Discrete Event Simulation in Healthcare

By:
Aabha Borle (1914001)–Team Leader
Aditi Pawar (1914002)–Researcher
Anam Choulkar (1914003)–Editor
Ansh Khatri (1914004)–Communicator

Flow of Presentation

- Objectives
- Literature Survey Methodology
- Results of Lit. Survey
- DES in Healthcare Case Study 1
- Results of Case Study 1
- DES in Healthcare Case Study 2
- Results of Case Study 2
- Inferences
- References

Objectives

- To identify both current trends in research and directions for future research related to DES in healthcare
- To demonstrate the potential of DES in solving all kinds of problems faced by the healthcare sector, including macro as well as micro (or unit-specific) systems.
- To simulate the operations of an ASC in Seattle, and to identify throughput capacity as the number of operating rooms was increased from three to four, while the PACU remained constant at 14 beds
- To investigate the effect of a new applied decision-making strategy and to compare its results with a proposed management strategy at a hospital's radiology department in Saudi Arabia

Literature Survey Methodology

- Studies had to be carried out in healthcare delivery or public health scenarios, which can be related to any specific context of health service systems, including a range of studies from the exploration of theoretical aspects of DES up to practical applications.
- Discrete event simulation frameworks should be pointed out as the main modeling technique
- How exactly work flows were structured and simulated should be clarified and clearly demonstrated in the form of either flow charts or descriptive texts.
- Only peer-reviewed original research was included for further review. Papers published as literature reviews, editorials, conference proceedings or methodological guidelines were excluded.
- Only articles written in English were considered.

... contd. Survey Methodology

The selection processes and methodologies of both [1] and [2] are illustrated below in Figure 1 and Figure 2 respectively:

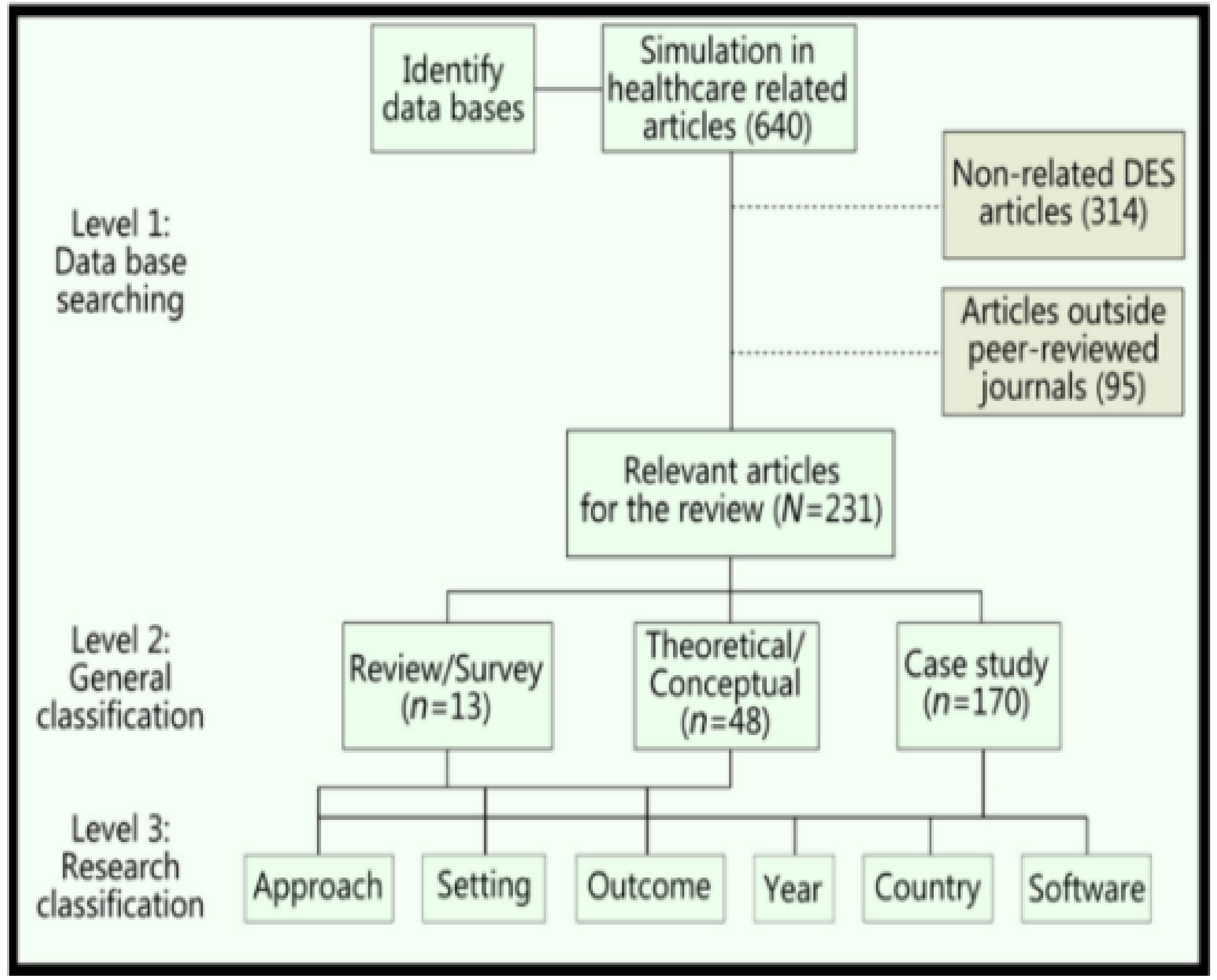

Fig 1. Inclusion and classification process of the review [1].

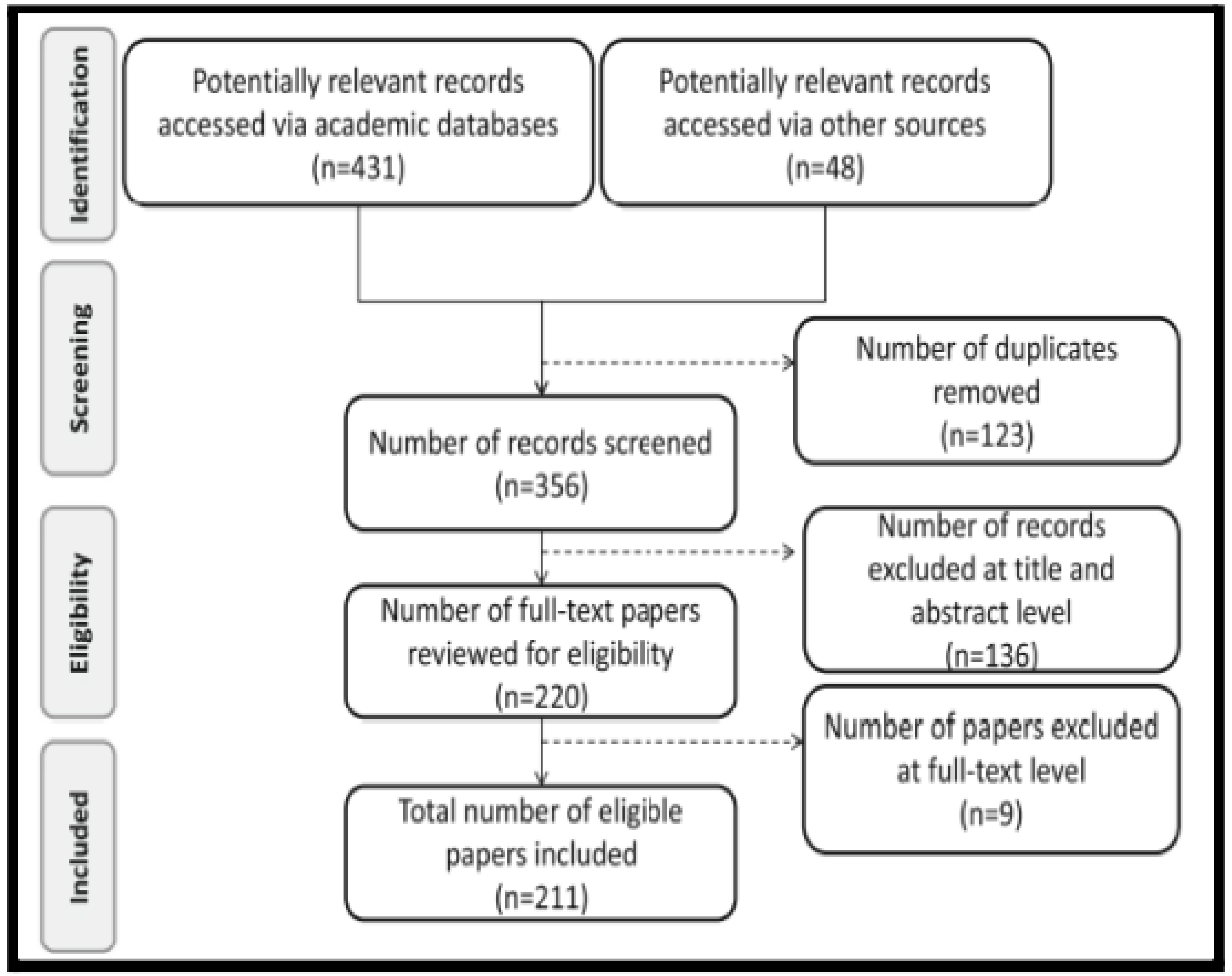

Fig 2. Inclusion and classification process of the review. [2]

Results of Survey

- The distribution of publications over the years according to the 3 categories mentioned in the Methodology section for paper [1] is shown in Fig. 3. It indicates that the popularity of DES in healthcare is notably increasing, as almost 40% of the papers were published in the last three years.
- Fig. 4 illustrates that HCSO accounts for the most considerable proportion (65%) of all modeling studies throughout the whole time span
- Healthcare modelers majorly focused on modeling workflows of emergency departments and ICUs, relative to other systems.

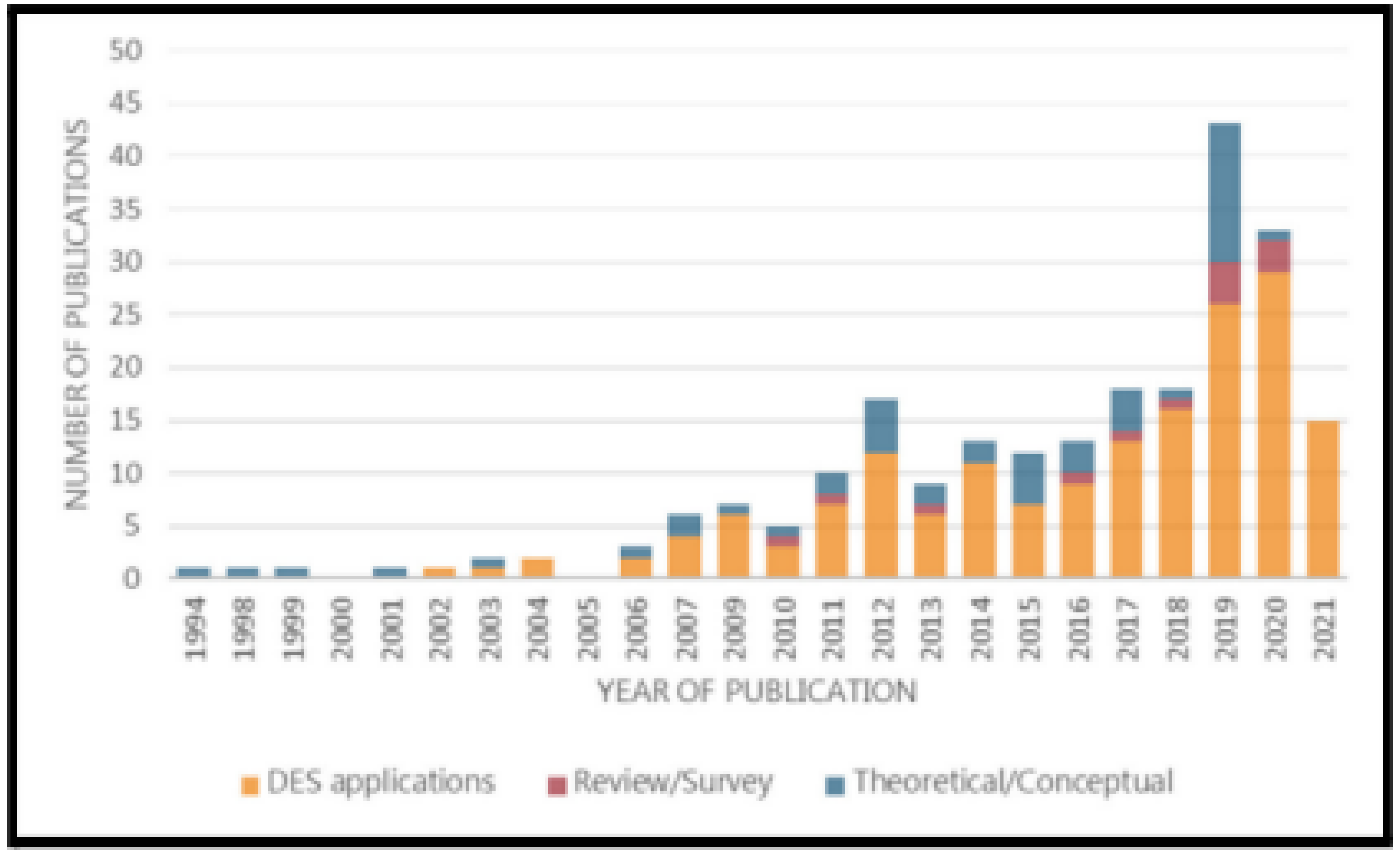

Fig 3. Number of publications per year

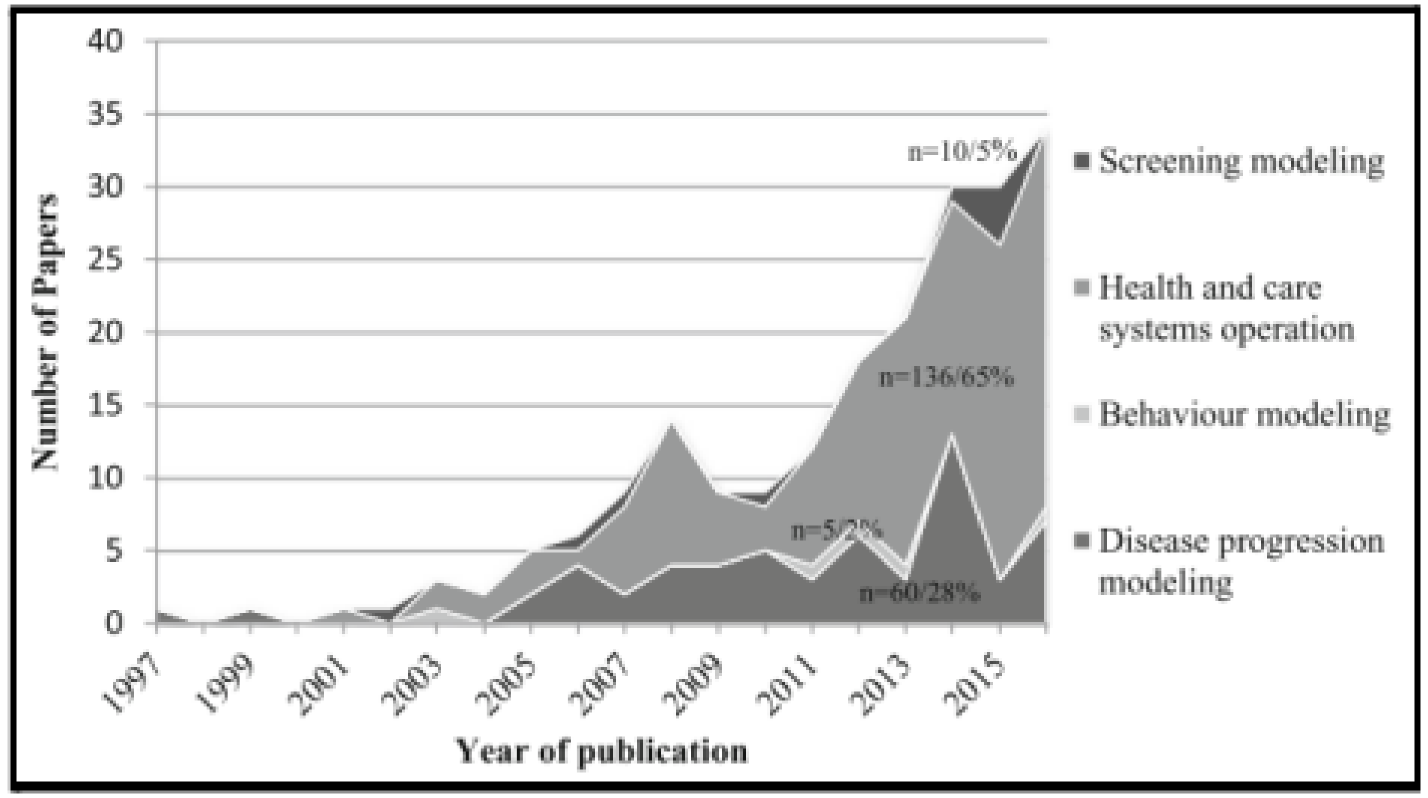

Fig 4. Categorization of applications of DES in health care

Results of Survey

- HCSO distinguishes 6 major operations issues as shown in Fig 5.
- The most frequently analyzed medical indications were related to circulatory system, nervous system, Neoplasm and musculoskeletal system diseases, occupying 18%, 15%, 15% and 13% respectively, as shown in Fig. 6

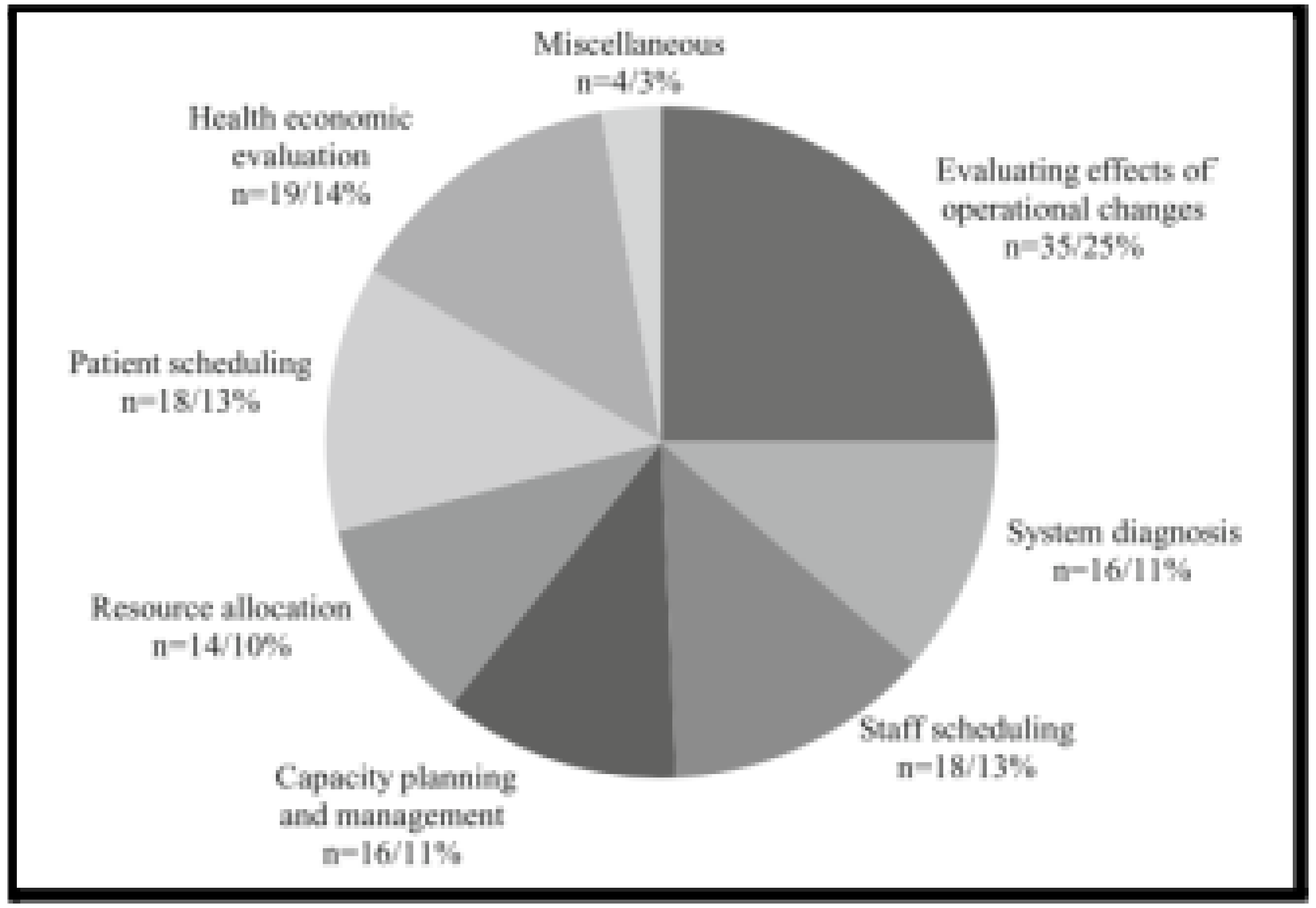

Fig 5. Distribution of sub-categories of HCSO

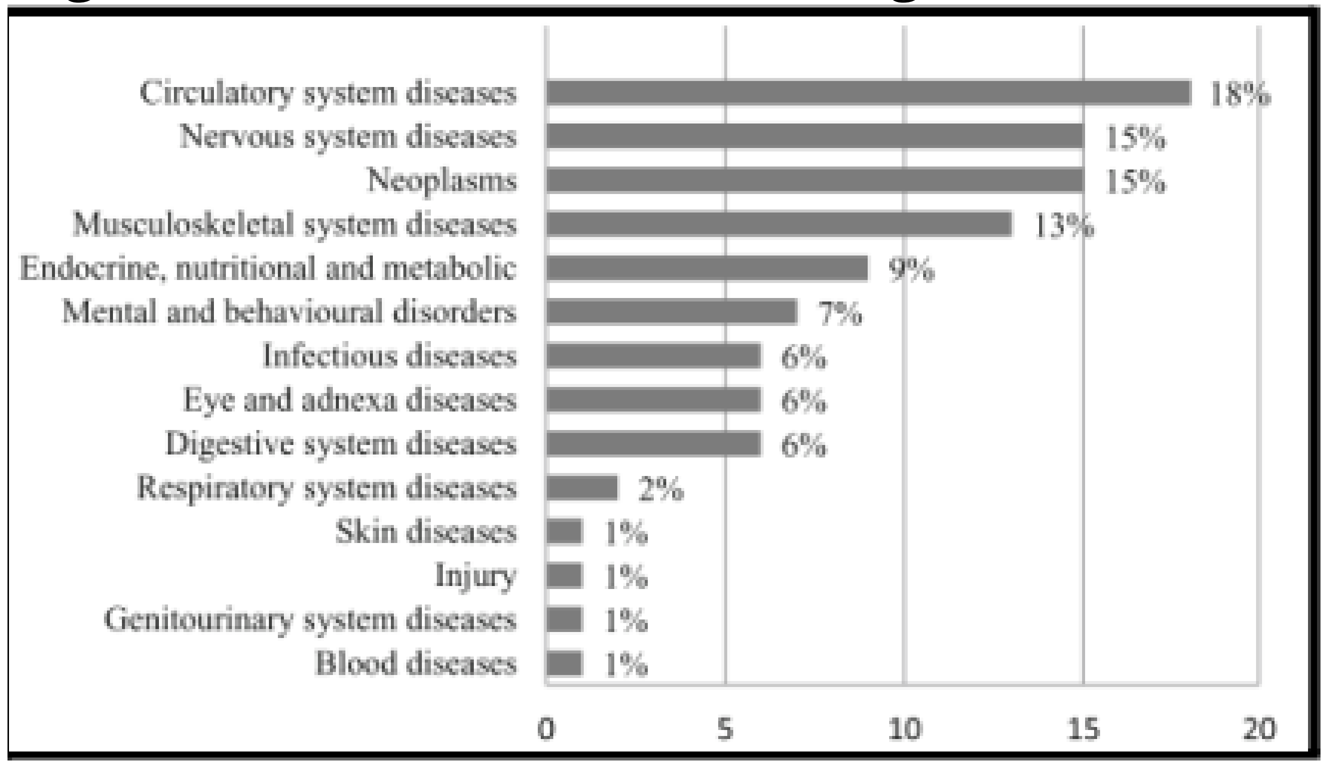

Fig 6. Distribution of disease areas analyzed in studies

As is evident from the results of the two surveys, applications of DES in healthcare are largely concentrated in

- Simulation of emergency care systems
- HCSO (Patient scheduling, evaluating effects of operational changes, etc)

Hence, we shall be discussing 2 case studies related to these applications in the coming slides

Case Studies

1) Future Capacity Determination for an Ambulatory Surgical Center (ASC)

- A DES was created to simulate the operations of the Seattle Children's Bellevue ASC, and i**dentify throughput capacity** as the number of operating rooms was increased from **3 to 4**, while the PACU remained **constant** at 14 beds
- The model was **queried** to determine the number of patients who could receive care while **minimizing** the duration of **crowding** (occupancy 13 or greater) in the PACU, limiting mean total crowding time to **1 hour** per week.
- The researchers wanted to understand the maximum capacity of the ASC using their **current practices and process model**, before optimizing the system.
- The objective of this study was tto determine the **maximum** number of **OR** cases that could be operated upon in their ASC.

Implementation

- The **flow of patients** through the system in question is mapped as shown in the figure and the model was **simplified** to a room-and-resource-occupancy level description of events.

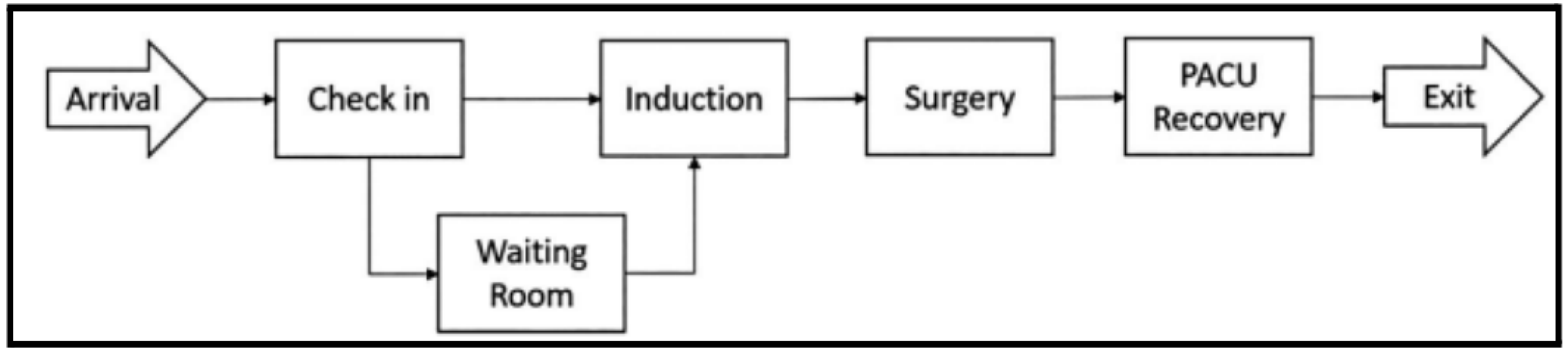

Fig 7. Patient flow through the system.

- As physical capacity is influenced by PACU bed turnaround time, they incorporated bed cleaning between patients as well as the delay while waiting for resources, into the model. These cleaning times were generated from observational data curve-fitted to a **random number generator.**
- The model was informed with **three months** of surgical data, from the time period immediately prior to modeling
- This was randomly parsed into a **training set,** from which the model was built, and a **test set,** against which the model was validated

...contd. Implementation

- **PACU length of stay** was curve-fit for each of these services and then called as a **random variable** when each simulated patient entered the PACU
- The simulation then recorded the entire number of minutes that the PACU **census was >= 13** patients for the duration of the simulation run.
- The number of patient arrivals was modeled based on real-world arrivals in the current system, after being fit to a **Poisson** random variable.
- When running the simulation, the mean number of daily patient arrivals was increased in intervals of 3–6 patients for a total of 12 scenarios, rising from the current practice of approximately **18, up to 60 patients per day**
- Each 10-week simulation run was repeated with random variation **10 times** to capture the **natural variation** in systemic performance.
- For **face validity** - reviewed by physicians and nurses
- For **internal validity** - thorough code review
- For **external validity** - simulation was determined to accurately replicate the real-world system with respect to all observable metrics.

Results of Case Study 1

- The results of [3] indicate that the number of minutes per week of crowded-time in the PACU followed a typical **Malthusian** curve.
- As the number of surgeries performed increased, crowded time rose exponentially, until **bounded** above by the total time available (there being only 10,080 min in a week), shown in Fig. 8 . The **error bars** represent **one standard deviation around the mean** as calculated from the multiple simulation runs
- The authors anticipated that **68%** of weeks would have crowding time between the error bars at each patient/week threshold
- It was determined that a **weekly threshold of 60** min of crowding time was the tolerable limit
- Thus, the total number of **patients** which can be seen in the system is calculated to be **50 per day**

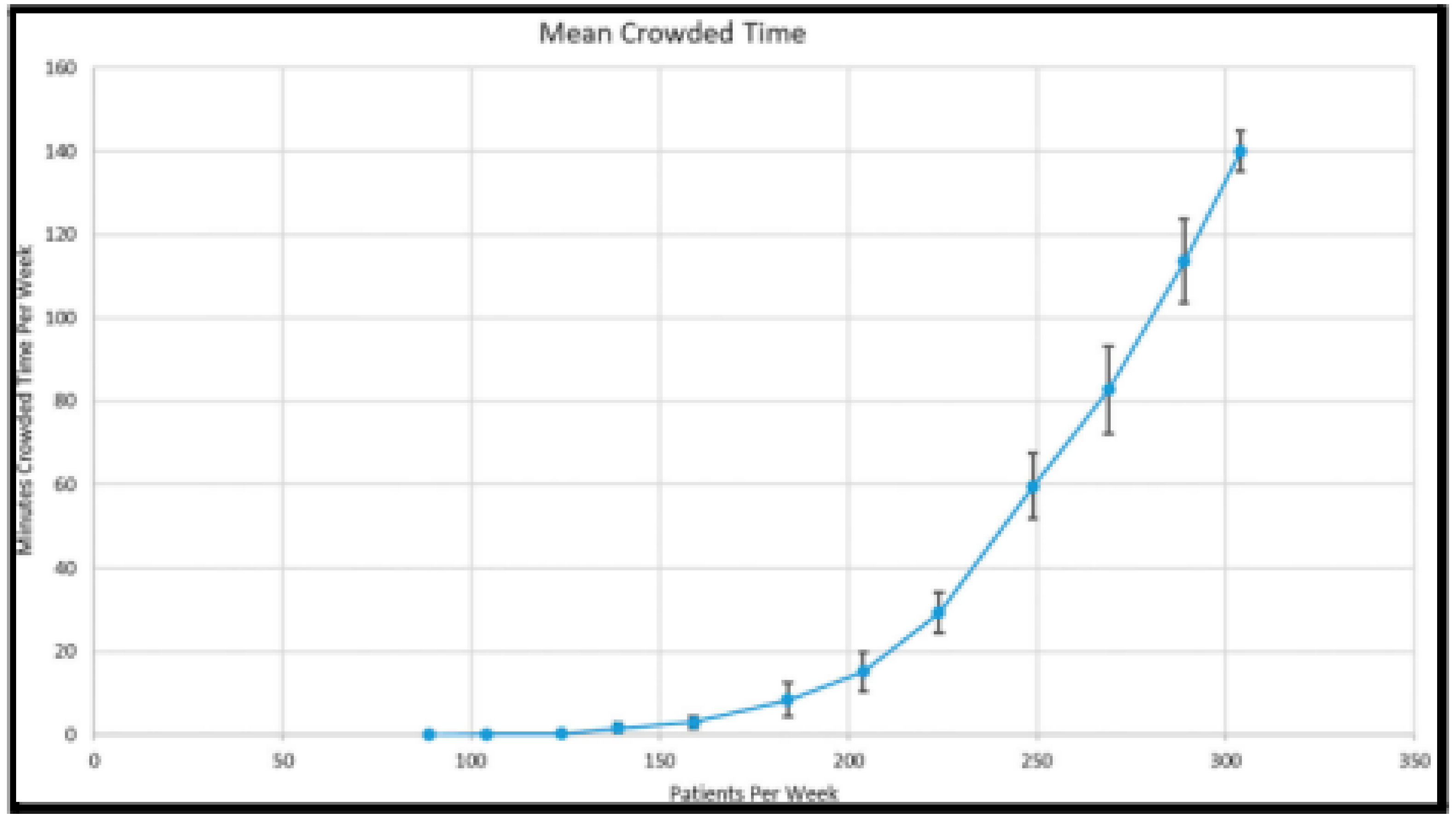

Fig 8. Patients per week vs Mean crowded time (min/wk).

2) Performance Evaluation of a Hospital's Radiology Department

- The main goal of this study is to evaluate the effectiveness of the applied and proposed management strategies for **managing resources** in a radiology department of one of the largest private hospitals in Saudi Arabia
- The hospital management **aims to provide same-day imaging** (no rescheduling of patients in queue) to as many people as possible, while **reducing the waiting time of patients** and enhancing their satisfaction with the MRI service and the hospital in general.
- The department has only **1 MRI** machine in service
- **FCFS policy** is normally used for patient scheduling, with some exception in case of emergencies.

The 3 Management Strategies in Question

Old Strategy

Department open for six hours a day, specifically from 9:00 am to 12:00 pm and then from 4:00 pm to 7:00 pm

Newly Applied Strategy

Department open for 2 shifts successively, with **no breaks** from 9:00 am till 10:00 pm for 6 days of the week.

- The first shift is from 9:00 am till 5:00 pm
- The second shift is scheduled from 5:00 pm till 10:00 pm

Proposed Strategy

Department to be working over two continuous shifts 6 days per week with

- **two break periods of 15 mins each** for the first shift and
- **one break period of 20 min during the second shift**

to accommodate the personal needs of the administrative staff and technicians

Implementation

- A simulation model to investigate 3 strategies was developed using **Arena software**
- The data required was collected by 3 team members who worked under the supervision of administrative staff, as well as an imaging technician at the MRI testing room
- The staff recorded the **arrival times** of the patients at the MRI room for a period of **5 month**s.
- The technician recorded the **start and end times** of the imaging process of each patient, as well as the **departure time** from the MRI room, for a period of **1 month.** Some assumptions made here for the model building process were:

  --> Patients' delay due to walking the distance from the waiting room to the imaging room was added to the imaging processing time.

  --> The time elapsed in undressing and dressing was added in the scanning processing time

… contd. Implementation

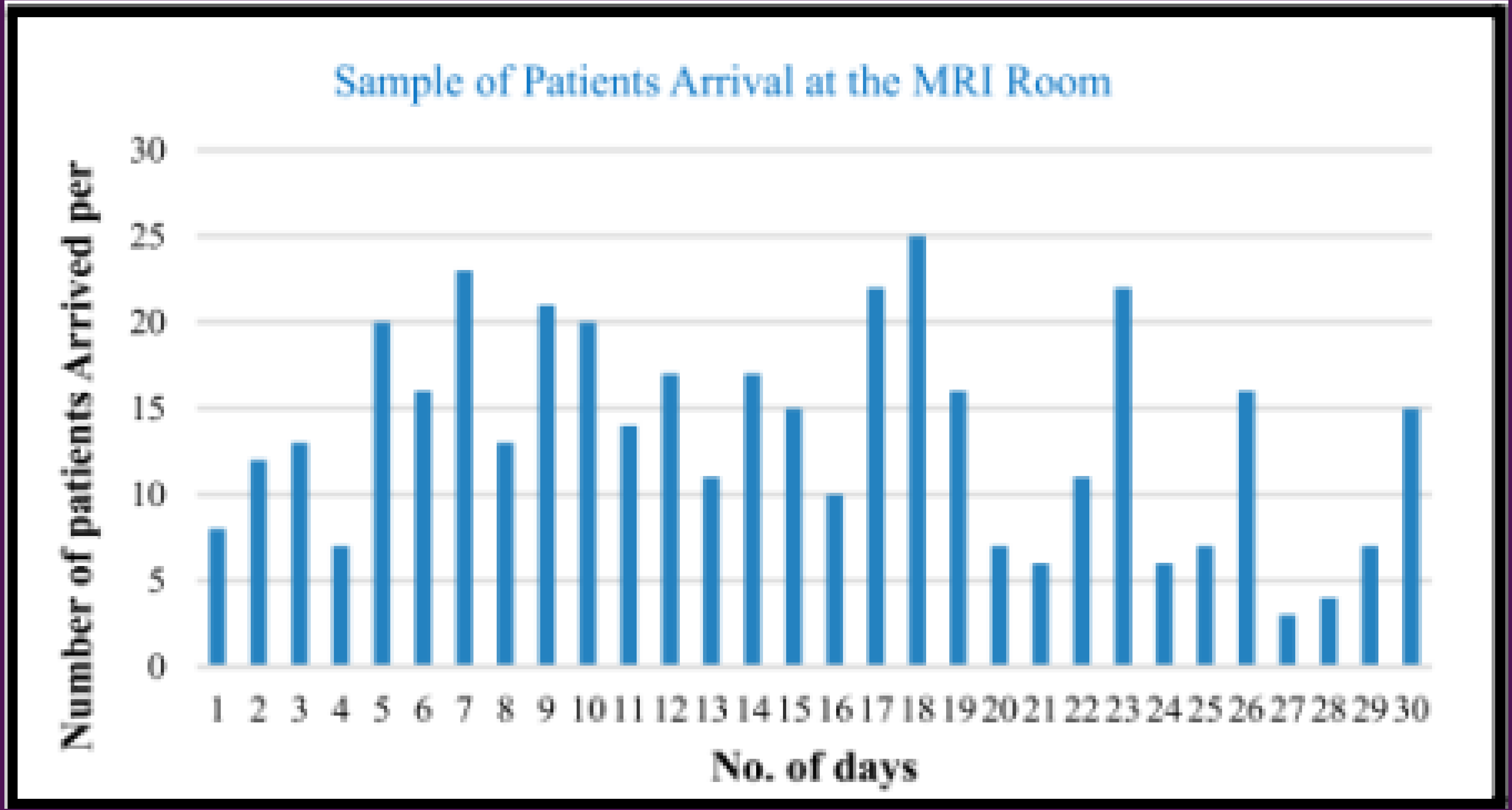

Fig 9. A sample of patients' arrival patterns at the MRI room per day

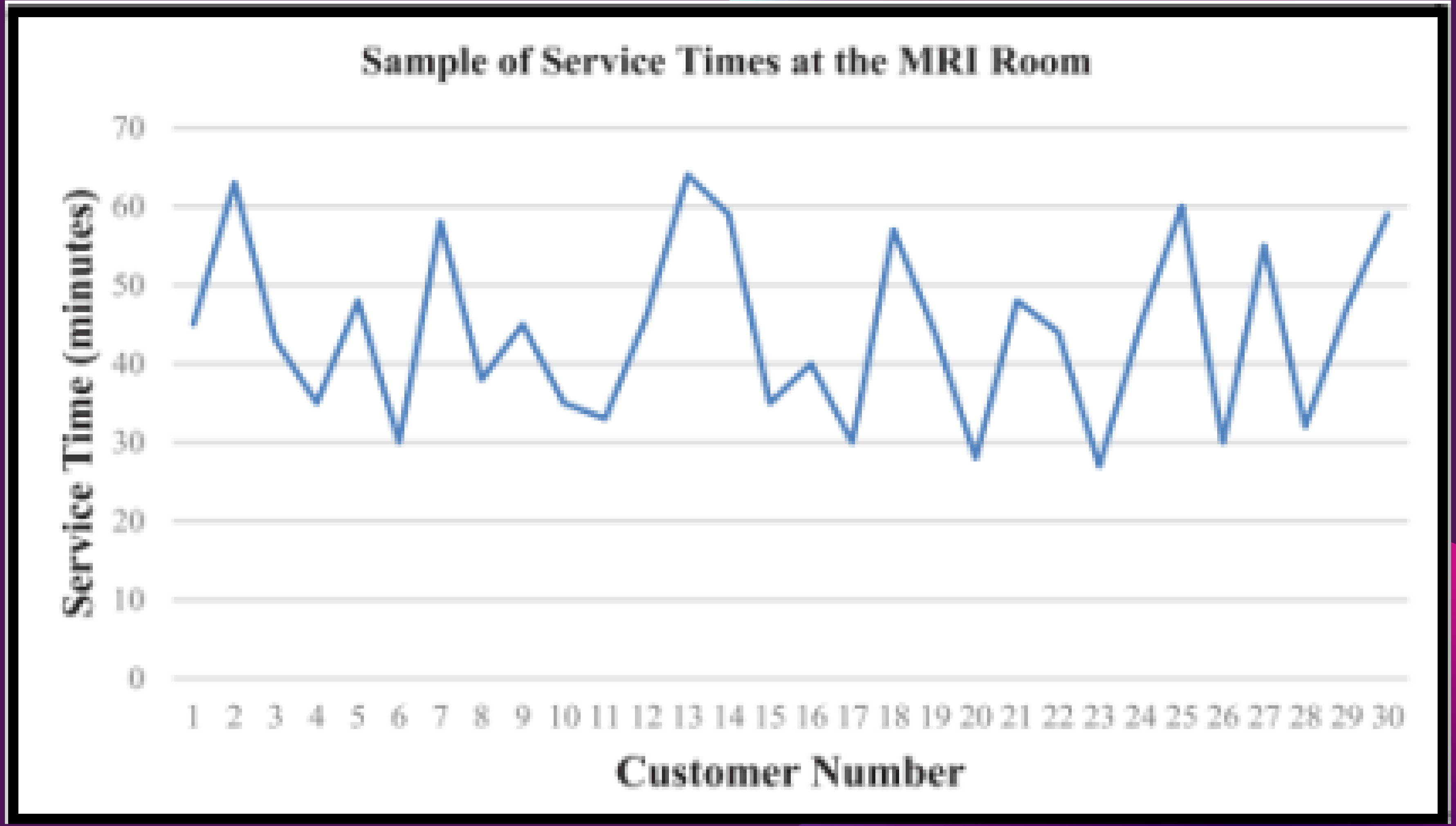

Fig 10. A sample of the patients' processing time at the MRI room (randomness)

...contd. Implementation

- The collected data showed that the patients' **processing time** is according to the **triangular probability distribution** function
- The **arrival rate** of the patients in the MRI room is according to the **exponential probability distribution function.**
- The data collected indicates that **42%** of the patients registered and scanned on the **same day**. The rest are scheduled for scanning in the following days with a **maximum waiting period of 5 days.**
- Hospital records showed that **31%** of the rescheduled patients **did not show up**.
- To verify the correctness of the model construction process, the basic dynamic **animation** provided by Arena was enabled. It simplified the verification of the model's logical operations, which assured the existence of all scanning resources and processes in the model and confirmed the **duplication** of the real system.

... contd. Implementation

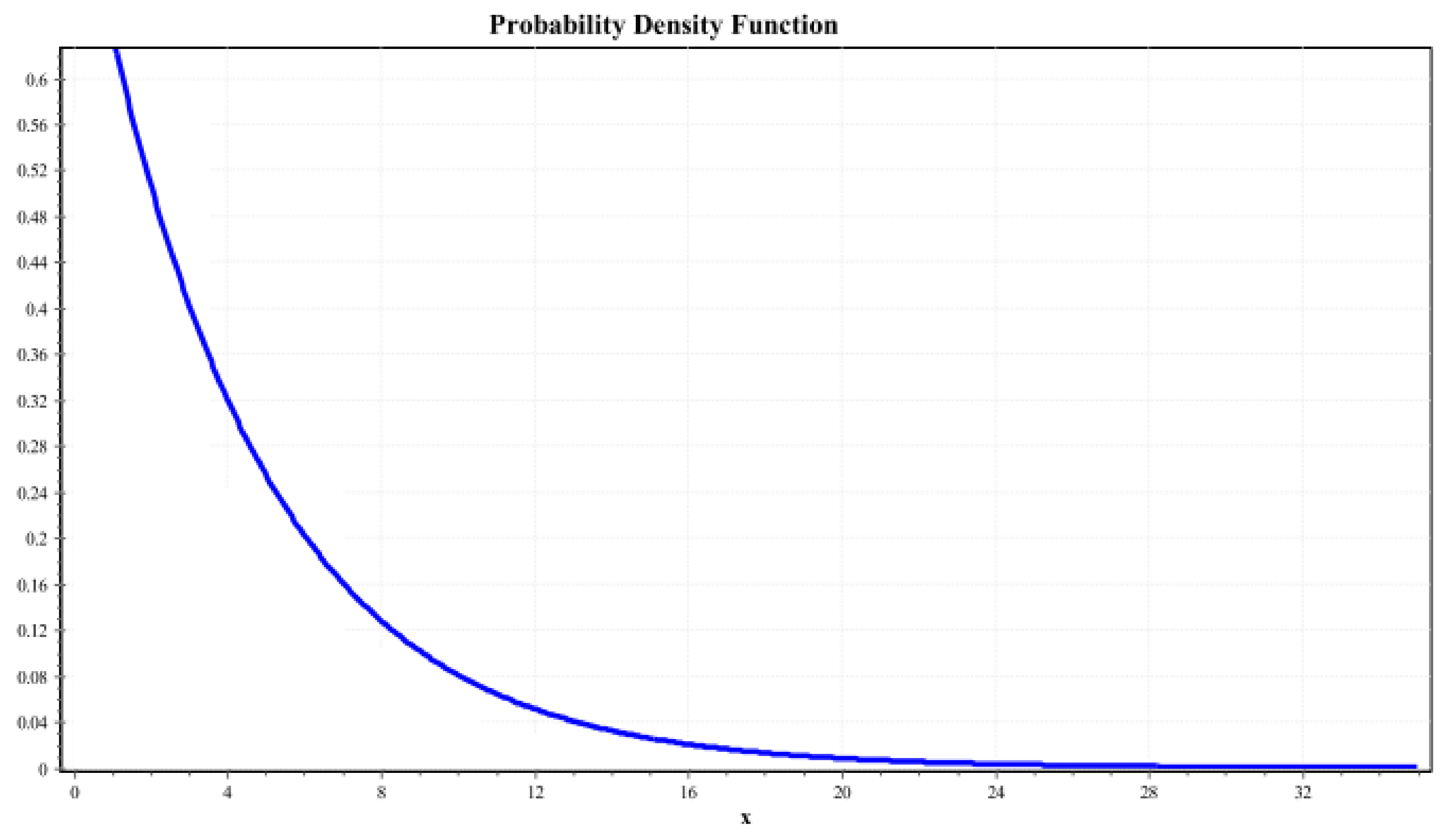

Fig 11. Probability statistical distribution that fits the arrival rate at the radiology room

Results of Case Study 2

Strategy	Break (min)	Minimum waiting time (min)	Average waiting time (min)	Maximum waiting time (min)	Average total time in the system (min)
Current strategy	0	0	41	58	66
Old strategy	MRI room is idle for 240 min (12:00–4:00 pm)	0	56	97	84
Proposed strategy	Day shift: 2 breaks @ 15 min Night shift: one break @ 20 min	0	37	45	57

Table 1. The simulation model output results of investigated strategies for system performance related to the MRI scanning room

Strategy	Break (min)	Minimum waiting time (min)	Average waiting time (h)	Maximum waiting time (days)
Current strategy	0	0	2.48	1
Old strategy	MRI room is idle for 240 min (12:00–4:00 pm)	0	103	7
Proposed	Day shift: 2 breaks @ 15 min Night shift: one break @	0	0.3	0

Table 2. System performance related to the appointment scheduling process of the investigated strategies

Table 2 shows that there is an improvement in the appointment scheduling process through the application of the current strategy

Results of Case Study 2

- The **average waiting time and average total time** in the system of the current situation are **56 and 84** min respectively if the old strategy is kept in place for managing the MRI testing room, i.e the current situation will be **even worse** if the old strategy is continued
- The **applied new strategy** will improve the performance of the system, with the average waiting time and the average total time in the system dropping to **41 and 66 min** respectively compared with the old strategy. These results prove that there is an improvement in the average waiting time and the average total time in the system by 26.8% and 21.4% respectively. The appointment scheduling process will also improve.
- Running the MRI room under the **proposed strategy** will lead to an **extra reduction** in the average waiting time and average total time in the system compared with the current applied strategy.
- These simulation results reveal that the proposed strategy is **more effective** than the currently applied strategy, and will enable the treatment of all patients on the **same day with no rescheduling.** These results also recommend providing the suggested break periods to satisfy the staff and technicians' personal needs.
- The results conclude that **adding several short breaks** for the employees as part of the proposed strategy will **not harm** the waiting time, and will also have a positive effect on the overall performance of the hospital staff.

Inferences

- DES is a methodological approach to **analyze the inefficiencies** in operational healthcare. It can also help assess operational interventions before putting them into action. DES is also used in **examining the relationship** between the variables affecting healthcare systems.

- The two concrete implementations of DES in healthcare from [3] and [4] provide **capacity predictions** of the operating room, improve the efficiency of hospital services so that the waiting time of patients is cut down by a significant margin, and increase the satisfaction of patients as well as staff considerably.

- Management of healthcare could benefit from **modeling systems as a whole** rather than just limiting to single units.

...contd. Inferences

- Given the intricate interdependencies of modern health care services, a more **realistic representation** of the workings of a real system can be achieved from this integrative perspective.

- Because patient satisfaction depends greatly on their experience throughout a whole integrated system, modeling **macro-systems** is imperative to improving this metric, thus ensuring better chances of retaining patients as loyal “customers” of a hospital or any other macro healthcare system.

References

- [1] Vázquez-Serrano, Peimbert-García and Cárdenas-Barrón, “Discrete-Event Simulation Modeling in Healthcare: A Comprehensive Review”, International Journal of Environmental Research and Public Health, 2021.
- [2] Zhang, “Application of discrete event simulation in health care: a systematic review”, BMC Health Services Research, 2018.
- [3] Reese, Avansino, Brumm, Martin and Day, “Determining future capacity for an Ambulatory Surgical Center with discrete event simulation”, International Journal of Healthcare Management, 2021.
- [4] Shakoor, Qureshi, Jadayil, Jaber and Al-Nasra, “Application of discrete event simulation for performance evaluation in private healthcare: The case of a radiology department”, International Journal of Healthcare Management, 2021