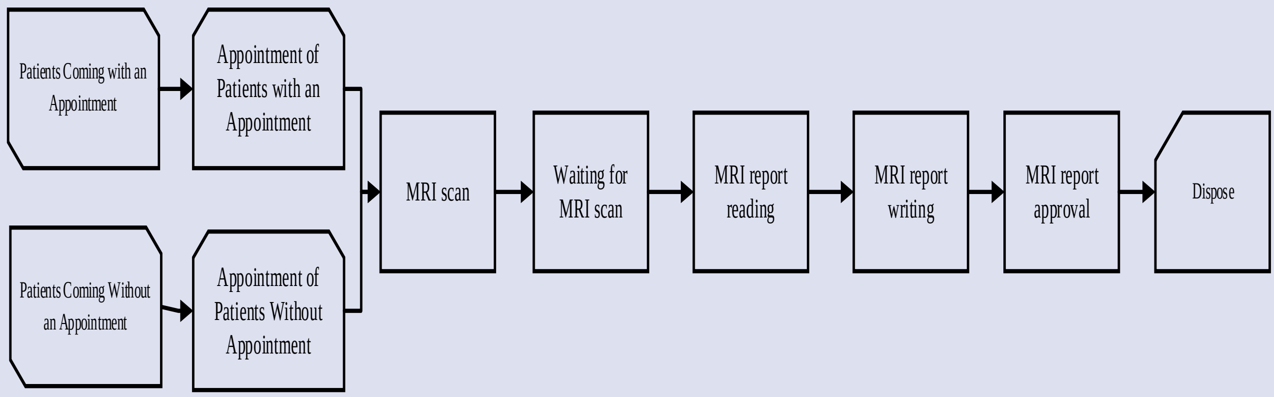

Figure 3. Arena simulation model of the hospital radiology unit

Model Verification and Validation

The verification and validation of the model were conducted by comparing its outputs with real data. This step is critical to ensure that the model accurately represents the actual operations of the MRI department. Using the verified model, the efficiency of current service processes and potential bottlenecks were analyzed. Various scenarios were simulated to evaluate the potential impacts of different capacity planning and operational strategies. These scenarios included interventions such as increasing staff numbers, optimizing device utilization rates, and improving the appointment scheduling system.

Results

This study aimed to analyze the service processes in the MRI department of a university hospital using the DES technique and to provide improvement suggestions. The data used in the study were obtained from historical MRI scan records retrieved from the hospital information management system, direct observations, and interviews with healthcare staff. A simulation model was developed to analyze the current state, and various scenarios were simulated. The findings are summarized below (Table 2).

In the current state (Simulation 1), a total of 37,037 patients entered the model, while the number of patients who completed the system was found to be 17,200.

The number of patients entering the system aligns with the actual number of patients applying for MRI services. In the current state, the average patient waiting time in the system was found to be approximately 2,275 hours (95 days). Accordingly, patients need to wait over three months to undergo an MRI, which is consistent with the hospital's existing data. When examining resource utilization rates in the current state, it is observed that MRI Machines 1 and 2 are operating at 100% capacity.

It was assumed that the long waiting times for patients to undergo MRI scans were due to an insufficient number of MRI machines. In the second scenario, the impact of increasing the number of MRI machines on the system was investigated. The system was re-simulated (Simulation 2) by adding one more MRI machine to the existing patient arrival distribution, and the following results were obtained (Table 3).

In Simulation 2, 38,621 patients entered the system, and it was observed that 38,446 of them completed their MRI scans and exited the system. When the number of MRI machines was increased by one, it was found that almost all patients who applied within a year could have their MRI scans completed within the same year. According to the simulation data, the average patient waiting time in the system would significantly decrease to 51 hours, approximately 2 days. While the utilization rates of MRI machines were at 100% with two devices, the addition of a third MRI machine would result in a substantial reduction in utilization rates.

Based on the analysis of data obtained from the Hospital Information Management System, it was projected that the number of patients would increase by approximately 15% annually. In the third scenario, the system was re-simulated (Simulation 3) with a 15% increase in patient numbers. For this simulation, the number of MRI machines was set to three. According to the simulation results (Table 4), the number of patients expected to apply for MRI scans was approximately 45,000. Of these, around 44,350 would be able to complete their MRI scans within the same year.

Patients will need to wait an average of 90 hours (4 days) to undergo an MRI scan. Resource utilization rates will increase compared to Scenario 2. According to the third scenario, while the utilization rates for doctors and MRI machines remain at an acceptable level, the utilization rate for medical secretaries is significantly high. Although the current workload can be managed with one medical secretary, this would lead to excessive fatigue and, over time, a decline in productivity.

Table 2. Simulation results of the current state

Number of Patients Entering the System			37037
Number of Patients Exiting the System			17200
Patient Waiting Time in the System (Hours)			
	Average	**Minimum**	**Maximum**
	2274.89	0.00	4582.64
Resource Utilization Rates			
	Average	**Minimum**	**Maximum**
Assistant	0.1810	0.00	1.0000
Doctor	0.2945	0.00	1.0000
Medical Secretary	0.3769	0.00	1.0000
MRI Machine 1	1.0000	0.00	1.0000
MRI Machine 2	1.0000	0.00	1.0000

Table 3. Results of simulation 2

Number of Patients Entering the System			38621
Number of Patients Exiting the System			38446
Patient Waiting Time in the System (Hours)			
	Average	**Minimum**	**Maximum**
	50.4528	0.00	195.60
Resource Utilization Rates			
	Average	**Average**	Maksimum
Assistant	0.4039	0.00	1.0000
Doctor	0.6586	0.00	1.0000
Medical Secretary	0.8419	0.00	1.0000
MRI Machine 1	0.7511	0.00	1.0000
MRI Machine 2	0.7436	0.00	1.0000
MRI Machine 3	0.7386	0.00	1.0000

Table 4. Results of simulation 3

Number of Patients Entering the System			**45128**
Number of Patients Exiting the System			**44346**
Patient Waiting Time in the System (Hours)			
	Average	**Minimum**	**Maximum**
	90.5771	0.00	245.69
Resource Utilization Rates			
	Average	**Average**	Maksimum
Assistant	0.4677	0.00	1.0000
Doctor	0.7597	0.00	1.0000
Medical Secretary	0.9711	0.00	1.0000
MRI Machine 1	0.8712	0.00	1.0000
MRI Machine 2	0.8654	0.00	1.0000
MRI Machine 3	0.8565	0.00	1.0000

Discussion

The operational challenges faced by the MRI department of the university hospital are multifaceted, primarily revolving around excessive patient waiting times and resource constraints. The study indicates that the average waiting time for patients was approximately 95 days, a figure that aligns with existing hospital data. This situation underscores the urgent need for capacity expansion to enhance service efficiency and patient satisfaction. The findings resonate with the literature, which emphasizes that healthcare systems often operate at maximum capacity, leading to significant delays in patient care (Bahadori et al., 2017; Singla, 2020). The implications of such delays are profound, affecting not only patient outcomes but also the overall operational efficiency of healthcare facilities (Vieira et al., 2019).

The simulations conducted in this study provided compelling evidence regarding the impact of adding a third MRI machine. The results demonstrated a significant reduction in average waiting times from 95 days to just 2 days, highlighting the critical role of capacity in healthcare delivery. This finding is consistent with previous research that has utilized discrete event simulation to identify bottlenecks and improve healthcare workflows (Granja et al., .2014; Bahadori et al., 2017). For instance, studies have shown that increasing service capacity can lead to significant improvements in patient throughput and reductions in waiting times, thereby enhancing the overall quality of care (Pendharkar et al., 2014). Furthermore, the study's projection of a 15% annual increase in patient demand emphasizes the necessity for proactive capacity planning to address future challenges in service delivery (Sun et al., 2023).

While the addition of an MRI machine significantly alleviated waiting times, the study also identified other resource constraints, particularly the high utilization rates of medical secretaries. This finding suggests that operational improvements must extend beyond just technical resources to include human resources as well. Research indicates that optimizing appointment scheduling systems and potentially increasing staffing levels are essential strategies for addressing these challenges (Bahadori et al., 2017; Vieira et al., 2019). The balance between human and technical resources is crucial for achieving sustained operational improvements, as highlighted in existing literature (Ghanes et al., 2014; Singla, 2020). A holistic approach that considers both aspects is necessary for enhancing the overall efficiency of the MRI department.

The assumptions made in the study, such as neglecting MRI machine failures and considering constant staff availability, may limit the model's applicability in real-world settings. Future research could benefit from refining these assumptions by incorporating stochastic elements, such as equipment downtime and variability in staff availability. This refinement would enhance the model's realism and applicability, allowing for more accurate predictions of operational performance (Sun et al., 2023). Additionally, while DES proved effective in modeling patient flow processes, integrating other methodologies, such as process mining or system dynamics, could provide a more comprehensive understanding of long-term operational trends (Ghanes et al., 2014; Singla, 2020; Durmuş & Özdemir, 2025).

The study offers actionable recommendations for enhancing the performance of the MRI department, emphasizing the importance of strategic planning and continuous monitoring. By addressing current bottlenecks and preparing for future demand, healthcare administrators can ensure more efficient, patient-centered care delivery. This aligns with the broader literature on healthcare operations, which advocates for the use of simulation and optimization techniques to improve service delivery and patient outcomes (Bahadori et al., 2017; Vieira et al., 2019). The integration of advanced modeling techniques can facilitate better decision-making and resource allocation, ultimately leading to improved healthcare delivery systems.

In conclusion, the operational challenges identified in the MRI department of the university hospital highlight the critical need for capacity expansion and resource optimization. The study's findings underscore the importance of using simulation techniques to inform decision-making and improve service delivery. By adopting a holistic approach that considers both technical and human resources, healthcare administrators can enhance the efficiency and effectiveness of the MRI department, ultimately leading to better patient outcomes and satisfaction. The insights gained from this study contribute to the growing body of literature on healthcare operations and provide a foundation for future research in this area.

Conclusion

In this study, the service processes in the Magnetic Resonance Imaging department of a university hospital were analyzed using the DES technique, and improvement suggestions were proposed. The current state analysis revealed that 37,037 patients entered the system, while 17,200 patients exited. The average patient waiting time in the system was found to be 2,275 hours (approximately 95 days), and it was observed that the MRI machines were operating continuously at 100% utilization. This indicates that the long waiting times for MRI scans are due to an insufficient number of MRI machines.

In the scenario where the number of MRI machines was increased, 38,621 patients entered the system, and 38,446 patients completed their MRI scans and exited. In this scenario, the average patient waiting time decreased to 51 hours (approximately 2 days). While the utilization rate of MRI machines was 100% with two machines, a significant reduction in utilization rates was observed when three machines were used. In the scenario with a projected annual patient increase of 15%, the number of patients applying for MRI scans was estimated to be approximately 45,000, with about 44,350 of them able to complete their scans within the same year. The average waiting time was found to be 90 hours (approximately 4 days). In this scenario, resource utilization rates are expected to increase compared to the current state. According to Simulation 3, the utilization rates of resources, except for the medical secretary, will remain at acceptable levels. However, the utilization rate for the medical secretary will reach 97%, potentially leading to negative effects such as fatigue and burnout due to overwork. To address this issue, increasing the number of medical secretaries by one is recommended.

Based on these findings, it is recommended to add a third MRI machine in addition to the existing two. This proposal is expected to significantly reduce patient waiting times, thereby improving service quality and hospital efficiency. Furthermore, given the projected annual patient increase of approximately 15%, planned investments and necessary infrastructure preparations should be undertaken to enhance current capacity. To reduce utilization rates and achieve more balanced use of MRI machines, it is essential to review and optimize operational processes. This approach will prolong the lifespan of the machines and reduce maintenance costs. Additionally, improving the training of healthcare personnel involved in MRI procedures and enhancing process management will further increase system efficiency. Identifying and resolving workflow disruptions, along with implementing continuous improvement initiatives, are also recommended. Regular monitoring of MRI service processes and conducting performance evaluations will help identify potential areas for improvement, ensuring the sustainability of service quality.

In conclusion, this study provides concrete recommendations to enhance the efficiency of MRI service processes in a university hospital and highlights the importance of strategic planning for potential future scenarios. The proposed recommendations will serve as a significant roadmap for hospital management. In this context, the scenarios evaluated using the DES technique were analyzed to improve the efficiency of service processes in the MRI department. The current state analysis revealed long patient waiting times and insufficient MRI machine capacity. Increasing the number of MRI machines by one would significantly reduce patient waiting times and improve system efficiency. Furthermore, while the utilization rates of MRI machines would decrease with the use of three machines, the likelihood of potential breakdowns due to excessive use could also be minimized.

Given the projected annual increase of approximately 15% in patient numbers, planning for this growth is essential. Measures such as procuring new MRI machines and hiring additional staff are critical to meeting future service demands. Enhancing the efficiency of the appointment scheduling system and ensuring patient adherence to appointment times will streamline service processes and reduce waiting times. These recommendations will contribute to strategic decision-making aimed at improving service efficiency and patient satisfaction in the MRI department of the university hospital. The improvement suggestions based on simulation results serve as a guide to enhancing the hospital's operational performance.

Declarations

Acknowledgments

Not Applicable.

Conflict of Interest

Authors disclose no potential conflicts of interest.

Ethics Statement

It was evaluated at the meeting of Dokuz Eylül University Social and Human Sciences Scientific Research and Publication Ethics Board dated 02/04/2024 and the decision numbered 29 was taken at the meeting.

Informed Consent

Not Applicable.

Author Contributions

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Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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