Application of Simulation Modeling and Lean Principles for Reducing Patient Waiting Queues and Cost: The Case Study of a Developing Country

Integration of Simulation and Lean

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ABSTRACT

Every day, health centers receive a significant number of patients seeking care and hospitalization, leading to long waiting times. Simulation modeling techniques are considered an effective solution to this issue. However, some research efforts had limited success mainly due to the neglect of systematic and straightforward approaches to identify and eliminate time waste in the healthcare system. To address this limitation, this study developed an LSS approach by collecting arriving patients and staff in a health center and using it as a case study. Then, a simulation model of the current system was created using the SIMPROCESS software. Finally, alternative solutions to shorten the queue time were proposed and supported by statistical graphs and tables. This is expected to improve overall health outcomes and enhance the delivery of healthcare services. A scenario is presented to evaluate the impact of the proposed improvements, which includes adding a general practitioner, a pediatrician, a dentist, and another pharmacy counter. This scenario improves system performance by up to 21%, reduces patient waiting times by approximately 50%, and ensures a fair distribution of workload among staff.

Keywords-simulation modeling; DMAIC; patient waiting queues; cost reduction; healthcare

I. INTRODUCTION

In recent years, as revealed by annual statistical data from the World Bank, allocations to the healthcare sector have accounted for approximately 11% of the World's Gross Domestic Product (GDP). Despite these allocations steadily increasing and with the challenge of limited capacity constraints, the pursuit of providing high-quality healthcare services remains unwavering [1]. However, significant improvements in healthcare services have not been achieved despite a considerable increase in healthcare expenditures. This poses a new challenge for many countries: How to strike a balance between increasing spending and ensuring the provision of effective and high-quality healthcare services [2]. This hesitation to provide the necessary service often stems from various factors, including patient waiting times, satisfaction levels, the adequacy of human resources, the effective use of available resources, and financing, which are inherent challenges in most health systems in many countries [3]. Crucial areas appear to be keys where investment is necessary to improve health systems, including reducing costs and improving operational efficiency and continuous innovation [4]. A notable trend is the ongoing adoption of lean thinking policies to facilitate access to and delivery of healthcare services, with the goal of high-quality, safe, comprehensive, integrated, affordable, available, and accessible healthcare for all [5]. Lean Six Sigma (LSS) represents a transformative workflow approach that is applied primarily in project management and is now increasingly used in healthcare to improve patient care, optimize hospital operations, and advance medical technologies [6]. The LSS DMAIC procedure focuses primarily on enhancing quality standards, minimizing workflow errors, and fostering continuous quality improvement. The effectiveness of this approach is due to its structure, consisting of five consistent and complementary stages: define, measure, analyze, improve, and control. Its design considers the possibility of tackling complex challenges that are often encountered in business processes with ambiguous root causes [7]. Given the complexity of the health system components due to variation and interconnectedness, both combinational and dynamic, the broad adoption of this strategy to dramatically increase performance levels in the industry has been justified [8, 9]. Modeling a system requires a sophisticated analysis of the links between decision-making, planning, and implementation strategies [10]. For faster adoption, most lean practitioners (LSS methodology) choose simulation modeling [11]. This fusion has shown a significant impact across various industries [12].

However, the utilization of this systematic approach, integrating LSS and simulation modeling, to improve healthcare operations, has been relatively limited. Expanding previous initiatives in this domain, this paper introduces a systematic approach to reduce queue length, reduce patient waiting times, and lower associated costs within the healthcare system by integrating LSS procedures and simulation modeling. This approach seeks to enhance system performance by increasing the number of patients receiving treatment and ensuring an equitable distribution of staff resources for patient care. The New Baghdad Polyclinic Center served as a case study for this investigation.

II. LEAN SIX SIGMA (LSS) AND SIMULATION IN HEALTHCARE

Simulation modeling is a potential solution that increases efficiency when combined with LSS. This combination has been used in various areas of manufacturing processes, and the adoption of this strategy is increasing worldwide. Over the past decade, numerous research efforts have utilized simulation modeling and LSS to improve healthcare. For example, in [13], LSS and simulation were applied to redesign emergency departments, resulting in better physician distribution and reduced patient waiting times. In [14], a significant reduction in patient waiting times and overall hospital stay duration was achieved. In [15], patient waiting times were reduced by 23.7% on average in an outpatient eye clinic in Singapore. Additionally, in [11, 16], LSS and simulation were combined to improve the quality of patient care. In [17, 18], the emergency room process was simulated to verify flexible improvements before implementing them. In [19], an LSS system was adopted to improve the efficiency of MRI operations in hospitals. In [20], LSS and simulation were used to improve drug distribution efficiency and nursing times in a hospital. In [21], LSS and simulation were used to reduce the risk of healthcare-associated infections in surgical departments. In [22], LSS and simulation were applied to improve operating room turnover. In [23], LSS with a simulation-based approach was applied to address the problem of patient discharge time at the King Hussein Cancer Center in Jordan, showing that it could reduce patient discharge time by 54%. In [24], a systematic approach was proposed to reduce the time spent making appointments in outpatient obstetrics and gynecology departments. This framework combined the Six Sigma method to identify defects in the appointment scheduling process with Discrete Event Simulation (DES) to evaluate the potential success of eliminating them in simulation before applying changes in real-world settings. In [25], the Six Sigma DMAIC model was used to evaluate the current service system at the Indonesian Community Health Center in West Java, using various tools to design alternative service system improvements by applying the Theory of Innovative Problem Solving (TRIZ). Alternative simulation models were also built using FlexSim software, and the optimization plan was evaluated. In [26], LSS with DES were integrated to reduce waiting times before blood collection in clinical laboratories. The average waiting time before sample collection decreased from 61 to 21.5 minutes per patient.

Several studies have pointed out the benefits of combining LSS with other techniques, such as simulation analysis, to improve performance and make healthcare systems more efficient. However, the research community still rarely uses this combination in practice. Few healthcare institutions around the world use this strategy as the most effective way to eliminate waste and improve processes. This study provides a feasible solution for clinics in developing countries, showing how combining LSS with simulation can help convince the relevant parties to implement improvements. Another important contribution is that this study not only focuses on improving waiting times but also takes into account the cost to serve and the balanced distribution of staff workload, which are aspects rarely considered in the literature.

III. RESEARCH APPROACH

The proposed approach integrates the Six Sigma model, DMAIC, and simulation modeling. This approach aims to proficiently identify factors that influence the problem of waiting queues, set performance measures, analyze collected data, define methods to enhance outputs, and subsequently control the process if necessary. Figure 1 shows the schematic of the method, highlighting the key elements of the LSS strategy. The primary emphasis lies on customer requirements, with a particular focus on patients. Additionally, the LSS approach underscores the management capacity, the application of statistical techniques, a structured method, and the realization of economic results.

The DMAIC procedure is implemented within the healthcare system, incorporating a simulation model and a comprehensive set of performance metrics. In the definition phase, it is imperative to articulate clear objectives for improving healthcare. The definition of patient needs plays a pivotal role in delineating the goals for improvement initiatives, with a primary focus on reducing patient waiting times. The waiting time is operationally defined as the total duration from patient registration to the start of the physician's consultation. To advance the improvement stage and optimize the performance of the healthcare system, the simulation model is designed to address the challenges by analyzing what-if scenarios. The final stage in DMAIC is the control stage, where various contributing factors play a pivotal role in maintaining improved results. Center policies delineate specific aspects of the plan and serve as crucial reference points. For instance, patients are expected to adhere to the procedures described, as shown in the case study. Direct control of procedures can serve as parameters to establish an effective start time, such as 08:00 am, and can also be employed to evaluate annual performance.

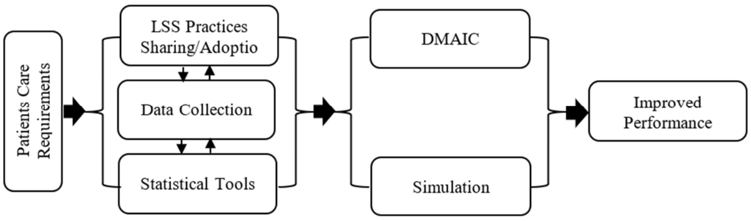

Fig. 1. Key elements that are critical for effectively executing the research method.

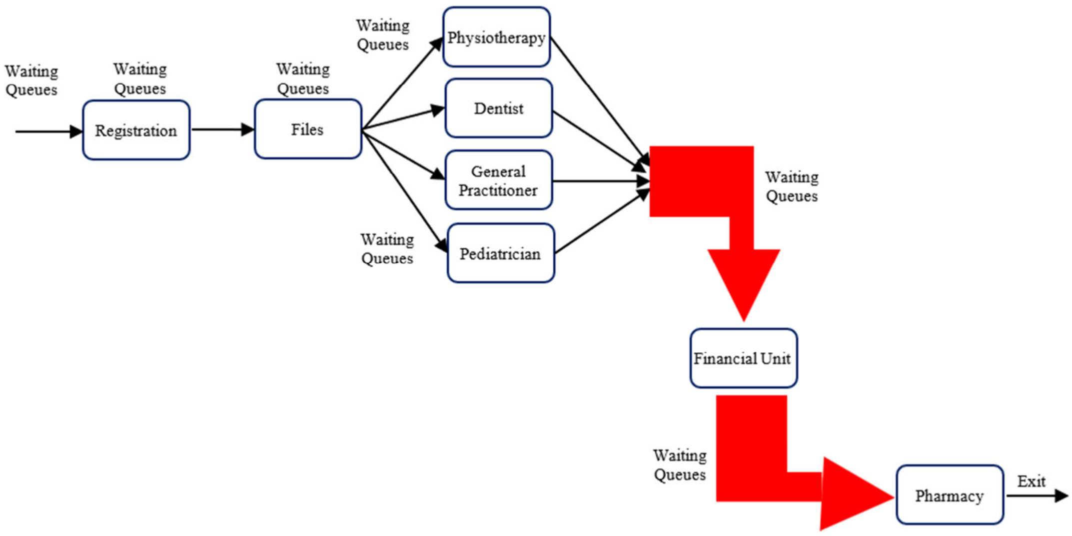

Fig. 2. Visualization of patient flow and existing waiting queues in the system.

IV. CASE STUDY: ANALYSIS OF CURRENT HEALTH CENTER CONDITIONS

The health center, namely the New Baghdad Clinic, provides medical services to Iraqi citizens of all age groups. It serves an estimated daily influx of around 300 patients, including 60 dental care cases, 50 sessions for physical therapy, 100 cases for pediatric care, and an additional 100 cases for general medical care. The center operates daily for 12 hours, with working hours spanning from 8:00 am until 8:00 pm, facilitated by two shifts. The most prominent challenges for the center revolve around the issues of overcrowding and waiting lines, particularly noticeable at the registration windows and pharmacy counters from 8:00 am until 12:00 pm. Furthermore, the limited capacity of the waiting area poses an additional problem, as it is insufficient to comfortably accommodate queues. This situation leads to patient discomfort and presents challenges for staff, including doctors, clerks, and nurses, as they strive to perform their tasks efficiently within the center.

Figure 2 provides a visual representation of the patient's journey within the healthcare center, beginning with their entry into the facility, progressing through the receipt of necessary care, and ending with follow-up procedures. Patient access characteristics can be summarized as follows:

- Access, diagnosis, and treatment of patients occur on an unscheduled basis.
- There is no identified pattern to describe the distribution of patient access.
- All incoming cases must be processed.
- Patients are classified and examined according to their needs.

The red arrow highlights congested areas where queues form in the registration and pharmacy sections. Diverse means and methods were employed to gather foundational data and delineate the structure and information flow within the current center. Special attention was paid to examining the factors influencing the accumulation of patient queues within the center. The center's records were screened for approximately a month to comprehend access patterns, identify patient categories, and establish optimal treatment times, including registration, waiting, and treatment durations. To ensure precision in data collection, an experiment was conducted that involved recording patient numbers, tracking their arrival and departure times, identifying their waiting locations within the center, and documenting instances of overcrowding. Subsequently, within the same month, patients were randomly selected and observed while navigating the center. The objective was to comprehend the time they spent at each stage and conduct a detailed study to identify potential challenges they might encounter within the system. The statistical data are stored and classified according to different sessions and various appointment allocations for doctors and staff, ensuring the retrieval and analysis of the most current data. Moreover, preliminary information into operations and challenges was collected from physicians and staff using a questionnaire, supplemented by interviews with the staff. Based on the current status of the center, this study aimed to achieve the following:

- Identify the factors that influence queue congestion in the health care center.
- Select the most optimal alternative to the current system under examination.
- Propose some recommendations to capture the attention of government officials and highlight the importance of application, emphasizing the significance of implementation, particularly through quantitative methods and computer analysis of problems to facilitate informed decision-making.

In the case considered, the source of service requests from the population is an infinite number of individuals. In theory, this suggests that a large number of community members could potentially seek service at any given time. However, a graphical representation of database information, as shown in Figure 3, indicates that the average daily patient population is approximately 300.

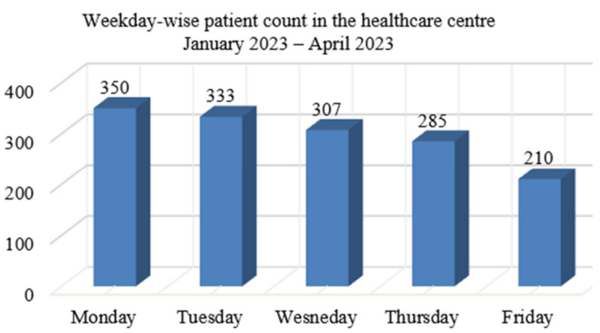

Fig. 3. Weekday distribution of patient numbers in the system.

V. RESULTS AND DISCUSSION

Simulation procedures and DMAIC were employed to assess and redesign the performance of the healthcare system at the center. The simulation model was built using SIMPROCESS software. The modeling assumptions were as follows:

- All patients arriving on the waiting list are automatically included, regardless of the list's length, and they do not have the option to decline or withdraw.
- Patients are categorized into four distinct groups: pediatric care, general medicine, dental care, and physical therapy.
- Patient arrival times follow a Poison probability distribution.
- Although the service time is stochastic, it has a known average rate.
- The simulation run time is from 8:00 am to 2:00 pm.

The simulation model is built on the statistical data mentioned above on access, service time, and resource availability. Figure 4 provides a glimpse of the simulation model illustrating the healthcare system at the New Baghdad Polyclinic Center. The model is implemented using the SIMPROCESS software package to identify bottlenecks in the queues in the center. Validating the model involves comparing the simulation results with the actual data representing the patients served in the center. Following five replications, the simulation model yields an average of 303 patients served. According to the data in Figure 3, the actual daily average of patients was 297. With an error rate of 1.98%, as confirmed by the manager and staff at the center, which they deemed acceptable, it can be concluded that the model's behavior aligns with expectations and accurately reflects the real-life case study.

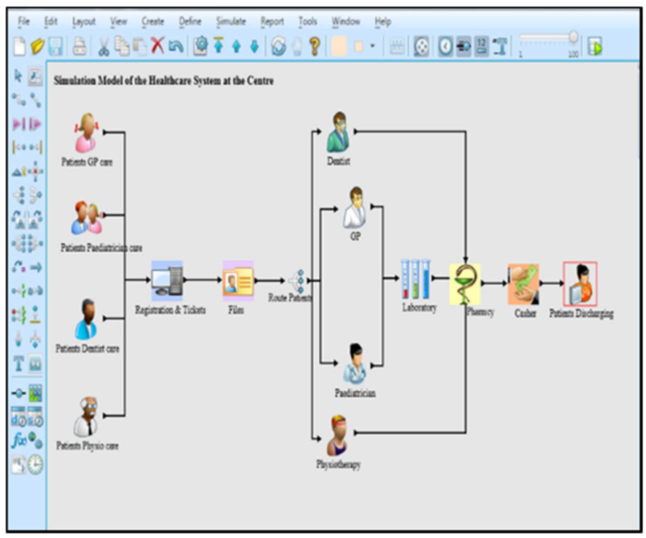

Fig. 4. Simulation model: The healthcare system of Baghdad Polyclinic Centre in SIMPROCESS.

A. Define Stage: Setting Performance Measures

In the first stage of DMAIC, to reflect the main objective, it is necessary to define performance measures. These measures are (i) to reduce waiting time, (ii) to increase resource utilization, (iii) to reduce care costs, and (iv) to reduce waiting costs. Thus, it is necessary to manage human resource requirements to provide an adequate level of services at a minimum cost. The goal is to increase productivity without expending additional capital and to reduce the costs associated with patient waiting as much as possible.

B. Measure Stage

The redesign process for the healthcare system started with analyzing and mapping the existing situation. This step is made via an "As-Is" model, where the simulation software package is used to model the existing processes to gain insight into the nature of a system or a process. In addition to visual display, the model provides outcome metrics for the process. This can help identify problems with system design, manage risk by making decisions, analyze the center's processes, and understand the costs in terms of waiting queues, place, and time.

C. Analyze Stage

Based on the parameters obtained from the Measure stage, and to comply with the Define stage objectives, this stage intends to provide the current system with a set of accurate improvement decisions.

1) Time and Resources Utilization Analysis

Figure 5 reveals notable waiting lists in the center, particularly for pediatricians, dentists, the General Practicioner (GP), and the pharmacy. Data indicate that adults, dental patients, and children endure a waiting time ranging from 1.5 to 2 hours to receive services. This duration appears to be relatively long compared to the time required for service delivery. Such findings suggest challenges within waiting processes presenting potential opportunities to improve scheduling and optimize resource distribution. Addressing these challenges could lead to reduced wait times and an overall improvement in patient experience. Targeted improvements may involve enhancing resource allocation, refining the service operations efficiency, and prioritizing patient punctuality.

The duration of waiting in queues at these stations is as follows: 111,829 minutes for the GP, 63,587 minutes for the pediatrician, 54,991 minutes for the dentist, and 15,696 minutes for the pharmacy. These waiting times are considered lengthy when juxtaposed with the actual service delivery time. Figure 6 shows the human resource utilization rate. Utilization rates for GPs, pediatricians, and dentists are notably high, indicating efficient utilization of resources and time, particularly during the morning hours with a half-hour break. Analyzing these data presents opportunities to enhance resource allocation and reduce waiting times, ensuring an optimal patient experience and increased service efficiency. The collected data underscore that patients predominantly spend a significant amount of time within the system awaiting service.

Moreover, the data show that waiting lists surpass the system's capacity. Consequently, the workloads at these facilities are exceptionally high, highlighting the urgent need to improve existing conditions. This analysis underscores the imperative for effective strategies to improve waiting processes and queue management. Prospective solutions include increasing resource usage efficiency, bringing in place logical scheduling techniques, avoiding unnecessary waiting, etc., and, more likely than not, refining the internal operations for better results. To ensure that the healthcare organization is effective and that its resources are utilized wisely at all times, proactive measures aim to prevent long waiting queues and other complications arising from delays in healthcare access.

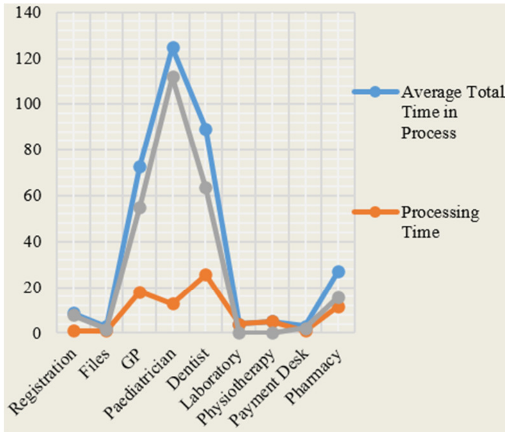

Fig. 5. Patient wait times at various service stations (min).

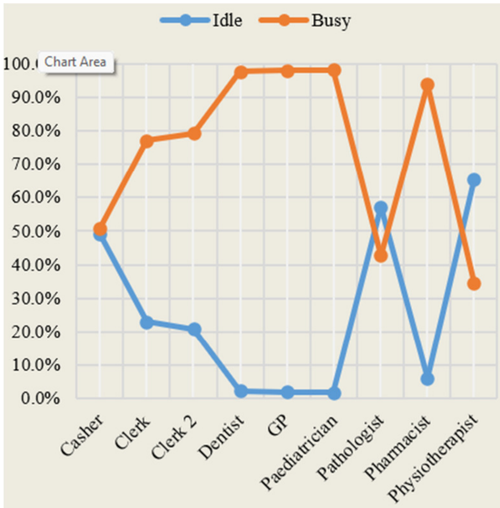

Fig. 6. Human resource utilization percentage at the center.

2) Cost Analysis

The time spent by people is now accountable to a measurement of waiting cost, as represented in Table I, where patients forfeit money due to delays in services in different care stations. The cost of a visit is determined based on the expected monthly income of the patient with a proportionate split in adult and pediatric segments. Adults are assumed to have a monthly income of $1,500 while mothers escorting their children are believed to earn $1,000 a month on average. These are the basic expressions obtained, which explain how the remaining costs of the healthcare center are calculated overall. Table I shows the detailed costs of waiting between the different stages of the process that the patient goes through.

TABLE I. DURATION OF PATIENT SERVICE ACQUISITION AT THE CENTER (IN MINUTES)

Patient Type	Average total time in the system	Service time	Waiting time
GP	118.76	34.27	84.49
Paediatrician	150.02	29.84	120.18
Dentist	140.36	43.55	96.81
Physiotherapist	50.77	17.75	33.01
Total	459.91	125.42	334.49

The first examination points to the crucial role that waiting plays on the patient, reflected in both time waste and additional expenses. This underscores the urgency to work on ways of reducing waiting times, as well as their duration, and to take steps toward the mere patient experience and address cost problems. When considering the expense estimates of patients, including adults and children, these costs look huge. It is crucial to emphasize that upon the treatment of each individual in the system, he indirectly participates in income generation by the health facility. Thus, it is assumed that each patient is worth $10 to the hospital on average. Many advantages can be gained by implementing measures on the waiting cost and upgrading service processes. This approach not only enhances the overall patient experience and alleviates the financial burden of waiting, but also increases system efficiency and the overall revenue stream. A cost and time analysis shows that a significant portion of patient time in the system is spent waiting for service. This defect is an inappropriate indicator of system performance, does not contribute to quality assurance, and is clearly a waste of time. Addressing this imbalance is essential to optimize system efficiency and improve overall patient experience.

D. Improve Stage

In this stage, the available resources are exploited to find a solution to the problem of waiting queues in the center. After exploring diverse scenarios and applying various assumptions to assess the impact of different modifications on patient waiting times, this study proposes a system to reduce the patient's time in the center from approximately 2.5 to 1 hour. The proposed improvements include two main changes: increasing staff, including adding pediatricians, dentists, and GPs, and adding a new pharmacy counter. The total waiting time for patients is significantly reduced when the clinic is operated by three pediatricians, three dentists, five GPs, and two pharmacy counters. This model is designated as "To-Be". Table II shows the results of the simulation model with these alterations. A comparison between the results of the To-Be and As-Is scenarios shows improvements in various indicators, such as the total number of patients treated, the time spent by patients in the system, and the distribution of workload among staff. Furthermore, the results demonstrate an improvement in the management and utilization of human resources available at the center, as shown in Figure 7. Implementing the To-Be scenario can reduce the time patients spend with the staff responsible for their care. This change is likely to boost staff productivity and reduce both patient waiting times and related costs. Based on the results derived from the To-Be simulation, enhancing the performance of the healthcare center requires hiring additional medical staff, including a GP, a pediatrician, a dentist, and an additional pharmacist. It is evident that the aforementioned adjustments, particularly the increase in the number of staff in the center, will yield positive effects by accommodating more patients for treatment. The processing cost under this modified configuration is $1,069.14, whereas the processing cost for the current As-Is model is $965.27. Assuming a patient service revenue of $10, the revenue for the To-Be scenario amounts to $2,650, compared to $2,180 in the As-Is scenario. Although there is an increase in costs resulting from hiring additional employees, the corresponding increase in revenue exceeds this expenditure.

TABLE II. RESULTS OF THE TO-BE SIMULATION MODEL FOR THE CENTER

Entity names	Total generated in the system		Patients remaining		Total processed		Improvement percentage
	As-Is	To-Be	As-Is	To-Be	As-Is	To-Be	
GP patients	107	110	31	10	76	100	20%
Dentist patients	46	46	21	12	25	34	20%
Paediatrician patients	105	110	53	23	76	87	6.7%
Physio patients	45	46	4	2	41	44	4.6%
Total					218	265	21.6%

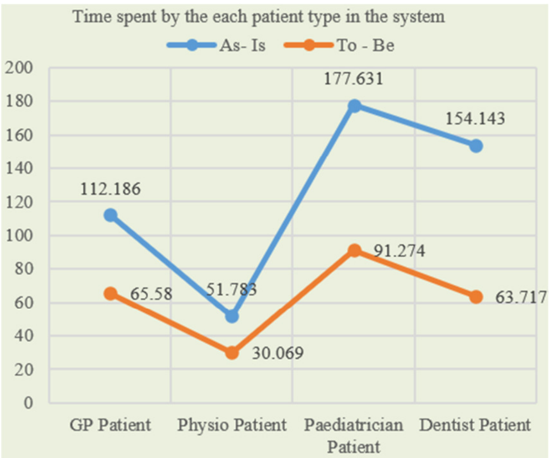

Fig. 7. The time spent by each patient type in the system.

E. Control Phase

The control phase involves implementing actions and establishing steps to ensure continuous improvement in the measurement process resulting from the implemented changes. This study faces uncontrollable limitations, as the proposed approach cannot be fully implemented after the COVID-19 pandemic ends due to financial constraints. The implementation of the proposed scenario is limited to the addition of a GP and a pharmacist. It was not possible to add a pediatrician and a dentist, as the technical equipment required exceeds the available budget. The center's top management has committed to fully implement the proposed approach once funding is available. It would not be particularly useful to detail the results of this partial implementation at this time.

VI. CONCLUSIONS

This paper tackles the issue of waiting queues in healthcare centers by employing an approach that integrates lean principles and simulation modeling. This study applied the LSS (DMAIC) procedure, consisting of five phases, along with a simulation model to analyze the current state of the healthcare system, as demonstrated in the case study center. Subsequently, the objective is to identify the optimal alternative to improve system performance. Data collection and analysis, facilitated by statistical methods, was the starting point of this endeavor. Subsequently, to reduce waiting time for patients and improve the center's overall performance, performance measures were adopted to track progress toward the established goals. To investigate bottlenecks in queues within the center and pinpoint potential causal factors, a simulation model was created using SIMPROCESS. When juxtaposing the actual data taken from the center's operational system with the results of the simulation model, the validity of the model was evaluated and approved as a reflection of the operational system adopted at the center. Comparison results revealed a slight variance between the simulation and the actual system operation.

Model validation was the first step in designing a simulation model that depicts the current center state, called the As-Is model. The simulation results from the As-Is model revealed persistent, extensive queues in the morning at GP, pediatricians, dentists, and pharmacy counters. Through analysis of the time extracted from the simulation results, it was determined that patients spend no less than an hour and can wait up to two hours in queues at these stations, representing an inefficient and unproductive use of time compared to the actual time required for the requested services.

A scenario was presented to assess the impact of the proposed improvements on the system to reduce waste time and enhance quality assurance. This scenario includes an additional GP, a pediatrician, a dentist, and a pharmacist. The results of the To-Be simulation model, incorporating the proposed improvements, indicate a quiet trade-off between the increased operating costs (as a result of the recruitment of additional staff and the establishment of another pharmacy counter) and the improved system performance, coupled with a reduction in patient waiting times. The system performance could potentially increase by up to 21% with the adoption of the proposed measures. Furthermore, these proposed improvements can lead to a substantial reduction in patient waiting times of approximately 50%. The proposed improvements could also lead to a more equitable balance in workload distribution among the center staff. Based on the results of the To-Be model, the proposed measures demonstrate a commendable performance enhancement, an equitable workload distribution, and a reduction in both patient waiting times and service costs. This approach, which amalgamates LSS and simulation modeling, showcases its ability to offer an informed decision-making pathway through simulated alternatives. This approach effectively contributes to mitigating unforeseen consequences and improving overall results.

Although this study focuses primarily on the primary healthcare setting, it has the potential to address issues related to human resource allocation plans and timelines in various other healthcare domains. Furthermore, the incorporation of a simulation tool enables a thorough and precise sensitivity analysis of system factors, presenting numerous possibilities for improvement and integration in diverse health contexts. Future research can focus on intervening in the implementation of industry 4.0 applications, specifically the Internet of Things (IoT), within the context of LSS applications, to effectively handle diverse information within a limited timeframe, a challenge that is becoming more prevalent in today's world.

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