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Research Article

A New Scenario-Based Simulation Model for Cost Management of Healthcare Services through Improving the Efficiency of the Health Centers

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There is a need for an appropriate decision-making approach and a precise costing method in order to make appropriate decisions that result in managing the resource utilization, improving the efficiency of healthcare systems and processes, increasing the patient consent, and reducing the costs of healthcare services. Therefore, this study is to develop a new method for estimating and reducing the services' costs by assessing the scenarios intended for the improvement of departments using time-driven activity-based costing (TDABC) and simulation model with conditions of uncertainty. To investigate the application of this method, the lithotripsy department of a kidney center has been studied and attempted to investigate the effects of different scenarios of scheduling the technicians' presence and scheduling patients' appointments, alongside the effects of controlling the factors of patient cancellation in different stages of the treatment process on lowering the healthcare costs and waiting time and on improving the hospital efficiency. The results showed that significant improvements in costs, waiting time, human resource utilization, and overall system efficiency were emerged. The impact of patient appointment scheduling scenarios on the abovementioned indexes was found to be far more than other scenarios. Furthermore, the results from the costs determined indicate a difference of 0.60, 0.61, 0.67, 0.67, and 0.63 percent between these costs and the costs determined by the traditional approaches. Such differences among the costs determined by these two approaches mainly occur due to different methods of allocating indirect costs and existence of uncertainty in the costs and time of therapeutic activities.

1. Introduction

The significant growth in healthcare costs has led to serious problems for the health system of countries; thus, controlling and managing these costs have become a fundamental necessity. The World Health Organization in 1989 estimated that about 40% of the resources that are available to the healthcare system were wasted. This indicates that a very significant amount of wasted resources could be obtained by savings through increasing the efficiency [1]. Many studies carried out in this area point to the fact that hospital resources, especially human resources, constitute a large share of healthcare costs; therefore, a significant cost reduction can be achieved through managing and controlling these resources [2–10]. This necessitates using appropriate tools to increase the productivity of hospital resources. In this case, discrete-event simulation (DES) is used as an efficient tool to optimize the allocation of scarce resources in order to improve patient flow, reduce the cost of healthcare, and increase the patient consent. Simulation is an imitation of the actual-world processes or system performance over time, and it can analyze and respond to the questions of "what will happen" and "if" about the actual-world scenarios [11]. It is very important to apply this tool along with a proper costing system, such as a TDABC system that can provide a significant share of managers' information needs in terms of resource managing and reducing the healthcare costs.

TDABC is a new cost management approach that facilitates the process of planning and controlling costs for hospital managers. This approach provides valuable information to identify nonvalue added activities, and it can be used to make decisions for improving the processes, better resource management, and reducing healthcare costs. Given that information of the TDABC system is presented in certainty conditions, its application in uncertainty conditions significantly decreases because the actual value of the input information required by this system (time, capacity, and cost) in uncertainty condition is not available; thus, it is usually estimated. Hospital managers need to understand how one can reduce the costs through improving the processes and service quality. Therefore, in order to achieve this goal, they are bound to make decisions based on information that are often available in uncertainty conditions. The use of fuzzy logic (FL) can usually resolve this problem and enhance the quality of information on the cost of the TDABC system [12]. This article presents a new model to estimate and reduce the cost of healthcare services through assessment of the improvement scenarios of health centers, which are based on the simulation method and FL-TDABC costing method, developed by Ostadi et al. [13]. By using these two methods in our proposed model, we can assess improvement scenarios of health centers and calculate the cost of changes made by each scenario; accordingly, a new model is developed to estimate and reduce the healthcare costs based on improving the efficiency of health centers, which includes the following motivation and novelty:

(1) Developing a scenario-based model to identify cost reduction opportunities by improving processes in health centers
(2) Developing improvement scenarios in health centers based on the simulation results and reviewing all the possible changes in the system
(3) Creating the possibility of assessing improvement scenarios for health centers through checking the cost of changes made due to each scenario
(4) Calculating the time needed to perform therapeutic activities based on repeated iterations of the simulation model with taking into consideration the uncertainty in activities' time
(5) Determining the practical capacity of the studied system in the form of triangular fuzzy number (TFN) based on a combination of the mean and the standard deviation of output data obtained from repeated iterations of the simulation model, including percentage of resource utilization and the fuzzy daily useful working hours (FDUT) of the system
(6) Calculating the cost of changes made by the improvement scenarios of the health centers using the FL-TDABC costing method by assessing the changes made by each scenario in the simulation model and determining the input information of the FL-TDABC system, including practical capacity of the system and activities' time in the form of TFN, through repeated iterations of the simulation model

The paper is organized as follows. Section 2 presents the theoretical bases of the research in four parts, including ABC, TDABC, and FL systems, and application of simulation in healthcare. In addition, the research background in each section is examined and new aspects of the present study are expressed. Then, Section 3 presents the new simulation-costing model for the healthcare services' costing based on improving the efficiency of health centers under uncertainty conditions. In Section 4, we test and discuss the proposed model, and finally, Section 5 presents the conclusion and provides some suggestions for future research on this topic.

2. Literature Review

2.1. Activity-Based Costing (ABC). ABC system is one of the recent systems for product and service costing, which was introduced by Cooper and Kaplan [14]. The system stems from the belief that products/services consume the activities and activities consume the resources. Therefore, in order to calculate the costs, ABC system determines the causal relationship between cost creation and activities needed to provide products and services that create economic value for the organization. As a result, information of this system can be used as a useful tool to manage the costs and determine the exact cost of healthcare services. In the field of healthcare, many studies have used the ABC methodology; some of the most important ones are mentioned in Table 1. Most of these studies have compared the costs determined by ABC with the approved tariffs for hospital services. The results of these studies demonstrate a significant difference between the costs provided by the ABC and the approved tariffs. In addition, many articles point to the fact that hospital resources, especially human resources and consumables, constitute a large share of healthcare costs; this fact necessitates hospital management paying special attention to resource management methods in order to control and reduce these costs.

2.2. TDABC. Since its introduction in 1980s, the ABC system resolved serious shortcomings and disadvantages of traditional costing systems. However, despite being very valuable, it is very difficult to implement and maintain an ABC system and such difficulties prevented this innovation from becoming an efficient and timely management tool [24, 25]. In order to resolve the problems of the ABC system, a new approach was introduced by Kaplan and Anderson, called TDABC [26]. The TDABC method is basically time-driven and its implementation method is completely different from that of the ABC method. The TDABC is simpler and less costly and runs faster than the ABC model. The TDABC uses an efficient framework, which needs only two sets, to perform the costing process: capacity cost rate and capacity consumption rate (in terms of time) [24, 27]. Given its features and advantages, the TDABC system has been used in different fields [28–33]. In the field of healthcare, many studies have used the TDABC methodology; some of the most important ones are mentioned in Table 1. In the

Table 1: A review of the previous studies on the applications of ABC and TDABC systems in healthcare.

References	Models	Objectives
[15]	ABC	Calculation of the cost of hematopathology laboratory services using the ABC method and comparing it with existing prices
[2]	ABC	Calculation of the cost of MRI services using the ABC method and comparing it with the approved tariffs
[3]	ABC	Calculation of the cost of dialysis in Shahid Sadoughi hospital and comparing it with tariffs
[4]	ABC	Calculation of the cost of eye surgeries using the ABC method and comparing it with approved governmental tariffs by the Ministry of Health
[16]	ABC	Healthcare services costing at a government hospital in India and evaluating physicians' performance based on cost parameters
[17]	ABC	Calculating the cost of services of Shahid Faghihi hospital in Shiraz using the designed ABC model and comparing it with the approved tariffs
[5]	ABC	Calculation of the unit cost of medical services as well as the cost price of occupancy bed-day of hospitalization in Kashani hospital in order to comparing ABC system and traditional costing method
[6]	TDABC	Calculation of the cost of total knee replacement (TKR) for each patient in the entire care cycle using the TDABC model and comparing it with tariffs, as well as considering cost reduction strategies for the patient treatment
[8]	TDABC	Comparison of the costs associated with (1) primary total hip arthroplasty (THA) and (2) primary total knee arthroplasty (TKA) as measured using TDABC versus traditional hospital accounting (TA) and also the evaluation of the impact of various processes on surgical costs by comparing the cost of three different surgeons
[18]	TDABC	Investigating the differences between resource consumption accounting (RCA) and TDABC systems in determining open and laparoscopic gallbladder surgeries costs for a one-year and long-term period
[19]	TDABC	Calculation of hip and knee arthroplasty costs in two hospitals with different logistical set-ups and comparing them with each other and with the calculated costs of fast track
[10]	TDABC	Calculation and comparison of seven treatment costs for prostate cancer based on the TDABC methodology from the initial urologic visit through 12 years of follow-up
[20]	TDABC	Calculation and analysis of the cost of pharmaceutical services in order to improve the management of public pharmacies and promote the drug policies through calculating and analyzing the cost structure of pharmaceutical services at three pharmacies in the city of Lisbon, Portugal using the TDABC model
[21]	TDABC	Implementation of a tariff system using the TDABC model to calculate the cost of home care services based on the amount of resources consumed at each level of complexity of the patient
[22]	TDABC	Implementation of TDABC in a clinic to investigate the relationship and management effects of a TDABC in outpatient clinics (examining the impact of advice specialization and the utilization of activities and equipment on clinical costs)
[9]	TDABC	Identifying the inefficiencies and cost-reduction opportunities in pediatric appendectomy by applying TDABC methodology to this high-volume surgical condition
[23]	TDABC	Improving access to cancer genetics service using quality improvement methods and TDABC by increasing the clinic capacity of the cancer genetics service without increasing direct personnel costs
[7]	TDABC	Development of a conceptual model from TDABC at a cancer center to calculate the cost of three types of specific cancer (oral cavity, pharynx and larynx) in the entire care cycle

reviewed articles, the use of ABC and TDABC systems for the costing of healthcare services in different countries has been mentioned that indicates the widespread use of these systems in the healthcare sector. Despite this issue, less attention has been paid to evaluation and improvement of the hospitals' performance, especially through developing the capability of these methods by combining them with other techniques such as simulation or other techniques of process analysis and improvement [34]. Moreover, most studies on healthcare costing have accounted hospital resources, especially human resources and consumables, as a large share of the total cost of healthcare services; however, not much attention has been given to reducing these costs through improving resource efficiency. Therefore, in the present study, using TDABC plus simulation approach, we have tried to develop a method for costing the healthcare services based on improving the efficiency of hospital resources. What is certain is that, so far, no study in this field has been carried out with aforementioned approach. As mentioned before, for this study, we collected our data from the lithotripsy department of a kidney center. Furthermore, no study has been conducted to date neither on the calculation of the costs of treating kidney stones using extracorporeal shock wave lithotripsy (ESWL), nor on reducing these costs by improving the efficiency of the processes and resources of the lithotripsy department using the aforementioned approach.

2.3. Fuzzy Set Theory. Fuzzy set theory was introduced by Zade in 1965 [35]. The fuzzy set is expressed based on the membership function, which includes a set of elements with different degrees of membership in the set. The membership function $\mu(x)$ included the membership degree of the element x in the fuzzy set, which belongs to interval [0, 1]. Among various forms of fuzzy numbers, TFN is more popular. The triangular fuzzy number A is determined by three parameters as follows. Parameter a_M represents the highest expected value and a_S and a_L represent the smallest and the largest possible values, respectively. The membership function of the triangular fuzzy number A, which is shown by $\mu_A(x)$, is defined as follows:

$$\mu_A(x) = \begin{cases} \dfrac{x - a_S}{a_M - a_S}, & a_S \le x \le a_M, \\ \dfrac{a_L - x}{a_L - a_M}, & a_M \le x \le a_L, \\ 0, & \text{otherwise}. \end{cases} \tag{1}$$

The fuzzy set has been used in many fields, including, engineering economics [36], cost-benefit analysis [37], project selection [38], capital budgeting [39, 40], and supply chain planning [41]. The fuzzy set was first used by Nachtmann and Needy in 2001 for investigating the uncertainty conditions in the ABC system, which in turn led to introduction of the new FABC system [42]. Then, many scholars used the fuzzy set method to take into account the uncertainty in ABC and TDABC systems in various fields. In Table 2, some of the most important studies of this kind are discussed. The results of these studies showed that application of fuzzy logic in ABC and TDABC systems improved the ability of such systems in reducing the uncertainty and complexity in various industries, especially healthcare industry and led to increase in the capability of ABC and TDABC systems in dealing with conditions of uncertainty.

2.4. Application of Simulation in Healthcare. Simulation is a comprehensive approach that is being used for decades in different fields, including manufacturing, commerce, transportation, and healthcare industry [51, 52]. This method is used to study virtual models and to evaluate the performance of a dynamic system during a specified period of time [53]. In recent years, the application of simulation in the healthcare field has grown exponentially; among the main reasons for this issue are the increasing complexity of healthcare systems, the great capabilities of simulation in modeling the complex and uncertain systems and the remarkable progress of simulation software [54, 55]. The main objective in application of simulation studies in the field of healthcare has been reducing the waiting time and the length of stay (LOS), improving the services for patients, making better use of resources, and finally reducing operating costs [56, 57]. Many studies have focused on these issues; some of the most important ones are mentioned in Table 3. Most simulation studies have targeted the emergency department of hospitals. The reason behind this issue is that there are many problems in this department, such as congestion, lengthy waiting times, lack of space, and lack of human resources. In general, simulation models used to analyze healthcare systems are mainly focused on two areas: (1) optimizing patient flow in different departments of the hospital aims at optimizing the patient discharge volume and reducing the waiting time and (2) allocating resources to improve the utilization of resources. According to the literature, no study to date has addressed reducing the waiting time and improving the processes of kidney stone treatment using ESWL. Owing to the high allocation of resources to this unit of kidney diseases treatment, it is necessary to take appropriate actions to properly plan resource utilization and improve the therapeutic processes in this department in order to reduce the cost of services. Besides, another aspect of this study that has not been addressed in previous studies is investigating some cases in order to reduce patient cancellation rate of this department which is a key factor in maintaining patient satisfaction. In addition, reducing the cost of healthcare services based on improving the efficiency of hospital resources as one of the main objectives of this study is somehow neglected in previous studies. In other words, previous studies have often focused on a single index or they have merely introduced different scenarios. Likewise, in previous research the waiting time has mostly been the basis of scenario selection and little attention has been paid to cost as an index for selecting scenarios. In this study, firstly by modeling and simulating the system under study, secondly by assessing different scenarios that were intended to reduce the cost of healthcare services based on improving the efficiency of hospital resources, and finally by ranking these scenarios based on cost and time indexes, we attempted to identify and establish the priority change of the scenarios as the basis of determining the cost of healthcare services.

3. The Simulation-Costing Model in Healthcare

This study employs the simulation method and FL-TDABC costing system to present a new scenario-based model to estimate and reduce the cost of healthcare services through improving the efficiency of the health centers. For costing under uncertainty conditions, this model uses the FL-TDABC method, which is developed by Ostadi et al. [13]. The model presented in this study can evaluate the improvement scenarios of health centers and calculate the cost of changes made by each scenario. In this model, we investigate the changes resulted from each improvement scenario in the simulation

Table 2: Application of fuzzy logic in activity-based costing systems.

References	Models	Objectives
[42]	Fuzzy activity based costing	Estimation of ABC model parameters and considering the uncertainty in it, as well as comparison of two FABC and traditional systems for costing products of a pharmaceutical company
[43]	Interval mathematics, Monte Carlo simulation, fuzzy set theory	Developing and comparing methods for handling uncertainty in the ABC system to calculate the cost of a software company's products in uncertainty situations
[12]	Traditional (TABC), fuzzy (FABC), and Monte Carlo (MCABC)	Comparing these systems with each other to calculate the cost of a medical center
[44]	Fuzzy activity based costing (FLABC)	Reducing complexity and uncertainty in the ABC system by identifying appropriate cost drivers
[45]	Fuzzy activity based costing (FABC)	Determining the cost of services in conditions of uncertainty using the FABC system and comparing it with the traditional method
[36]	A combined modelling of FABC and value chain	Evaluation of the influence of investment in information technology on cost of value chain activities using fuzzy logic and ABC method in a manufacturing company
[46]	Fuzzy time-driven activity-based costing (Fuzzy-TDABC)	Calculation of the exact cost of products of a manufacturing company with uncertain resource costs using the fuzzy-TDABC model and comparing it with the TDABC model
[47]	Fuzzy time-driven activity-based costing (FTDABC)	Introduction of the new FTDABC model for estimate the time more accurately and reduce error coefficient as a cost driver by using fuzzy logic
[48]	Fuzzy time-driven activity-based costing (FTDABC)	Introducing a new mechanism for TDABC using fuzzy logic to estimate costs in uncertainty situations
[49, 50]	Fuzzy TDABC	Calculation of the cost of accessing spatial data based on fuzzy logic and TDABC method in the context of an NSDI
[13]	FL-TDABC in healthcare	Developing a combined modelling of fuzzy logic and TDABC for hospital services costing under uncertainty conditions

Table 3: Applications of simulation in healthcare.

References	Data sources	Objectives
[58]	Cardiothoracic surgery	Investigating the reduction of patient waiting times and the removal of resource constraints by enhancing the schedule and reallocating capacity
[59]	Obesity center	Identifying the impact of capacity changes in resources and patient referral rates on the waiting time and waiting list of obesity patients
[60]	Multispecialty outpatient clinic	Development of a DES model for analyzing the patient admission process to reduce waiting time and the number of phone calls unanswered
[61]	Ultrasound department	Reducing waiting times for patients and unemployment time for doctors in the appointment scheduling system using combined mathematical programming and simulation optimization procedures
[62]	Outpatient clinic	Investigating the impact of various appointment schedules for patients on key performance indicators such as unemployment time and overtime of doctors and waiting time of patients
[63]	Outpatient chemotherapy department	Reviewing patient appointment scheduling policies to reduce waiting times for patients and improve resource utilization
[64]	Accident and emergency department (AED)	Improving the accident and emergency department (AED) service quality by reducing waiting times for patients and enhancing the efficiency of emergency operations
[55]	Emergency department	Developing an integrated simulation model using DES with an approach to system dynamics (SD) in order to reduce waiting times for patients, improve the flow of emergency patients, and analyze the implementation of a fast track strategy (FT)
[65]	Neonatal intensive care unit (NICU)	Planning and predicting the number of nursing staff needed in a NICU
[66]	Orthopedic surgery department	The surgery scheduling of patients in the orthopedic surgery department using DES and integer programming with the aim of using the operating rooms' time and minimizing the make span in order to provide the best allocation of patients to the operating rooms (ORs)
[67, 68]	Outpatient orthopedic clinic	Identification and evaluation of improvement alternatives such as optimizing staff levels and better patient scheduling in order to reduce waiting time, lot of stay, and the end (time) of the total visit of patients
[69]	Surgical center	Investigating the impact of various scheduling planning of both point-by-point (PBP) and anatomically-designed (AD) procedures in the treatment of atrial fibrillation on resource consumption, average cost, and OR utilization
[70]	Emergency department	Simulation with DEA and ABC method in order to evaluate the impact of human resource allocation scenarios on patient waiting time, nursing staff productivity improvements and costs
[71]	Emergency department	Simulation combined with optimization in order to determine the optimal number of physicians, laboratory technicians and nurses required to maximize patient throughput and to reduce patient waiting time
[72]	Outpatient patients	The economic evaluation of doripenem antibiotics compared with imipenem for the treatment of nosocomial pneumonia in the criteria such as the rate of disease recurrence, seizure rates, mortality rate, hospital costs, and duration of stay of patients
[73]	Orthopedic surgery department	Simulation combined with ABC method to compare resource costs, efficacy of both virtual fracture clinic (VFC) and traditional fracture clinic (TFC) with the aim of improving the care and treatment of orthopedic patients

model, then after repeated iterations of the model, the simulation outputs, which are inputs of the FL-TDABC costing system, will be used to determine the practical capacity of the system and activities' time in the form of TFN. This way, the new model can calculate the cost of changes made by each scenario and, thus, evaluate the scenarios based on these cost calculations. The proposed model can be employed as follows: we use the sum of data of the therapeutic activities' time and the practical capacity of the system, which are obtained from the outputs of the simulation runs, as a combination of mean and standard deviation, to determine TFN required for the FL-TDABC model to calculate the cost of changes made by each scenario. Figure 1 shows the proposed approach compared to the TDABC model.

3.1. Stage 1: Identifying the System under Study and Creating a Conceptual Model. In the first stage of the model, the system under study is investigated to identify its method of providing healthcare services. This means that processes and activities as well as their sequences, the way of doing the required activities for providing the healthcare services, etc., are examined. At this stage, a conceptual modeling that contains documented processes of the system under investigation is carried out and the preparations for designing a simulation model are made.

3.2. Stage 2: Identifying Resources, Estimating Activities' Duration and Collecting the Cost Data. This phase is focused on data collection. The collected data includes resources used for activities carried out by healthcare provider and their costs and time spent on doing each activity by each source. In this stage of the model, all costs associated with the system under investigation, including the costs of human resources, consumables, and equipment are identified.

3.3. Stage 3: Creating the Computer Simulation Model. At this stage, programming or creating a computer simulation model for the conceptual model is carried out. The identified processes are modeled and simulated by computer software. Furthermore, this model which is created based on statistical distributions obtained from the previous stage, will be completed and implemented, also the results of its implementation will be analyzed.

3.4. Stage 4: Verification and Validation of the Model. After creation of the simulation model and its initial implementation, verification and validation of it are carried out using different methods. The aim of this stage is to assure that the conceptual model is accurately reflected in the simulation model and that simulation model can accurately represent the real system.

3.5. Stage 5: Developing Performance Improvement Scenarios for the System under Study. Following the implementation of the simulation model, the performance improvement scenarios of the system under study are determined based on simulation results and expert opinions to reduce the cost of healthcare services, reduce the waiting time, and improve the hospital efficiency. (In this phase, simulation software is used along with Matlab software to create the intended scenarios that are discussed in the following section.)

3.6. Stage 6: Estimating the System's Fuzzy Practical Capacity (FPC). At this stage, after executing each of the proposed scenarios, the practical capacity of the system under study is created for each scenario in the form of TFN. In this case, the outputs of simulation iterations are processed in Matlab software to result in TFN. Simply put, the total data related to the useful working hours of the system obtained from the output of the simulation model are used to determine TFN based on a combination of mean and standard deviation calculated in Matlab software. In this model, TFNs are formed based on the following rule; if there is a dataset with a mean of μ and a standard deviation of σ, with a probability of 99%, the data will lie within three standard deviations (left and right) of the mean. Upon completion of the method, the daily useful working hours of the system are determined in the form of TFN. FDUT_S, FDUT_M, and FDUT_L represent, respectively, the smallest, the most probable, and the largest daily useful working hours of the system under study. The practical capacity of the system is calculated based on the occupancy percentage of each resource, as well as the system's daily useful working hours, as follows. The fuzzy practical capacity is shown with three values including FPC_S, FPC_M, and FPC_L, which are, respectively, the smallest possible value, the most probable value, and the largest possible value for the system's fuzzy practical capacity.

$$\text{FPC} = \left(\text{FPC}_S, \text{FPC}_M, \text{FPC}_L\right) = \left(\sum_{i=1}^{r} \text{FDUT}_S * \text{AWY} * \text{OPR}_i, \sum_{i=1}^{r} \text{FDUT}_M * \text{AWY} * \text{OPR}_i, \sum_{i=1}^{r} \text{FDUT}_L * \text{AWY} * \text{OPR}_i\right). \quad (2)$$

In this regard, AWY represents the average number of useful working days of the system per year that is determined by subtracting the holidays from the total days of the year. Also, OPR_i represents the occupancy percentage of the resource i per day that is resulted from the output of the simulation model. Furthermore, r is equal to the number of existing resources in the system.

3.7. Stage 7: Calculating the Fuzzy Capacity Cost Rate (FCCR). Capacity cost rate is calculated by dividing the total costs of the system under study by its practical capacity. The numerator includes all the costs associated with the system which are determined in the second stage of the proposed model. The denominator includes the practical capacity of those resources required to perform the activity, which was

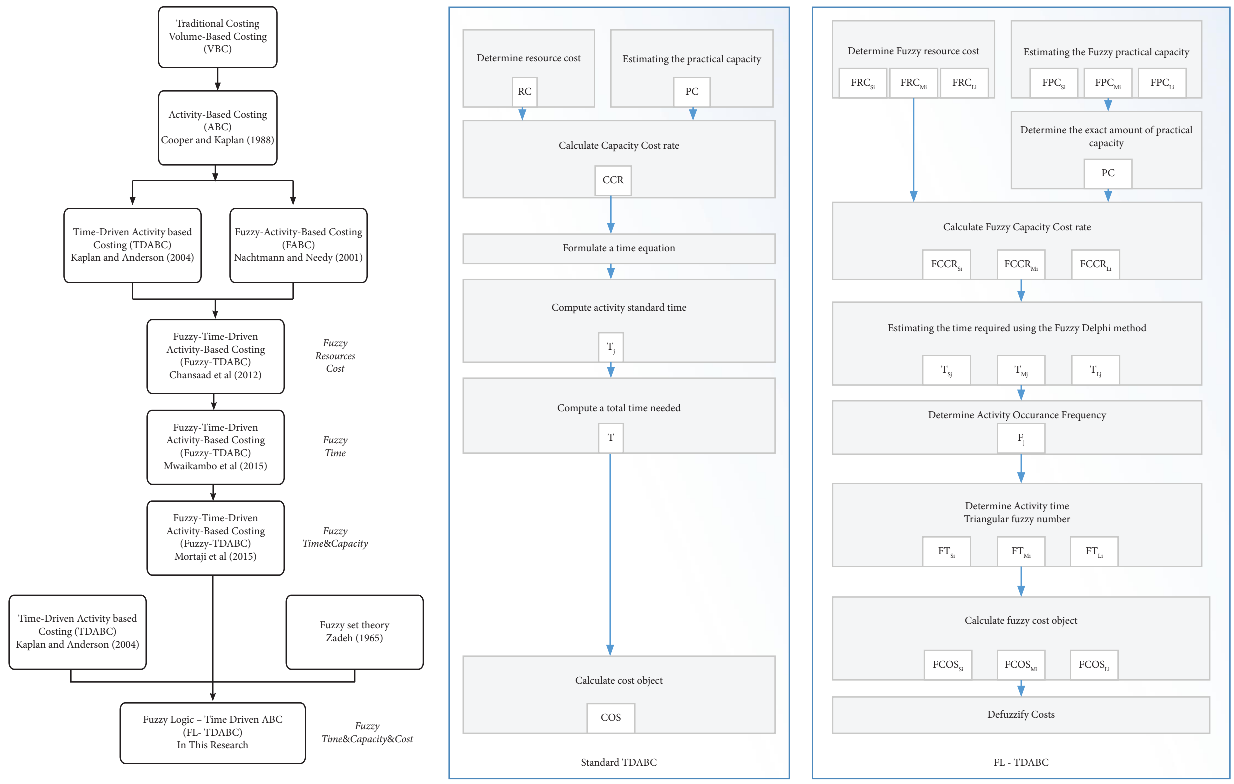

FIGURE 1: Comparison of simulation-costing model with standard TDABC model.

calculated in the previous stage. The smallest possible ($FCCR_{Sj}$), the most promising ($FCCR_{Mj}$), and the largest possible value ($FCCR_{Lj}$) of FCCR of the cost source j is calculated through the following equation:

$$FCCR_j = \left(FCCR_{Sj}, FCCR_{Mj}, FCCR_{Lj}\right) = \left(\frac{RC_j}{FPC_S}, \frac{RC_j}{FPC_M}, \frac{RC_j}{FPC_L}\right). \tag{3}$$

In this equation, RC_j represents the total cost of the source j, which was determined in the second stage of the proposed model.

3.8. Stage 8: Determining the Fuzzy Time Required for the System Activities (FT). At this stage, the method presented in stage 6 is used to determine the time required for the completion of system activities in the form of TFN. The time parameter in the proposed model is shown with three values, including the smallest possible value (FT_S), the most promising value (FT_M), and the largest possible value (FT_L), which are obtained through the total time of all activities within the system that is estimated by fuzzy set method.

$$FT = \left(FT_S, FT_M, FT_L\right) = \left(\sum_{k=1}^{n} AT_{Sk} * F_k \sum_{k=1}^{n} AT_{Mk} * F_k \sum_{k=1}^{n} AT_{Lk} * F_k\right). \tag{4}$$

In this equation, AT_{Sk}, AT_{Mk}, and AT_{Lk} represent the smallest, the most probable, and the largest time needed to perform activity k, respectively. F_k represents the number of occurrences of activity k and FT represent the total time of n activity within the system.

3.9. Stage 9: Calculating the Fuzzy Cost of Services (FCOS). At this stage, the cost of each service is obtained according to equation (5) by multiplying the total estimated fuzzy time of the system activities (FT) associated with the intended service by the fuzzy capacity cost rate of each cost source

($FCCR_j$). In this equation, $FCOS_S$, $FCOS_M$, and $FCOS_L$, respectively, represent the smallest possible, the most probable, and the largest possible amount of the cost of the intended service. Given the point that the "capacity cost rate" and "time required to perform activities" are shown by TFN, there will be nine different modes that will be examined based on the cost parameter in three different relationships equations (6)–(8). For example, one relationship is for a mode in which the capacity cost rate is in optimistic condition (smallest possible) and time is in three conditions of optimistic ($FCOS_{SS}$), moderate or most possible ($FCOS_{SM}$), and pessimistic or largest possible ($FCOS_{SL}$), respectively. This mode determines the values for the smallest possible value for the final cost of services ($FCOS_S$).

$$FCOS = (FCOS_S, FCOS_M, FCOS_L), \quad (5)$$

$$FCOS_S = (FCOS_{SS}, FCOS_{SM}, FCOS_{SL}) = \left(\sum_{j=1}^{s} FCCR_{Sj} * FT_S, \sum_{j=1}^{s} FCCR_{Sj} * FT_M, \sum_{j=1}^{s} FCCR_{Sj} * FT_L\right), \quad (6)$$

$$FCOS_M = (FCOS_{MS}, FCOS_{MM}, FCOS_{ML}) = \left(\sum_{j=1}^{s} FCCR_{Mj} * FT_S, \sum_{j=1}^{s} FCCR_{Mj} * FT_M, \sum_{j=1}^{s} FCCR_{Mj} * FT_L\right), \quad (7)$$

$$FCOS_L = (FCOS_{LS}, FCOS_{LM}, FCOS_{LL}) = \left(\sum_{j=1}^{s} FCCR_{Lj} * FT_S, \sum_{j=1}^{s} FCCR_{Lj} * FT_M, \sum_{j=1}^{s} FCCR_{Lj} * FT_L\right). \quad (8)$$

In this equation, s is equal to the number of existing cost sources in the system under study.

3.10. Stage 10: Determining the Precise Cost of Services (COS). At this stage, fuzzy outputs related to the cost of each service will be defuzzified by equation (9) in order to determine the final cost of services. This study uses the center of gravity (COG) method for defuzzification, which is one of the most common methods to convert fuzzy numbers to definitive values (equation (9)). This can also be achieved by calculating the mean of triple values of TFN, which is used in formation of the relationships 10 to 13 [74].

$$x^* = \frac{\int \mu(x).x\,dx}{\int \mu(x)dx}, \quad (9)$$

$$COS = \left(\frac{FCOS_S + FCOS_M + FCOS_L}{3}\right), \quad (10)$$

$$COS_S = \left(\frac{FCOS_{SS} + FCOS_{SM} + FCOS_{SL}}{3}\right), \quad (11)$$

$$COS_M = \left(\frac{FCOS_{MS} + FCOS_{MM} + FCOS_{ML}}{3}\right), \quad (12)$$

$$COS_L = \left(\frac{FCOS_{LS} + FCOS_{LM} + FCOSL_{LL}}{3}\right). \quad (13)$$

3.11. Stage 11: Assessing System Performance Improvement Scenarios Based on Time and Cost Indexes. This stage of the proposed model is dedicated to the repeated executions of the simulation model and their analysis for the purpose of estimating the performance indexes of the scenarios that are simulated. At this stage, various scenarios using simulation software and TDABC method, in accordance with the abovementioned stages are analyzed and assessed with regard to time and cost indexes.

3.12. Stage 12: Ranking the System Improvement Scenarios and Determining the Final Cost of Services Based on the Selected Scenario. In the final stage of the proposed model, the results of scenarios' assessment based on time and cost indexes are investigated, and accordingly, scenarios will be ranked. Then, the best scenario that has the most favorable results in most of the indexes is selected and will be regarded as the basis for changes. Finally, the cost of healthcare services that were studied and estimated based on the selected scenario will be discussed and compared with the current costs. (Matlab software is used at this stage to study this issue. The method of ranking and selecting the top scenarios are discussed in the following section.)

4. Case Study

In this section, the application of the simulation-costing model is demonstrated in a case study. For this purpose, we used the data collected from lithotripsy department of a kidney center. The data required for this study were collected in the period from September 2017 to May 2018. The aforementioned department has four staffs including a lithotripsy technician, an anesthesiologist, a secretary, and an orderly. Three lithotripsy technicians work in this department that based on a predetermined schedule are present at different times of the week.

4.1. Results of the Simulation-Costing Model in Healthcare

Stage 1. The conceptual model that contains the documented processes of the system under study is created in the first stage of the proposed model. At first, the patient flow and its related services were investigated through interviews with the staff and observation. Then, the patient arrival status and treatment processes were studied.

Stage 2. At this point, time information related to the therapeutic activities as well as resources used for activities done by healthcare provider and their costs were identified. Cost source associated with the lithotripsy department are identified. Information about the times of these activities were collected by stopwatch time study technique in specific forms. Other information about patient arrival time and how they arrived was collected from hospital information system. Information on consumption costs of the lithotripsy department was obtained from financial and accounting departments of the hospital. Input analyzer software was used to examine the probability distribution of each activity. It should be noted that depending on the type of technicians, time distributions vary for some activities. In addition, depending on the type of patient, such a difference exists in most of the time distributions which are considered in the simulation model separately.

Stage 3. A computer simulation model of the conceptual model was created at this stage of the proposed model. Arena simulation software was used for computer modeling. In order to clarify the modeling process, the computer model is described in three parts, including patient arrival, treatment process, and patient discharge.

4.1.1. Patient Arrival. Patients who enter the hospital are either outpatient or inpatient. Outpatients are divided into two categories: adult and pediatric patients. After patients' arrival, their profile, condition, and history of illness are assessed by the department's secretary. Then, if patients are prepared for the operation, according to their type, they will be prioritized and added to operation queues. Generally, the pediatric patients will enjoy a higher priority than other patients.

4.1.2. Treatment Process. After identifying the type of patient, if there is at least one empty bed in the recovery room, the patient will be guided to the next stage of the process. In this model, depending on the type of patients and their conditions, waiting queues are considered different. After allocation of the bed, if technician and anesthesiologist are not busy, the patient will be transferred to the lithotripsy room and he/she undergo examination, diagnosis, and ESWL processes. In this model, when each patient's turn comes, depending on the current time of the system, he/she will be treated by technician 1, 2, or 3. Upon completion of these stages, technician provides the necessary postoperative instructions to the patient's attendant, then the patient is transferred to the recovery room by an orderly.

4.1.3. Patient Discharge. At the end of the process, when ESWL operation is completed, the patient will be transferred to the recovery room and stays there until anesthetic symptoms fade away. The recovery time distribution depending on the patient type varies. Inpatients do not need recovery; thus, only in case of waiting to be transferred to the intended department, they will be transferred to the recovery room for a short time. Pediatric patients, as for their particular conditions, usually spend more time in recovery room.

4.1.4. Running the Simulation Model. After creating the simulation model and loading it with probability distributions of activities' time, the completed model was run in 50 iterations based on the technicians' schedule in different shifts and days of the week for each working day.

Stage 4. After building and running the simulation model, it was verified and validated using different methods. During the simulation process, that is to say, the stages of system identification and conceptual modeling, patient flow process was constantly investigated with the help of those working in our research environment. Among other issues that contributed to verify the computer model was a step-by-step investigation of the patient flow. Furthermore, the outputs of the model were compared with actual results (Table 4). As it is shown, there is no significant difference between simulation model results and actual results. Another change applied for the purpose of model validation was the change in the patient arrival rate. As an example, we increased the interval between patients' arrival. With this change, it was obviously expected that the patient discharge volume, waiting time, and utilization percentage of resources would reduce.

Stage 5. After running the simulation model, based on the simulation results and expert opinions, performance improvement scenarios were determined for the system under study. First, we reviewed different scenarios of changing technicians' work schedules. In this category of scenarios, the appropriate allocation of technicians to different shifts and days of the week was discussed. In doing so, we first prioritized different days of the week based on their congestion rates, and then the ability of each technician on different days of the week was investigated. By so doing, we wanted to allocate technicians with higher ability to busier days for the purpose of improving the performance indexes of the system under study. In order to measure how much different days of the week are crowded, several tests were performed based on various indicators, such as the average number of discharged patients at 14, 16, 24, and 48 hours with no arrival limit, the frequency of number of discharged patients more than the third quartet at 14, 16, 24, and 48 hours with no arrival limit, the frequency of the number of days with end (time) of service provision is greater than

Table 4: Comparison of the results of the simulation model with actual data.

Performance index / Week days		Average number of discharged patients	Average number of cancelled patients per day	Average waiting time in the system	Average time spent in the system
Saturday	Act	19.62	2.67	5987.23	9326.98
	Sim	19.64	2.8	6227.68	9428.29
Sunday	Act	20.14	2.33	6971.86	10538.27
	Sim	21.08	2.72	6858.29	10338.01
Monday	Act	19.3	3	5401.6	8745.33
	Sim	19.48	3.16	5532.23	8855.31
Tuesday	Act	20	2.75	4872.83	8281.897
	Sim	20.36	2.44	5195.52	8509.1
Wednesday	Act	19.9	2.2	5302.76	8471.368
	Sim	19.72	2.8	5619.05	8880
Thursday	Act	15.75	2	5728.4	8813.231
	Sim	16.76	2	5479.01	8347.22

19, 18 : 45, 18 : 30, 18, 17 : 30, and 17 with a maximum of 25 incoming patients, the average waiting time of patients for 15 working hours with a maximum of 25 incoming patients, and the average time spent in the system for 15 working hours with a maximum of 25 incoming patients in 50 iterations of the simulation model. By reviewing these figures, Sunday was found to be the busiest and Thursday was concluded as the quietest day of the week. The ranking of different days of the week based on congestion is as follows: Sunday, Saturday, Wednesday, Monday, Tuesday, and Thursday.

After examining the abovementioned cases, the ability of each technician in different shifts and days of the week was evaluated based on similar indicators in 50 iterations of the simulation. By examining these cases, technician 1 demonstrated the best performance overall with respect to various indicators and technicians 2 and 3 were ranked after him, respectively. Based on these results and according to the ranking of different days of the week with regard to congestion, best possible schedules for each technician's presence on different days of the week were identified. By preliminary results, Saturday was assigned to technician 1; and, Sunday, Monday, and Thursday were assigned to technicians 1 and 2. Furthermore, other days were assigned to technicians 1, 2, and 3. Subsequently, based on the abovementioned schedules and considering the total time limit for technicians' presence on different days of the week (technician 1 could only attend three shifts, while technicians 3 could attend two shifts) and the ability of each technician on different days of the week, possible schedules for the presence of technicians in different shifts and days of the week were determined. Based on what stated before, all possible schedules for the presence of technicians were determined. Based on the results and using Matlab software, a total of 36 different schedules for the presence of technicians on different shifts and days of the week determined which is presented the first and second scenarios for the example in Table 5.

In scenarios of the second category, determining the best schedule for patient arrival was targeted. In this category, a total of 32 scenarios were considered for patient arrival rate. Each scenario included a uniform time distribution between 0 to 60 minutes at intervals of 5 minutes. According to this, all possible conditions of patient arrival were studied. Also, at this stage, based on assessment of the abovementioned scenarios, 15 other scenarios were proposed. These scenarios represent a combination of the abovementioned scenarios plus overtime work for patient admission. After executing these 32 scenarios, for those scenarios that were not able to manage the maximum number of arriving patients (25 patients) by following the time distribution of this study and the timing of patient admission (that every day continues till 13 : 45, except Thursday that ends at 11 : 00), we increased the working time for patient admission to re-evaluate their results by indexes, such as the number of discharged patients. By applying these changes, some of these scenarios required more time than the predefined maximum time (15 hours) to provide services for all the admitted patients (25 patients); hence, since these categories of scenarios were not practical, we excluded them. Some instances of such scenarios are scenarios 34, 35, 39, and 42.

Those scenarios belonging to the third category are related to the investigation of the factors reducing the patient cancellation rate. The possibility of patient cancellation exists in three stages of the treatment process, namely, admission, examination, and diagnosis. Cancellation factors of admission and examination stages are mostly related to the patient's lack of knowledge about the preoperative preparations for the lithotripsy operation. Some cases that lead to the cancellation of the treatment process at the admission and examination stages are as follows: problems with taking drugs such as aspirin, those that are taken for cold, fever, and chills, inadequate medical tests, presence of comorbidities, such as respiratory and cardiovascular diseases, high blood pressure, infection, etc. Therefore, controlling this factor by informing the patients before operation can reduce the patient cancellation rate. It should be noted that the patient constellation at the diagnostic stage is related to failure in detection of the stone's exact location by ultrasonography or x-ray; nonetheless, examining these cases is beyond the scope of this study. It is worth

Table 5: Scheduling scenarios for presence of technicians at different shifts and days of the week.

Week days		Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
Scenario 1	Shift 1	1	1	2	2	3	2
	Shift 2	1	2	2	2	3	2
Scenario 2	Shift 1	1	1	2	2	2	2
	Shift 2	1	2	2	3	3	2

mentioning that the abovementioned information was obtained by examining the recorded observations on patient cancellation factors during the therapeutic procedures. After the experts' comments on this information we identified the most important causes of patient cancellation; also, patients' lack of knowledge about abovementioned cases was identified as the main patient cancellation cause.

Stage 6. At this stage, by executing each of the proposed scenarios for different days of the week and based on the results obtained from Matlab software processing, useful working hours of the system per day was obtained in the form of TFN for each scenario. Then, the system's practical capacity based on the equation (2) was determined. In this equation, AWY is 291 days. OPR_j was also obtained from the simulation model output. In this section, for the sake of clarification, we show how the cost of lithotripsy operation (stages 6 to 11 of the proposed model) based on the data derived from the current state of the system, is determined.

Stage 7. At this stage, the FCCR was determined by dividing the total costs of lithotripsy by the practical capacity equation (3). Accordingly, based on different types of cost sources of the lithotripsy department, FCCR for different days of the week was calculated.

Stage 8. At this stage, we used the method presented in Stage 6 to estimate the time needed to complete the system activities in the form of TFN. The number of occurrences of each activity on the basis of calendar year 2017 data was determined 4967 times.

Stage 9. In this point, based on the equations (5) to (8), the cost of lithotripsy operation was determined through multiplying FT that was associated with the intended service by $FCCR_j$. Table 6 shows an instance of allocating the human source costs to various activities of the lithotripsy department. In addition, this table presents the cost of lithotripsy operation in the form of TFN for Saturday in the current state of the system.

Stage 10. In this stage, we defuzzified the fuzzy sets of lithotripsy costs by means of equations (10) to (13). Table 7 presents the exact costs of lithotripsy based on the type of the activity for Saturday. Following these stages, we could calculate the yearly cost of lithotripsy. Also, the average cost of each lithotripsy operation was calculated with respect to 4967 operations in 2017. Table 8 shows the final cost of lithotripsy operation according to the current state of the system.

Stage 11. At this stage, the different scenarios mentioned in the fifth stage were executed using simulation software and were investigated with respect to cost and time indexes in accordance with the abovementioned stages.

The third category of the scenarios examined the factors that reduce the patient cancellation rate. Cancellation factors were found to be related to the patients' lack of knowledge about the preoperative preparations for the lithotripsy operation. Increasing the patients' knowledge about these issues were examined by means of some measures, such as phone calls intended for setting the appointments, announcements on the hospital website, sending text messages to patients, distributing questionnaires about patients' health condition among them, and counseling them during the preoperative waiting time.

Stage 12. At this stage, the results of assessing the scenarios based on time and cost indexes were studied and the best scenario that resulted in satisfactory results in most of the indexes, was selected and set as the basis for the changes. For the purpose of investigating this issue, Matlab software was used. The following section explains how we selected the top scenarios.

At first, scenarios of the first category were examined. Regarding the scenario assessment method, we examined and compared the results of different scenarios for each day of the week; then, based on the results of the assessment, all the scenarios were ranked based on each of the performance index by Matlab software. Obviously, for all indexes, such as waiting time which is optimal when is at the lowest possible value, or in the indexes of the number of discharged patients which is optimal when is at the highest possible amount, lower values represent higher ranking, and higher values indicate the lower ranking of that scenario, compared to other scenarios, in the assessment table. Based on the results of the ranking, for Sunday, scenarios 7–12; for Monday, scenarios 1–12, and scenarios 25–36; and for Tuesday, scenarios 1–7–13–19 had the same performance and enjoyed the best possible results. Summing up the results of these three days, scenario 7 has the best results in different indexes. Based on all indexes, except waiting time, this scenario is also appropriate for Wednesday. Based on the assessment of different scenarios for Wednesday, scenarios 2–4–8–10–14–20–22–26–31 enjoyed the best result in terms of different indexes. scenario 8 is, also, one of the best scenarios for Sunday and Monday, and its results are also very close to the results of scenario 7 for Tuesday. Consequently, scenario 8 was selected as a new schedule for technicians at different shifts and days of the week. This scenario is shown in Table 9.

Table 6: Allocation of human resources costs to various types of therapeutic activities (A) and the final cost of the lithotripsy operation in the form of triangular fuzzy numbers (B) (sample: Saturday in the current state of the system).

Activities	Cost type	$FCOS_S$			$FCOS_M$			$FCOS_L$		
		$FCOS_{SS}$	$FCOS_{SM}$	$FCOS_{SL}$	$FCOS_{MS}$	$FCOS_{MM}$	$FCOS_{ML}$	$FCOS_{LS}$	$FCOS_{LM}$	$FCOS_{LL}$
Reception	A	31148600.74	41481201.47	51813802.21	40140782.76	53456266.33	66771749.91	56431918.51	75151490.78	93871063.05
	B	54102823.24	72049789.01	89996754.78	69721580.51	92849593.88	115977607.2	98018082.35	130532599.4	163047116.4
Transferring the patient to changing room before surgery	A	21960370.68	27934002.86	33907635.04	28300034.28	35998173.72	43696313.16	39785602.53	50608031.68	61430460.83
	B	38143544.97	48519303.7	58895062.44	49155073.3	62526174	75897274.71	69104658.65	87902420.27	106700181.9
Examination	A	4892339.206	9510417.745	14128496.28	6304691.723	12255947.41	18207203.1	8863450.712	17230023.39	25596596.06
	B	8497632.543	16518894.53	24540156.51	10950784.75	21287677.16	31624569.58	15395160.48	29927280.44	44459400.41
Diagnosis	A	23409914.82	33661973.21	43914031.6	30168042.32	43379732.06	56591421.79	42411741.59	60985395.3	79559049.01
	B	40661296.29	58468365.94	76275435.6	52399665.55	75347396.67	98295127.79	73666068.6	105927135.9	138188203.1
ESWL operation	A	168566453.1	181750086.5	194933719.9	217229320.5	234218891.6	251208462.6	305391835.2	329276623.2	353161411.2
	B	292787502.5	315686501.8	338585501.1	377311315.9	406820948.3	436330580.6	530443104.7	571929220.7	613415336.6
Transferring the patient to changing room after surgery	A	14099181.22	24093595.31	34088009.39	18169425.18	31049092.17	43928759.15	25543485.96	43650365.5	61757245.04
	B	24489238.41	41848798.9	59208359.39	31558952.1	53929984.19	76301016.27	44367152.08	75817467.02	107267782
Transferring the patient to the recovery room	A	5218964.192	7240281.539	9261598.886	6725608.948	9330453.423	11935297.9	9455197.184	13117217.73	16779238.27
	B	9064956.065	12575835.29	16086714.51	11681886.94	16206309.76	20730732.59	16422980.48	22783640.21	29144299.93
Recovery	A	60647826.57	120173781.1	179699735.7	78156038.27	154866335.2	231576632.1	109875664.6	217718833.7	325562002.8
	B	105340803.9	208732998.7	312125193.6	135751276.9	268991407.6	402231538.3	190845929.5	378161564.1	565477198.8
Sum	A	329943650.5	445845339.8	561747029	425193944	574554891.8	723915839.6	597758896.3	807737981.3	1017717066
	B	573087797.9	774400487.9	975713178	738530535.9	997959491.5	1257388447	1038263137	1402981328	1767699519

Table 7: The exact costs of lithotripsy operation based on the type of activity (sample: Saturday with data of the current state of the system).

Activities	COS_S	COS_M	COS_L	COS
Reception	72049789.01	92849593.88	130532599.4	98477327.43
Transferring the patient to changing room before surgery	48519303.7	62526174	87902420.27	66315965.99
Examination	16518894.53	21287677.16	29927280.44	22577950.71
Diagnosis	58468365.94	75347396.67	105927135.9	79914299.49
ESWL operation	315686501.8	406820948.3	571929220.7	431478890.2
Transferring the patient to changing room after surgery	41848798.9	53929984.19	75817467.02	57198750.03
Transferring the patient to the recovery room	12575835.29	16206309.76	22783640.21	17188595.09
Recovery	208732998.7	268991407.6	378161564.1	285295323.5
Sum	774400487.9	997959491.5	1402981328	1058447102

Table 8: The final cost of each lithotripsy operation for different days of the week based on the data of the current state of the system.

Week days	COS
Saturday	225001.3
Sunday	216270.4
Monday	227851.7
Tuesday	221249.8
Wednesday	238041
Thursday	308640.7

Table 9: Selected scheduling scenarios of technicians' presence on different days of the week.

Week days	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
Shift work 1	Technician 1	Technician 2	Technician 2	Technician 2	Technician 2	Technician 2
Shift work 2	Technician 1	Technician 1	Technician 2	Technician 3	Technician 3	Technician 2

In the scenarios of the second category, the best schedule for patient visits was investigated. The assessment method for these scenarios is similar to the one used for the assessment of first category scenarios. Table 9 shows an example of the results of the assessment of patient visit scheduling scenarios for Saturday. As can be seen, the best scenario for Saturday regarding the cost and the number of discharged patients is scenario 20; nonetheless, since reducing the waiting time is also targeted, reviewing other scenarios and comparing them with scenario 20 is also important. As stated before, the waiting time index and the number of discharged patients are in the opposite direction. That is to say, an increase in the number of discharged patients will reduce the cost; however, waiting time will increase too. For this reason, we should select a scenario that enjoys a desirable state considering all the indexes. Scenarios 27 and 28 are two examples in this regard. These two scenarios have a better position in waiting time index compared to scenario 20, and furthermore, their positions are rather close to this scenario with respect to cost, the number of discharged patients, and other indexes. Scenario 27 is closer to scenario 20 regarding the number of discharged patients; however, since reducing the waiting time is very important, scenario 28 is selected for Saturday as enjoying the best patient arrival rate. The case of Sunday is similar to Saturday. Scenario 22 is the most appropriate scenario regarding the number of discharged patients and cost indexes; yet, similar to the previous case, waiting time should be considered. In this regard, scenarios 25 and 31 have a more reasonable position compared to scenario 22. Scenario 25 is closer to scenario 22; however, due to the waiting time issue scenario 31 is our choice. Since technicians' schedules for shifts 1 and 2 is the same on Sunday and Monday, we selected scenario 31 for scheduling the Monday too. For Tuesday, scenario 20 is the best scenario in terms of the number of discharged patients. But then again, there is the issue of waiting time. The closest scenario to the scenario 20 in terms of the number of discharged patients and cost indexes is the scenario 31; at the same time, it enjoys even a better waiting time than scenario 20. Such a situation also exists for Wednesday, thus, again the best scenario for scheduling patient visits on Wednesday is scenario 31. For Thursday, these results are different, because the end time of patient admission on Thursday is different from other days of the week. The best scenario for this day is scenario 15, which gained the best results regarding different perspectives. Table 10 shows the best time distributions for scheduling patient visits on different days of the week. The results of the assessing the combined scenarios made of patient appointment scheduling scenarios plus overtime work for patient admission are also done in a similar way (Table 10).

4.2. Discussion and Conclusion of the Results. In this study, a combined model of simulation and costing was developed to estimate and reduce the costs of healthcare services based on improving the efficiency of health centers using TDABC and simulation approach in uncertainty conditions. This model consists of 12 key stages that include all the steps of building the simulation model and estimating the costs of

Table 10: Selected scheduling scenarios of patient visits on different days of the week.

Week days	Probability distribution	Probability distribution + overtime
Saturday	UNIF (600, 1800)	UNIF (1200, 1500) + overtime
Sunday	UNIF (900, 1500)	UNIF (900, 2100) + overtime
Monday	UNIF (900, 1500)	UNIF (900, 2100) + overtime
Tuesday	UNIF (900, 1500)	UNIF (1200, 1800) + overtime
Wednesday	UNIF (900, 1500)	UNIF (1500, 1800) + overtime
Thursday	UNIF (600, 900)	UNIF (1200, 1500) + overtime

healthcare services. In this model, the costs of healthcare services are determined based on TDABC in conditions of uncertainty and through fuzzy approach. Furthermore, the estimated costs are used to assess the system improvement scenarios. The proposed scenarios in the present study aim at determining the most suitable schedule for the presence of human resources during different days and shifts, determining the best schedule for patient visits, and also examining the factors that reduce the patient cancellation rate. In order to evaluate the effect of scenarios, the proposed model was run for each scenario, then the results of all scenarios were studied and compared with each other based on time and cost indexes. Next, based on the results of the assessments, scenarios were ranked based on each performance indexes by Matlab software. After reviewing the impact of each scenario based on performance indexes, the best scenarios were selected. Table 11-A demonstrates the differences resulted from applying the selected scenario's changes for scheduling of technicians' presence and compares the results of these changes with the current state of the system under study. Obviously, any negative figure in each of our indexes, such as cancellation numbers, waiting time, and cost, implies a system improvement resulted from a new change in that specific performance index. As it is shown, selecting a new scenario for scheduling the presence of technicians has reduced the waiting time, the length of patients' stay, and the cost of lithotripsy operation; furthermore, it has increased the average number of discharged patients of the system. It is worth mentioning that on Tuesday and Wednesday, due to different patient arrival rates, the increase in the volume of discharged patients, and the ability of technicians present in these days, waiting time has slightly increased. On Sunday and Monday, the presence of a more skilled technician alongside a more appropriate distribution of patients, has lessened the effects of this problem; therefore, the utilization of the selected scenario has resulted in much more improvements on the aforementioned days. Also, Table 12 shows the results of applying the changes derived from selected scheduling scenarios of patient visits compared to the current state of the system under study. As it is shown, selecting new scenarios for patients' visits, with or without overtime work, has reduced the waiting time, the length of stay, and the costs of the lithotripsy operation; besides, it has increased the average number of discharged patients of the system. It should be noted that in these scenarios, especially in scheduling scenarios that include overtime work, waiting time has decreased on most days of the week, even in cases that the number of discharged patients increase. This issue indicates a significant improvement in the system compared to its current state. Another interesting finding in the results is the significant decrease in the cost of lithotripsy operation for different days of the week compared to other scenarios. Also, Table 11-B compares the results obtained from reviewing the factors that reduce patient cancellation rate in comparison with the current state of the system under study, with respect to the performance indexes on different days of the week. As it is presented, controlling the patient cancellation rate by informing patients before operation can lead to a reduction in the number of cancellations and the cost of lithotripsy operation. It similarly can increase the volume of daily discharged patients and improve the resource efficiency alongside the system state.

In the present study, the cost of each proposed change is calculated using the simulation-costing model and this cost is considered as the basis for comparing different options. Table 13 and Figure 2 shows the lithotripsy operation cost for the selected scenarios and for the current state of the system under study. As can be seen in this figure, there is a significant difference between the costs calculated by the proposed simulation-costing model and the approved tariffs that are determined by the traditional accounting methods of the hospital. Costs obtained by means of simulation-costing model in conditions of uncertainty for the current state of the system under study, for technicians' scheduling scenarios, for patient visits' scheduling scenarios, for scenarios of combined scheduling plus overtime work, and also for the scenarios of investigating the patient cancellation factors were respectively 0.39536, 0.392762, 0.332224, 0.329579, and 0.365189 percent of the costs calculated by the traditional accounting method of the hospital. These differences in the calculated costs are largely related to the methods used for allocating indirect costs in traditional accounting approaches. In the proposed method, due to the use of the logic of TDABC method, costs are considered only if resources are used in the provision of a service, while in traditional methods all costs are allocated to services without checking this issue. Furthermore, in traditional methods, those activities that do not have value added for the patient and the system cannot be distinguished and identified. Consequently, the lower costs determined by the proposed method imply that the costs determined by the traditional method are not correct. In addition, the uncertainty in the cost of consumable sources and also in the time required to complete the therapeutic activities, which is dependent on the number and type of discharged patients and has been emerged due to uncertainty in the capacity and ability of the technicians to perform these activities, has also contributed

Table 11: Differences resulted from application of the changes derived from the selected technicians' scheduling scenario (A) and controlling the patient cancellation factors (B) compared to the current state.

Performance indexes	Change	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
Average number of discharged patients	A	0	0.08	0.4	0.08	0.28	0
	B	2.04	1.64	2.04	2.28	2.84	0.56
Average number of cancelled patients per day	A	0	−0.12	−0.12	0.2	−0.16	0
	B	−1.72	−1.48	−1.48	−1.32	−1.76	−0.88
Average waiting time in the system	A	0	−216.56	−66.54	154.28	191.84	0
	B	1632.33	1425.71	1833.78	2094.49	1478.31	279.06
Average time spent in the system	A	0	−275.27	−121.72	177.98	254.16	0
	B	1966.88	1614.14	1987.62	2400.35	1743.71	332.04
Anesthesiologist utilization rate	A	0	0.003394	0.004727	−0.00081	0.000165	0
	B	0.009156	0.00836	0.021505	0.010074	0.020701	0.005053
Bed utilization rate	A	0	0.003165	0.009442	0.00053	−0.00165	0
	B	0.011185	0.012153	0.036968	0.023458	0.030167	0.013551
Technician utilization rate of shift 1	A	0	−0.00425	0.001259	0.0028	0.002216	0
	B	0.003293	0.002862	0.022756	0.01843	0.016891	0.004025
Technician utilization rate of shift 2	A		0.005548	0.002941	−0.0016	−0.00012	
	B		0.008738	0.003344	−0.00223	0.010209	
The end of system's service provision average time	A	0	−1320.63	−274.118	1263.886	1188.96	0
	B	3275.089	2486.543	3198.552	4111.672	4220.047	590.6695
Average cost	A	0	−4246.8	−3164.24	−1700.36	−333.4	0
	B	−8953.15	−14074.6	−18775.4	−20488	−35306	−12068.3

Table 12: Differences resulted from the application of patient visits' selected scenarios without overtime work (A) and with overtime work (B) compared to the current state of the system.

Performance indexes	Scenario	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
Average number of discharged patients	A	2.08	0.88	2.48	1.92	2.52	4.56
	B	2.84	1.24	2.84	1.88	2.6	3.72
Average number of cancelled patients per day	A	0.12	0.32	−0.12	0.28	−0.04	1.68
	B	−0.28	−0.04	−0.48	0.32	−0.24	0.72
Average waiting time in the system	A	−688.92	−544.76	781.47	1146.73	680.68	5233.41
	B	−1726.19	−3279.14	−1952.91	−2012.98	−3489.7	−1310.19
Maximum waiting time in the system	A	−1739.84	−3165.37	−1834.32	−1378.58	−1285.24	1266.65
	B	−4393.9	−5114.35	−3783.3	−5371.05	−6101.64	−6012.08
Average time spent in the system	A	−504.87	−493	989.7	1360.21	980.46	5760.42
	B	−1392.55	−3122.85	−1640.15	−1790.38	−3194.22	−931.48
Maximum time spent in the system	A	−2199.31	−2527.2	−1723.94	−1182.56	−890.17	1528.99
	B	−4475.04	−4763.05	−3959.79	−5317.18	−5475.13	−5407.72
Anesthesiologist utilization rate	A	0.031507	0.019095	0.067038	0.025631	0.024396	0.019818
	B	0.0304	0.00139	0.049334	0.015026	−0.01559	−0.00054
Bed utilization rate	A	0.014102	0.005898	0.081513	0.029244	0.031432	0.044506
	B	0.007233	−0.04894	0.026678	−0.03126	−0.10196	−0.00678
Technician utilization rate of shift 1	A	0.012134	0.004249	0.048058	0.033123	0.019935	−0.00206
	B	0.020299	−0.00951	0.034295	0.016864	−0.00177	0.000877
Technician utilization rate of shift 2	A		0.015951	0.021942	−0.00252	0.010065	
	B		0.013613	0.019605	0.003136	−0.00583	
The end of system's service provision average time	A	2232.211	839.6955	2007.174	3272.893	3648.052	8162.264
	B	4015.397	2009.407	3176.885	3276.117	5412.814	6791.46
Average cost	A	−21233.9	−17153.8	−28735.1	−22263.2	−36550.06	−103552
	B	−192254	−180257	−191838	−184946	−198435	−278374

Table 13: The costs of lithotripsy department based on selected scenarios.

Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
The current state of the system					
225001.2633	216270.388	227851.6678	221249.8174	238041.036	308640.7246
Scheduling scenarios of technicians' presence on different days of the week					
Scenario 8					
225001.2633	212023.5859	224687.4311	219549.4615	237707.636	308640.7246
Scheduling scenarios of patient visits on different days of the week					
UNIF (600, 1800)	UNIF (900, 1500)	UNIF (900, 1500)	UNIF (900, 1500)	UNIF (900, 1500)	UNIF (600, 900)
203767.3733	199116.5751	199116.5751	198986.6396	201490.9755	205088.6891
Scheduling scenarios of patient visits plus overtime on different days of the week					
UNIF (1200, 1500)	UNIF (900, 2100)	UNIF (900, 2100)	UNIF (1200, 1800)	UNIF (1500, 1800)	UNIF (1200, 1500)
199356.7679	194762.3541	194762.3541	197010.3686	196064.6547	215998.467
Investigating factors that reduce patient cancellation rate					
216048.1	202195.8	209076.3	200761.8	202735	296572.4

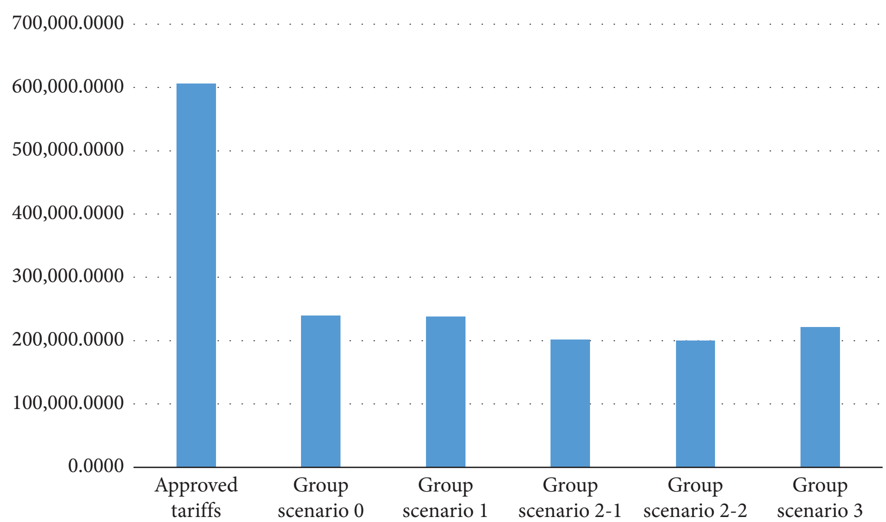

Figure 2: Graphical comparison of the lithotripsy operation cost in selected scenarios with the approved tariffs.

Table 14: Comparison of the lithotripsy operation cost in simulation-costing model and TDABC method.

Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
TDABC (the current state of the system, scenario 0)					
212823.367	201946.6798	213654.4629	208945.2025	214759.1995	249289.9
Simulation-costing model in healthcare (the current state of the system, scenario 0)					
225001.2633	216270.388	227851.6678	221249.8174	238041.036	308640.7246

to these differences. Table 14 and Figure 3 compare the cost of lithotripsy operation in the current state of the system in the proposed model and in TDABC model. As it is shown, since TDABC model fails to consider the conditions of uncertainty in time and cost parameters that have emerged due to the technicians' capacity and ability, patient type and arrival, the volume of discharged patients and etc., this model determines the cost of lithotripsy operation lower than the real values. Therefore, in the present study, by taking the uncertainty into account in the proposed model by using the FL-TDABC method, we could obtain more accurate estimates of capacity cost rate and time of activities under uncertainty conditions; hence, it enabled us to identify the costs of healthcare services more accurately.

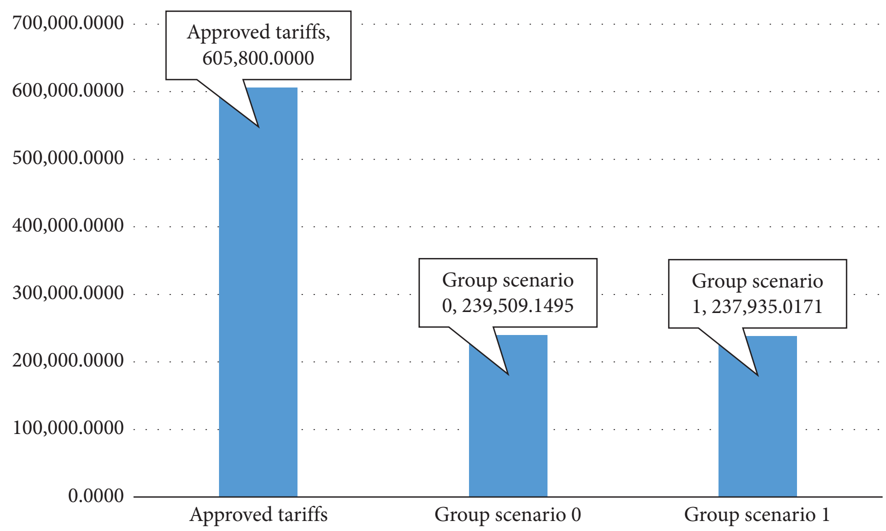

Figure 3: Investigation of the effect of conditions of uncertainty on the cost of lithotripsy operation (sample: current state of the system under the study).

5. Conclusion and Recommendations

The present study aimed to develop a new method for costing the hospital services using TDABC and simulation approach in conditions of uncertainty. In this study, the lithotripsy department of a kidney center was studied and different scenarios for scheduling the presence of technicians, scheduling patients' appointments, and also the examining the patient cancellation factors in different stages of the treatment process were investigated. By doing so, we tried to improve the state of the system under study and to reduce the cost of healthcare services through reducing the waiting time, the patient cancellation rate, and by improving the resource efficiency. By focusing on these issues, the main objective of this study that was reducing the cost of healthcare services by improving the efficiency of hospital resources could be addressed. For each category, possible scenarios are determined based on the results of the repeated iterations of the simulation model and also with respect to the existing conditions and limitations. In this study, the Arena software was used to create the simulation model of the system under study. In the next step, different categories of scenarios, based on predetermined indexes, were ranked and assessed separately for different days of the week using Matlab software. We used various indexes to assess the scenarios; all of these indexes were based on time, resource utilization, and cost. Since our indexes, to some extent, were in contradiction with each other, by examining different perspectives, we tried to select a scenario that could achieve a favorable and balanced position in all the indexes. The results of the study showed that by selecting each category of the proposed scenarios and applying some changes to the system based on these selected categories, significant improvements in costs, waiting time, human resource utilization, and overall in-system efficiency were emerged. Furthermore, the comparison of the costs determined by the new system for each of the categories of the proposed scenarios and for the current state of the system under study, with the costs determined by the traditional accounting method of the hospital, showed that there is a significant difference between the costs calculated by the new method and the approved tariffs that were determined by the traditional methods. Such differences partly exist due to different methods of allocating indirect costs, but much of such differences have emerged due to the existing uncertainty in the costs of consumable sources and in the time associated with technicians. The use of fuzzy approach in the proposed simulation-costing model by using the FL-TDABC method can increase the ability of the proposed system in dealing with the conditions of uncertainty; as a result, the costs of healthcare services will be determined more accurately under the uncertainty conditions.

The results showed that significant improvements in costs, waiting time, human resource utilization, and overall system efficiency were emerged. The impact of patient appointment scheduling scenarios on the abovementioned indexes was found to be far more than other scenarios. Furthermore, the results from the costs determined indicate a difference of 0.60464, 0.607238, 0.667776, 0.670421, and 0.634811 percent between these costs and the costs determined by the traditional approaches. Such differences among the costs determined by these two approaches mainly occur due to different methods of allocating indirect costs and existence of uncertainty in the costs and time of therapeutic activities.

In the current study, no particular limitation has been taken into consideration. In this study, the effect of scheduling scenarios of technicians' presence and patient visits were separately examined on the current state of the system. Undoubtedly, examining all different conditions that include the effect of both abovementioned types of scenarios together, can lead to better results. It is worth noting that, in the present study, controlling the patient cancellation factors by informing patients led to a reduction in the number of cancellations and costs of lithotripsy operation; it also increased the volume of daily discharged patients and improved the resource efficiency and system's state. Nevertheless, compared to the current situation, due to the increase in the volume of discharged patients, waiting time increased to some extent. For future research, it is suggested that reducing cancellation factors be considered in scheduling scenarios of both technicians and patients, and the impact of these factors be investigated on improving the key performance indexes of the system. Furthermore, in this study, to change the schedule of patient visits we used a time distribution for the entire time of each weekday. The use of other patterns of patient arrival, such as multisection pattern arrival, in which arrival distribution differs across different hours of the day, is also suggested for future studies.

Data Availability

The data used to support the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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