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A combined modelling of fuzzy logic and Time-Driven Activity-based Costing (TDABC) for hospital services costing under uncertainty

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ABSTRACT

Hospital traditional cost accounting systems have inherent limitations that restrict their usefulness for measuring the exact cost of healthcare services. In this regard, new approaches such as Time Driven-Activity based Costing (TDABC) provide appropriate information on the activities needed to provide a quality service. However, TDABC is not flawless. This system is designed for conditions of relatively accurate information that can accurately estimate the cost of services provided to patients. In this study, the fuzzy logic in the TDABC model is used to resolve the inherent ambiguity and uncertainty and determine the best possible values for cost, capacity, and time parameters to provide accurate information on the costs of the healthcare services. This approach has not yet been tested and used in determining the costs of services of a healthcare setting. Therefore, the aim of this study is to present a new Fuzzy Logic-TDABC (FL-TDABC) model for estimating healthcare service costs based on uncertainty conditions in hospitals. The proposed model is implemented in a sample of the hospital laboratory section and the results are compared with the TDABC system. The TDABC model, by allocating the activity costs including fixed costs and not considering the uncertainty regarding the cost, capacity, and time required for each patient, often estimates the unused capacity and costs with a higher margin of error. The results show that the maximum difference in the prescribed costs was 4.75%, 3.72%, and 2.85% in blood bank, microbiology, and hematology tests, respectively, mostly due to uncertainty in the costs of consumables, equipment and manpower (on average 4.54%, 3.8%, and 3.59%, respectively). Also, The TDABC system, in comparison with the proposed system, estimates the unused capacity of the resource with more error. Cost of unused capacity derived using FL-TDABC were 80% of costs derived using TDABC. In conditions where the information is ambiguous, using the new system in hospitals can lead to a more accurate estimate of the cost compared to the TDABC system. Moreover, it helps hospital managers to make appropriate decisions about the use of capacity, capital budgeting, cost control, and etc.

1. Introduction

Hospitals and healthcare centers as major operating units of the healthcare sector play an important role in promoting public health. One of the important factors in the continued service of this sector is how to manage resources and control costs. Balancing costs with generated revenues is one of the main challenges of many hospitals in the country. In most hospitals in the country, costing and determining the cost of services are directed via traditional costing systems (TCSs) based on reimbursement, which does not provide information on the exact amount of healthcare costs. Due to the prime focus of these systems on reimbursement, less attention has been paid to understanding the exact amount of true healthcare costs and implementing strategies to reduce them.

A costing approach that can provide true cost of patient care services would enable hospitals to manage resources, improve the efficiency of processes, adapt medical skills to processes, increase patient satisfaction, and ultimately reduce the costs. The lack of such knowledge will lead to the lack of understanding the link between costs and process improvements. Moreover, it could be an obstacle to reduce costs in hospitals and healthcare centers, leading to higher healthcare costs. Therefore, designing and implementing a system that provides suitable decision-making grounds for managers to better manage resources in order to reduce the cost of healthcare is of high necessity.

Activity Based Costing (ABC) is a new costing system that provides hospital managers with relevant information on the activities needed to provide quality and desirable services, and about the proper utilization

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of resources. This information will help them to better manage resources and maximize their potential profitability by reducing their costs. Although several articles have addressed the importance of using this method in service activities and in healthcare and medical activities, it is better to act prudently in employing it [18,4,24,35,41,23]. Many studies have shown that for most organizations, the continuation of updating this system is not sustainable. In addition, the data collection process required for this system, which is done through numerous interviews and reviews, is very time-consuming. Another shortcoming of this method is that it is unable to identify unused capacity [27]. Many hospitals implemented the ABC method in the 1990 s, but its use in other industries was not considered as a sustainable costing method [6]. Thus, TDABC method was developed by Kaplan and Anderson in 2004 to eliminate the problems of the standard ABC model and then was proposed in 2011 by Kaplan and Porter for the healthcare industry [26,29].

TDABC model, using time equations and cost drivers, can take into account complex activities and processes and provide more accurate cost information. It is also able to identify unused resources and capacities and thus provides better management of resources. Nevertheless, this system also has its own problems and deficiencies that have made it not to be completely satisfying when it comes to calculating the cost of hospital services. The TDABC provides fairly accurate information so that it can accurately estimate the cost of services. However, estimating the cost and time required for most hospital activities is subjective and uncertain. Since many decisions and costing processes in the hospital environment are done under uncertainty, the use of TDABC method will often not lead to satisfactory results. Because health care costs often vary according to the performance of physicians and other healthcare personnel, there are large variations in the cost of healthcare services due to the uncertainty of their capacity and performance. Such cases also have a significant impact on the time and cost of services provided to patients, making it impossible to estimate accurately the cost and time required for most hospital activities. To solve this problem, we need an approach that reduces the uncertainty of the TDABC system in order to accurately estimate hospital costs and increase the reliability of the results.

Fuzzy logic is one of the most effective methods for reducing uncertainty in the TDABC system, which can provide more accurate results compared to the standard TDABC system [39,12]. Therefore, using fuzzy logic, we can examine issues that are related to data inaccuracy and uncertainty in the TDABC system and provide more reliable results. Taking these points into consideration, the purpose of this study is to present a model for estimating hospital services costs based on fuzzy logic and TDABC method.

In this paper, we try to use fuzzy logic to compensate for the lack of reliable and definitive data in the TDABC system and to introduce a new system called Fl-TDABC that is in accordance with the healthcare conditions. The remainder of the paper is organized as follows. This paper first investigates the studies in the field of fuzzy logic and ABC systems application in the healthcare services costing in Section 2. Then, it presents a new model for healthcare services costing under conditions of uncertainty and in accordance with healthcare features in Section 3. Section 4 presents the application of the proposed model in a pilot experiment. Finally, Section 5 presents concluding remarks and some recommendations for future research.

2. Theoretical framework and research background

2.1. ABC

The ABC method was introduced by Cooper and Kaplan in the mid-1980 s as an alternative to traditional accounting methods [10]. The ABC system calculates the cost of services and products by linking organizational costs to the activities required to perform services or products. The ABC goal is to allocate more precisely overhead costs to products or services through cost drivers. The structure of an ABC system consists of two stages. In the first stage, resources that are classified as indirect costs are allocated to activities, and in the second stage, the cost of each activity is allocated to the products or services by the cost drivers. Allocating of costs to products or services by means of a variety of bases for the allocation of activities leads to more accurate costs of the product or service [20].

The ABC system allocates proportionate cost drivers to each activity, calculates the costs based on it, and thus provides more proper information about the costs and resources needed to produce goods or provide services. Using such information provides useful tools for controlling costs and also accurate information on the cost of services provided in hospitals and healthcare centers. In the field of healthcare, many studies have used the ABC method. In a study by Gujral et al. in 2010, the ABC model was used in the Hematopathology Laboratory (HPL). In this study, the total cost for each sample of various experiments conducted in the HPL was determined using the ABC method and compared with the existing prices. The results indicated that there is a significant difference between the calculated costs using the ABC method and prices that were set [18]. In another study, the ABC system was used to calculate the cost of diagnostic MRI services. The results of this study showed that direct costs account for most of the cost of the MRI center, with the highest costs associated with manpower and consumables. Comparison of calculated actual costs with approved tariffs also indicates that more than 60% of the services include lower costs than the approved tariffs and existing tariffs are more than true costs for these services [4]. Mohammadi et al. [35] calculated the cost of dialysis using an ABC method. They showed that dialysis costs are less than tariffs and there is a possibility of cost reduction by improving human resource management methods [35]. Also, in another study, the cost of eye surgery was analyzed using the ABC system and the obtained results were compared with government-approved tariffs. The results of the study demonstrated that the cost of manpower has the largest share of cost (64.15%). The comparison of estimated costs with the approved tariffs of the Ministry of Health indicated that the costs of selected surgeries are higher than the approved tariffs, and there is a significant difference between them. In addition, indirect costs and costs related to human resources and equipment depreciation account for over 90% of the total cost [23]. Javid et al. [24] calculated and compared the cost of hospital and outpatient services and the cost of bed occupancy in order to compare the ABC system with the TCS. They reported a significant difference between the results of the two costing systems. The costs calculated by ABC system were about 30% lower than those calculated by TCS and the largest share of the costs was attributed to CCU, which are much higher compared to other units of the hospital. In addition, manpower accounted for most of the total hospital costs while hospital wards (48%) cost was more than outpatient departments (29%) [24].

2.2. Moving from ABC to TDABC

Today, the ABC method has become widespread in most organizations and TCSs have disappeared. Following a great success and substantial expansion of the ABC system in the industry, and with regard to its capabilities, its application in service activities, especially in hospitals and healthcare centers, has been flourished since the early 1990′s. By the introduction of this system, the accuracy of calculated costs in the treatment sector has become of great importance to hospital managers, investors, and government departments who used this kind of information in their decisions. Thus, by the introduction of this system and its proven capabilities, more than 20% of the US and Canadian hospitals, by 1997, used the ABC system to calculate and control the cost of services. This system not only provides more accurate and reliable information about the cost of hospital services but also provides managers with comprehensive information. However, the implementation of this method is not easily feasible, since collecting information to complete the ABC model is a time-consuming and costly

Table 1
Activity-based costing versus time-driven activity-based costing.

Panle A: Activity-based Costing
Step1: Identify the different overhead activities,
Step2: Assign the overhead costs to the different activities using a resource driver,
Step3: Identify the activity driver for each activity,
Step4: Determine the activity driver rate by dividing the total activity costs by the practical volume of the activity driver,
Step5: Multiply the activity driver rate by the activity driver consumption to trace costs to orders, products or Customers.
Panle B: Time-Driven Activity-based Costing
Step1: Identify the various resource groups (departments),
Step2: Estimate the total cost of each resource group,
Step3: Estimate the practical capacity of each resource group (e.g., available working hours, excluding vacation, meeting and training hours),
Step4: Calculate a capacity cost rate (CCR) of each resource group by dividingthe total cost of the resource group by the practical capacity,
Step5: Determine the required time for each event of an activity using a time equation,
Step6: Multiply the capacity cost rate (CCR) of each resource group by the time required to perform the activity.

process. The ABC model data are often based on personal estimation and difficult to update. Moreover, the model ignores the potential of unused capacity, which is not appropriate theoretically [27,16]. To overcome these problems, Kaplan and Anderson derived a new method from ABC, which was called TDABC. TDABC facilitates the process of data collection using the time component as the main cost driver. It also estimates the capacity needed for each cost object and uses the capacity cost rate to advance and allocate departmental resource costs to cost objects. The TDABC system abandons the initial phase of the ABC model and does not allocate departmental costs to the various activities that are being carried out in the department such that the costs are allocated directly to the cost objects by time equations. Using time equations, TDABC can also model complex activities and processes. The time-oriented approach also abandons staff survey, which is time-consuming, costly, and based on personal opinions. This can make the process of costing easier, more accurate, and cheaper, as well. The simplicity of this model results from the fact that it needs only two parameters for the corresponding estimations: the rate of the departmental capacity cost and the capacity utilization rate of each activity performed in the department [27,26,5]. Each parameter can be simply and objectively estimated.

2.2.1. Estimating capacity per unit cost rate (CCR):

Two estimations have to be made to calculate the cost of each unit's capacity. Firstly, the cost of the supplied capacity, which is the same as the total cost of a department, is calculated by calculating the practical capacity of the supplied resources. Finally, by dividing the total cost of each department by the practical capacity, capacity per unit cost will be obtained.

$$\text{Capacity cost rate} = \frac{\text{supplied capacity cost}}{\text{Practical capacity of supplied resources}}$$

Practical capacity can be calculated by two different approaches:

1- Arbitrary Approach: This approach assumes that the practical capacity is a certain percentage of the nominal capacity. Typically, 80% to 90% of nominal capacity (maximum capacity) is determined as practical capacity, which is obtained by previously used capacity or more accurately through direct attention to the actual time used.
2- Analytical approach: In this approach, calculation of practical capacity starts with the calculation of nominal capacity, and then the entire time that employees and machines are not accessible tangibly for more efficient work is deducted from this nominal capacity.
3- In order to estimate the cost of supplied capacity, attention should also be paid to issues such as the cost of employee and supervisor salary, the cost of indirect wage, and other indirect support costs.

2.2.2. Determining the consumption of capacity (unit times) by the activities:

In the TDABC system, after determining the capacity cost rate of the department, management should determine the amount of utilized capacity per transaction for each activity. In this stage, to determine the amount of capacity utilization, the total time related to the activities of each department should be estimated, and then multiplied by the capacity per unit cost.

The ABC and TDABC models typically include the steps shown in Panel A and Panel B of Table1, respectively [13]. As can be seen, the TDABC model has a close relationship with time calculation, while the ABC method is related to the calculation of resource costs and the cost of activities. In complex circumstances, where the time needed to run an activity is affected by various factors, TDABC can make the cost calculation process easier and more accurate than the ABC method [47]. Furthermore, this model, unlike the ABC model does not require regular updating and its maintenance is very easy. Accordingly, the cost of implementing TDABC is also lower than the ABC because its implementation process is very simple and easy. TDABC also identifies unused capacity more accurately. Based on all of these features and benefits described, Kaplan and Anderson claimed that the TDABC model could be used by most organizations, regardless of the complexity of products, services, customers, parts, or processes [27]. Various studies have been conducted on using TDABC model [44,14,31,15,43,28]. In the field of healthcare, many studies have used the TDABC approach in a variety of areas. Chen et al. [8] used the TDABC model to calculate the cost of Total Knee Replacement (TKR) surgery and to determine the main cost drivers in an educational hospital in London. In this study, the cost of each patient for the TKR operation was calculated for the entire treatment cycle and then compared with the approved tariffs for it. The total cost of a patient's treatment cycle of TKR surgery was calculated for an average of 5.25 days of the patient's stay, and it was found to be lower than the approved tariff for it. Also, based on the findings of this study, the operating room consumables accounted for most of the total cost of the TKR treatment cycle[8]. In another study, Akhavan et al. [2] compared this method with traditional costing (TA) methods in arthroplasty surgery. They compared the costs of two total hip arthroplasty (THA) and total knee arthroplasty (TKA) operations using the TDABC method with the costs estimated by the hospital traditional accounting system. The results show that the cost of THA and TKA surgery using the TDABC method is 54% and 55% of the estimated total cost of the TA system, respectively. This outcome is due to the difference in methods for allocating indirect costs by the two systems under investigation TDABC provides a more accurate measure of true resource use associated with arthroplasty surgeries and can be used to identify high-cost/high-variability processes that can be targeted for process/quality improvement [2]. Also, Andreasen et al. [3] used of this method to determine the costs of arthroplasty of knee and hip. The calculated and compared costs of total hip arthroplasty (THA) and total knee arthroplasty (TKA) in two hospitals, with different organizational structure and sets of different processes throughout the therapeutic cycle using TDABC method. Comparisons show that there is a very small difference in costs and the organizational structure, and a set of different processes have little impact on the costs incurred. However, a comparison between the results of their study with other similar studies, including the study by Akhavan et al. and Chen et al., shows that the mean length of stay and the time spent in different phases of the treatment cycle has a significant effect on the costs incurred [3]. Laviana et al. [33] applied this model to calculate and compare the cost of prostate cancer treatment. Based on the findings, the use of TDABC for hospital services analysis is possible and provides an insight into cost-cutting tactics. In this study, the costs of each treatment were determined based on the TDABC methodology through the development of process maps for each phase of treatment from the beginning of the urology to the follow up of 12 years for 7 different treatments. Based on their results, active surveillance (AS) is considered as the cheapest and radiotherapy as the most expensive treatment for 5 years of follow up. Moreover, they showed that the use of TDABC is feasible for analyzing cancer services and provides insights into cost-reduction tactics [33]. In another study, Gregório et al. [17] calculated pharmaceutical services cost using the TDABC model. They showed the importance of analyzing the costs of healthcare services, especially pharmaceutical services, for the purpose of improving the management of community pharmacies and promoting pharmaceutical policies. In this study, the TDABC model was used to calculate and analyze the cost structure of pharmaceutical services in three pharmacies in the city of Lisbon, Portugal. Examined services at these pharmacies include prescription medicine dispensing, ”over-the-counter” (OTC) medicines dispensing, counseling without dispensing, and health screening services (blood pressure, glycemia, cholesterol measurement, etc.). Based on the analyses conducted, prescription medicine dispensing and health screening services have been the most expensive investigated services. In addition, the study found that valid and dispense prescription alongside managing the inventory and records were the most costly activities [17]. Ippolito et al. [22] analyzed the experience of the Italian government in implementing a tariff system based on the TDABC model for home care services. They presented a method for calculating the daily cost of home care services. In this method, the level of complexity of the patient, the types of care provided, and the types of home care providers are used to calculate the actual cost of services per day. The result of the study is to establish a system of tariffs for home care services based on the amount of resources consumed at each level of complexity of the patient [22]. Demeere et al. [11] tried to explain and examine the management relationships and effects of TDABC system in outpatient clinics. TDABC method was implemented on five separate sections in this research. The results of this study showed that the cost of provided services was significantly different from government tariffs. The authors also concluded that the use of the TDABC model illustrates the impact of specialized counseling and use of activities and equipment. Based on the results of this study, the use of the TDABC system provides clinicians and clinic directors with valuable information that helps them improve their operations, analyze profitable departments, and decide on future investments [11]. Yangyang et al. [50] conducted a study to identify opportunities for reducing the cost of a pediatric appendectomy. They used the TDABC method to estimate the costs of pediatric appendicitis surgery and compared it with the costs determined by the hospital traditional accounting system. Also, the applications of this method, along with developed process maps, were used to identify inefficiencies in the system under study. According to the results, the total cost of the pediatric appendicitis is $ 2753.39, which represents a 17% reduction compared to the cost generated from hospital traditional accounting system. Additionally, the operating room, hospital floor, and emergency department account for 44%, 23%, and 17% of the costs, which share the most of the total hospital costs. Moreover, in this study, post-operative monitoring, operating room availability and emergency department evaluation were identified as the most important factors in increasing the length of stay of the patients. Accordingly, the following interventions have been proposed to address these inefficiencies: Triage-based standing delegation orders, early surgical consultation and evaluation through the use of surgical advanced practice providers in the emergency department, and a standardized same-day discharge protocol [50]. Tan et al. [46] conducted a study to improve access to cancer genetic services using TDABC and quality improvement methods. They employed process mapping and plan-do-study-act (PDSA) cycles in a quality improvement project for the Cancer Genetics Service clinic. Based on the main findings of the study, interventions have been proposed including the substituting a genetic counselor with a physician for genetic counseling and manual preappointment reminder calls to reduce the variation in the nonattendance rate of patients. Also, the impact of suggested interventions was evaluated by tracking the weekly number of patient consultations and access times for appointments. The cost impact of implemented process changes was calculated using the TDABC method. The results revealed an increase of 350% in the clinic’s capacity as a result of using a genetic counselor, reduction in the number of changes in the absence of patients, reducing the unused capacity of the clinic, and increasing the number of patients visited per week to 10 cases by telephone reminders before the appointment. Also, after applying these changes, costs were dropped by 18% [46]. Huang [21] developed a conceptual model of TDABC at a cancer center. In this study, three types of cancer (oral cavity, throat, and larynx) were investigated for the purpose of calculating the total cost of the treatment cycle using the TDABC method. It was attempted to review the results of the implementation of TDABC by examining a pilot study at a cancer center. Based on the findings of this study, TDABC cost information can be used for annual budgeting, resource management, human resource, and equipment planning. It was also revealed that TDABC implementation helps to reduce healthcare costs on a large scale [21].

2.3. Application of fuzzy set theory in costing

The theory of fuzzy sets was first introduced in 1965 by Lotfi Zadeh in a treatise called “fuzzy sets”. The most important application of the fuzzy sets theory is its ability to present vague issues through quantified accurate information so that decision-makers take advantage of the quantification of uncertain and inaccurate information and thus reduce potential risks in their analysis models using fuzzy data [38].

A fuzzy set is a membership function that attributes the elements of the domain, space, or matter × to the unit interval [0,1]. When a given value is closer to 1, there is a higher degree of its membership, and greater power of the subject to be associated with that set. If the membership value is zero, it indicates the absence of membership and if it is equal to one, it indicates full membership [51]. We call a convex normal fuzzy set A of real numbers as a fuzzy number whenever:

1- There is exactly one $x_o \in R$ so that $\mu_A(x) = 1$
2- $\mu_A(x)$ piece by piece is jointed

where μ is called membership function that maps each $\times \in X$ to a value in the interval [0,1] and $\mu_A(x)$ is called the membership degree in set A. Depending on whether × is jointed or discrete, A will either be jointed or discrete. A triangular fuzzy number (TFN) is a special type of fuzzy number defined as a triple (a_S, a_M, a_L) (Fig. 1). These parameters

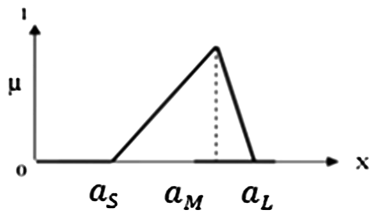

Fig. 1. Triangular fuzzy number.

represent the smallest possible value, the most promising value, and the largest possible value. The membership function (μ) of the triangular fuzzy numbers is defined as:

$$\mu_A(x) = \begin{cases} \frac{x-a_S}{a_M-a_S} & a_s \le x \le a_M \\ \frac{a_L-x}{a_L-a_M} & a_M \le x \le a_L \\ 0 & otherwise \end{cases} \tag{1}$$

In this paper, triangular fuzzy numbers (TFN) are used to indicate the uncertainty in the input parameters of TDABC system. The reason for using TFN is that it is easier to use and better to understand compare to other complex types of fuzzy numbers such as trapezoidal, bell-shaped, S-shaped, quadratic, and exponential [9]. These advantages are taken into account from the perspective of mathematical calculations and the extraction of the information required in the development process of the FL-TDABC system. The main advantage of using triangular fuzzy numbers compared with other fuzzy numbers in this study is that the TDABC system uses the most probable input values of the FL-TDABC system in costing. This advantage makes it possible to examine the impact of the uncertainty conditions in the TDABC model through the use of the minimum and maximum possible values. Because of using both systems from a probable value, it is possible to examine the effect of uncertainty conditions on the TDABC system through the two maximum and minimum amounts in calculating the cost of health care in the proposed model while it is not possible in other fuzzy numbers such as trapezoidal. In addition, the use of fuzzy triangular numbers in the new system ensures that the combination of fuzzy input data provides only additional information for the costing system and the TDABC system information will not be lost. The defuzzification method was used to achieve the best possible true value. In fact, fuzzification is the conversion of true values into fuzzy values while defuzzification is the determination of the best true value representing a fuzzy value. There are several methods for defuzzification, such as the center of gravity, the center of sums, the largest of the maximum method, the smallest of maximum, and the mean of maximum methods. Since the center of gravity (COG) method is one of the most commonly used and most accurate methods, we will use this method in the current paper. Defuzzification using the COG method first was developed by Sugeno [45]. This method can be calculated as follows:

$$x^* = \frac{\int \mu(x).\, xdx}{\int \mu(x)dx} \tag{2}$$

where × represents the fuzzy output and x^* also represents the exact value of the fuzzy output. The center of gravity method of defuzzification of triangular fuzzy numbers (a_S, a_M, a_L) can be calculated by calculating the mean of three values (a_L, a_M, a_S). In this study, this method is also used because of its simplicity and comprehensiveness.

$$x^* = (a\_S + a\_M + a\_L)/3 \tag{3}$$

Recently, the theory of fuzzy sets has been extensively used in many fields; e.g., engineering economics such as evaluation of information technology investment [42], cost-benefit analysis [48], project selection [34], capital budgeting [25,32], and supply chain planning [40]. In the absence of complete and accurate information, the fuzzy set theory covers ambiguity and risk for each of the above materials. In cost analysis, the Fuzzy set theory was first used by Nachtmann and Needy [38] as a method for estimating ABC model parameters and considering prediction error and uncertainty conditions of this system. In this study, introducing a new Fuzzy Activity-based Costing (FABC) system, they compared the results of this system with the TCS by examining the overhead and product costs as well as the profitability of products in a pharmaceutical company. Then, the results of both systems were examined and analyzed for each of the products [38]. In another study, Nachtmann and Needy [39] developed and compared methods for considering uncertainty in the ABC system. To this end, they applied intermediate mathematics, Monte Carlo simulation with triangular input parameters, Monte Carlo simulation with normal input parameters, and fuzzy set theory to compare the costing of a software company products under conditions of uncertainty. The aforementioned methods were analyzed and compared from the point of view of time-related costs, consumption of resources, and benefits from the implementation of each method. Accordingly, the fuzzy set theory was recommended as an effective and efficient method for combining ambiguous and unclear data in the ABC system [39]. Esmalifalak et al. [12] compared three different types of ABC systems at a medical center: Traditional (TABC), Fuzzy (FABC), and Monte Carlo (MCABC). They used T-test to compare these systems and statistically analyzed the results of each system. Based on the results of this study, the use of FABC system in hospitals could lead to a more accurate estimation of costs than TABC system for conditions in which information is significantly obscure [12]. The fuzzy set theory has potential benefits for managers in providing them with important information for the purpose of decision-making. In addition, it represents the sensitivity analysis of ABC models with the best and worst results. Accordingly, many authors have used fuzzy logic to consider uncertainty in ABC systems in various fields. For instance, Werikat and Rawabdeh [49] applied fuzzy logic to cope with uncertainty in the implementation of ABC systems. The proposed FL-ABC model is presented to address the problem of determining the cost drivers in the ABC system for small and medium-sized manufacturing enterprises. The fuzzy logic in this paper was used to determine the appropriate cost drivers for allocating resource costs to activities and allocating the cost of activities to products. They showed that the combination of fuzzy logic with the ABC system improves the ability to reduce uncertainty and complexity in the ABC system for small and medium-sized manufacturing enterprises, which can improve the capability of ABC system in dealing with conditions of uncertainty [49]. Akbarzade and Hematfar [1] reviewed the performance of the ABC system at Ordibehesht Hospital in Shiraz. In this study, based on a hospital division into operational, diagnostic, and support centers, they performed the ABC model through seven proposed steps to calculate the costs of the radiology department and then compared the results with the traditional system. Due to the uncertainty in cost estimation, they used a fuzzy approach to enhance the reliability of data [1]. In another study, a new model of ABC system in accordance with TDABC and fuzzy set theory was proposed. The proposed model was used to calculate the precise costs of products of a toy manufacturing company with uncertain sources of costs and the results of this model were compared with the standard TDABC system. Researchers concluded that cost estimation is more supportive by using a fuzzy-TDABC system for managerial decision makings such as setting prices, assessment evaluation, and strategic planning [7]. In another study, Mortaji et al. [36], using TFN, proposed a new mechanism for the TDABC system. They applied this model to a hypothetical sample and compared the results with the conventional TDABC system. Eventually, the reported a significant difference between the estimated costs of these two systems [36]. Mwaikambo et al. [37] presented a model for estimating the cost of accessing spatial data based on fuzzy logic and TDABC. They used fuzzy set theory to consider the uncertainty in cost parameter values, which resulted in achieving more reliable estimates for the cost of accessing spatial data and relevant sources [37]. One of the main issues in the TDABC system is to determine appropriate time drivers and the cost of

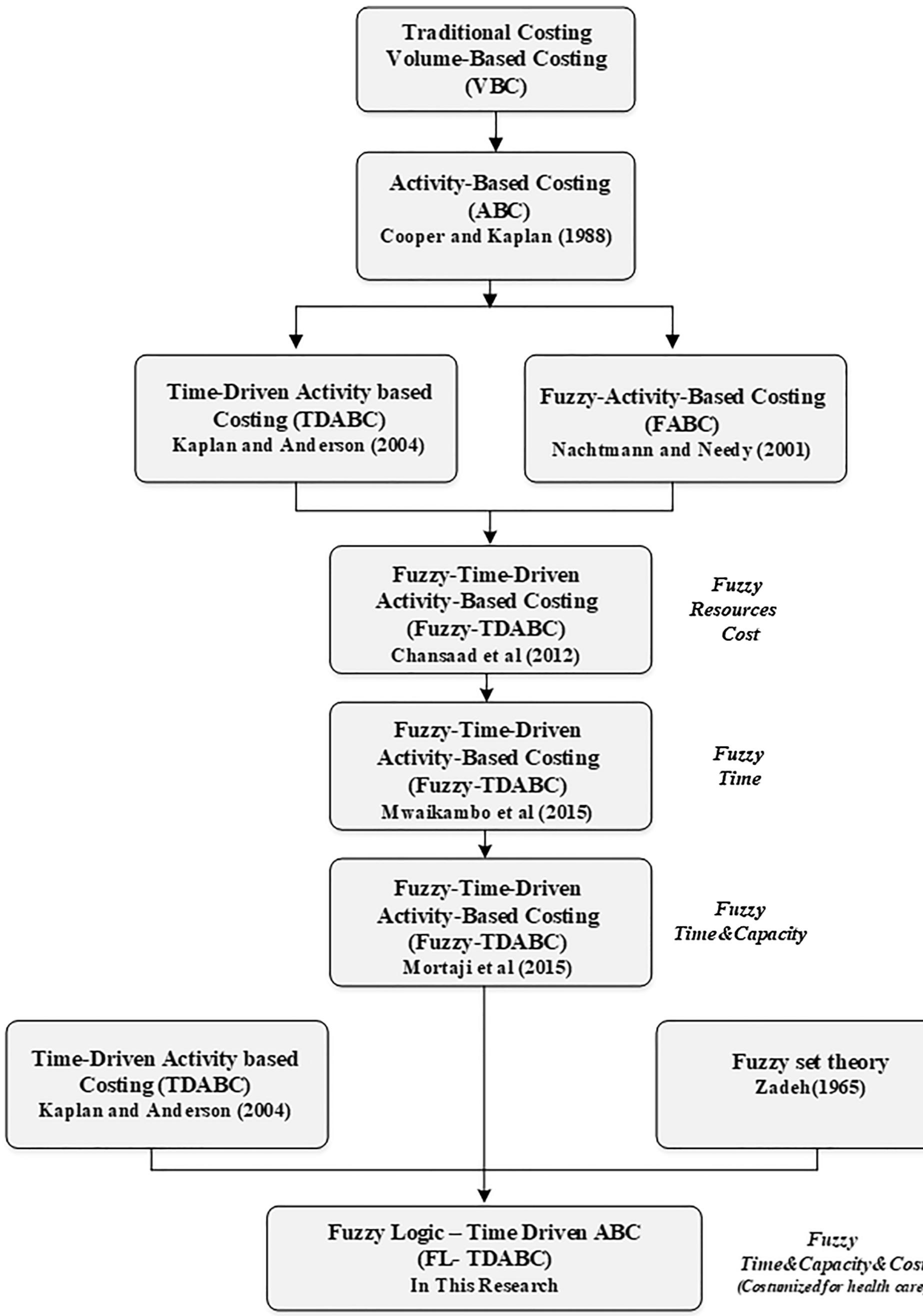

Fig. 2. Evolutionary Process of Costing Models.

used resources in order to allocate costs to the activities. Since hospital environment involves with ambiguity and uncertainty in determining resources cost and estimating the time it takes to perform activities, the use of fuzzy logic in determining these cases will lead to better and more precise results. In studies conducted on healthcare services costing so far, information on capacity, time, and cost, even under uncertain conditions of cost estimation, is often taken into account as definitive and conditions of uncertainty in the hospital services costing systems have not been investigated. In fact, the fuzzy models presented in these investigations are generally presented in the field of ABC systems, and so far no model has been developed to match the existing features in hospitals to address their uncertainties. Furthermore, the uncertainty conditions in cost, capacity, and time parameters in models that have been used so far in the use of fuzzy logic in ABC systems are not simultaneously considered. Incorrect estimates of these three parameters may cause a significant deviation in determining the costs assigned to the services compared with the actual values. To solve the problems, a new framework for costing based on Fuzzy Logic-TDABC is presented in this paper. Fig. 2 shows the evolutionary process of costing models. The use of fuzzy logic in the TDABC system improves the method of estimating parameters based on the theory of fuzzy sets. Using this method enables us to consider the inherent data inaccuracies in the TDABC system and to examine the effects of such inaccuracies.

3. Fuzzy Logic-Time Driven Activity-based costing model (FL-TDABC)

Practical capacity, time, and cost are important elements of the TDABC system that have a significant impact on the results of this system. Actually, their inaccurate estimation may lead to a significant

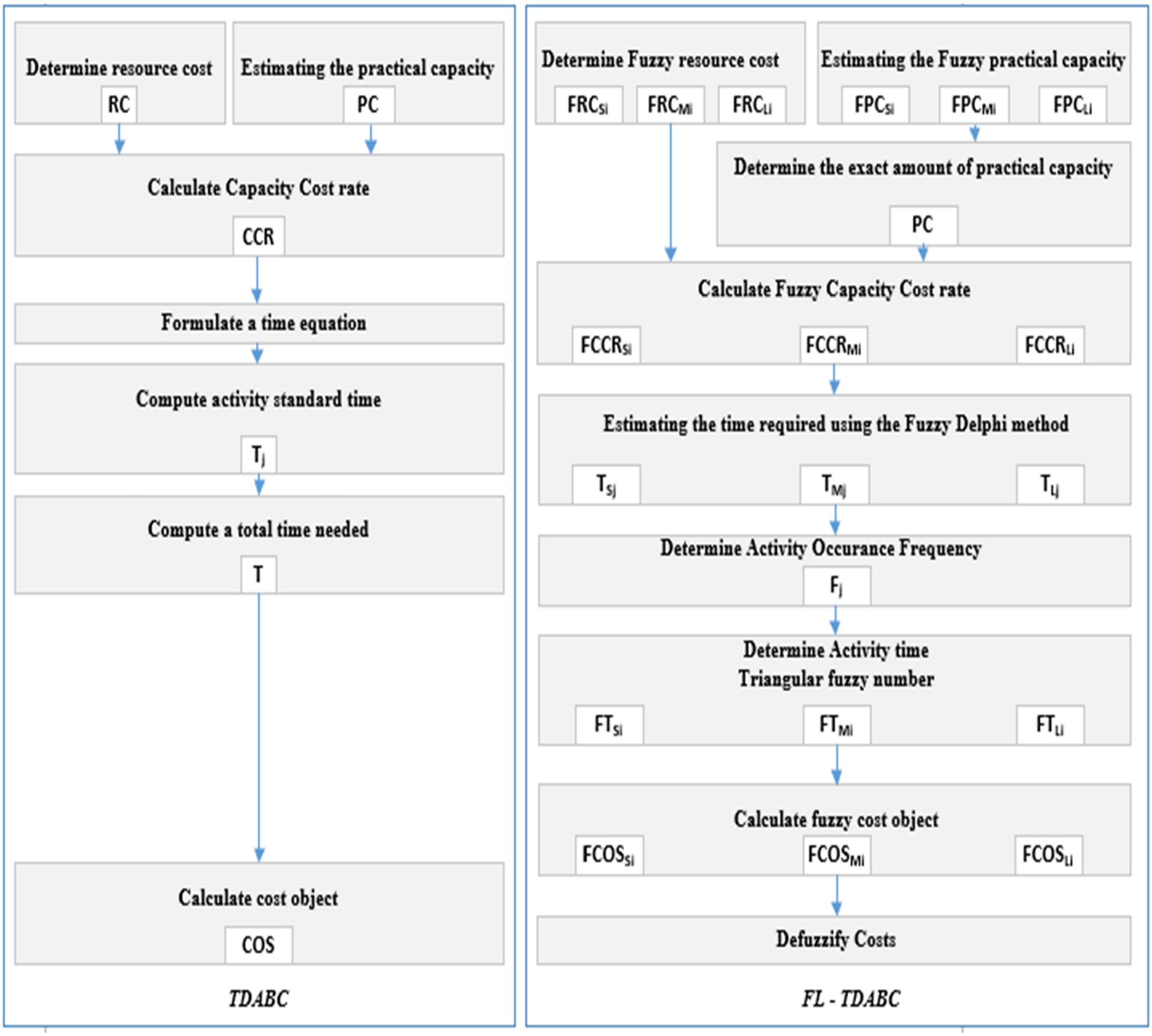

Fig. 3. Difference between FL-TDABC and Standard TDABC Model (modified from [7,37], Mortaji et al., 2015).

deviation from true values in the calculation of costs associated with products or services. Since the TDABC system is time-based, even the least errors occurred in the estimation of key activities' time will lead to undesirable effects. Also, in cases where there is any uncertainty in determining the cost of resources, the resulted deviation in determining the costs will have adverse effects. Hence, we introduced a new framework, called FL-TDABC. The fuzzy set in the proposed model is used to represent the ambiguity and uncertainty in capacity, resources, and time data. Fig. 3 illustrates the proposed FL-TDABC approach compared to the standard TDABC. As can be seen, the proposed model consists of seven key steps that can be described as follows:

Step 1: identifying the resources and activities and collecting cost data using fuzzy set method (FRC)

At this stage, all activities related to the provision of services, as well as the resources used by these activities and their costs are well identified. In the FL-TDABC model, the resource costs of each department are represented in the form of triangular fuzzy numbers. The cost parameter in this model has three values; smallest possible value (FRC_{Si}), the most possible value (FRC_{Mi}), and the largest possible value (FRC_{Li}).

$$FRCi = (FRC_{Si}, FRC_{Mi}, FRC_{Li}) \tag{4}$$

Step 2: Estimating the practical capacity of each department using the Fuzzy Delphi (FPC) method

According to the arbitrary approach, the practical capacity is determined as a specific percentage of nominal capacity. In this stage, the Fuzzy Delphi method is used to estimate this percentage in the form of triangular fuzzy numbers. An important feature of this approach is providing a flexible framework that covers many of the barriers related to inaccuracies and ambiguity. Fuzzy Delphi method can achieve the highest degree of reliability of the results and it can be appropriate and effective in long-term predictions. This technique was presented by Kaufmann and Gupta in 1988 [30]. The Fuzzy Delphi method consists of a group of experts who respond anonymously to some questionnaires and then receive feedback in the form of statistical representation of the group's response. This process continues until a consensus is achieved. The phases of the Delphi method are as follows:

1- Experts provide their estimates in the form of the minimum value, the most possible value, and the maximum value (triangular fuzzy numbers).

$$Ai = (aS^{(i)}, aM^{(i)}, aL^{(i)}), \ i = 1, 2, \cdots, n \tag{5}$$

2- The answers of N experts form a group of responses. Then, using the fuzzy averaging techniques, the mean of this group (of the experts' opinion) and the difference in opinion of each expert from the mean are calculated, and then this information is sent to the experts for obtaining new estimates.

$$Aave = (m_S, m_M, m_L) \tag{6}$$

$$A_{ave} - A_i = (m_S - a_S^{(i)}, m_M - a_M^{(i)}, m_L - a_L^{(i)}) = (\frac{1}{n}\sum_{i=1}^{n} a_S^{(i)} - a_S^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_M^{(i)} - a_M^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_L^{(i)} - a_L^{(i)} \tag{7}$$

3- Each expert presents a new estimate based on the information obtained from the previous step and, thus, at his discretion, modifies his previous opinion.

$$B_i = (b_S^{(i)}, b_M^{(i)}, b_L^{(i)}), \ i = 1, 2, \cdots, n \tag{8}$$

4- This process continues until the mean of the opinion group is stable enough. If the mean difference of 2 fuzzy rounds (the distance between two fuzzy numbers) falls below a threshold (e.g., 0.2), it means that the mean of the obtained numbers is stable enough and the Delphi process will be stopped.

Upon completion of the Delphi process, the practical capacity percentage of each department is determined in the form of triangular fuzzy numbers. $FPCP_{Si}$, $FPCP_{Mi}$, and $FPCP_{Li}$ respectively represent the practical capacity percentage of departmental i of its nominal capacity. Since the practical capacity of the department is determined as a percentage of its nominal capacity, the practical capacity of each department can be estimated by this way. The practical capacity in the FL-TDABC model is shown with triplet values including FPC_{Si}, FPC_{Mi}, FPC_{Li}, which are respectively the smallest possible value, the most possible value, and the largest possible value for the practical capacity of department i. For more clarity, the practical capacity of department i is expected to be equal to FPC_{Mi} and it is not expected to be smaller than FPC_{Si} or greater than FPC_{Li}.

$$FPC_i = (FPC_{Si,}FPC_{Mi,}FPC_{Li}) = (FPCP_{Si} * NC_i, FPCP_{Mi} * NC_i, FPCP_{Li} * NC_i) \tag{9}$$

In this regard, NC_i represents the nominal capacity of department i, which is determined by interviewing the staff and questionnaires. For example, nominal capacity is the number of the days per year that each source has access to.

Step 3: Determine the exact amount of practical capacity of each department (PC)

After determining the fuzzy practical capacity, the values obtained through Eq. (3) are converted to definite values and are used in the Fuzzy Logic-Time-Driven ABC model.

$$PC_i=(FPC\_Si + FPC\_Mi + FPC\_Li)/3) \tag{10}$$

Step 4: Calculation of Fuzzy Capacity Cost rate (FCCR)

Capacity Cost rate is equal to monetary value per minute of the time spent by the activity, which is obtained by dividing the total cost of each department by the practical capacity. The smallest possible value ($FCCR_{Si}$), the most possible value ($FCCR_{Mi}$), and the largest possible amount ($FCCR_{Li}$) of FCCR for department i is calculated through Eq. (11).

$$FCCR_i = (FCCR_{Si}, FCCR_{Mi}, FCCR_{Li}) = (FRC\_Si/PC\_i, FRC\_Mi/PC\_i, FRCF\_Li/PC\_i) \tag{11}$$

Step 5: Estimating the time required for each department using the Fuzzy Delphi method (FT)

In this stage, the Fuzzy Delphi method is used to estimate the time required for each department in the form of triangular fuzzy numbers. The time parameter in the FL-TDABC model has three values, including the smallest possible value (FT_{Si}), the most possible value (FT_{Mi}), and the largest possible value (FT_{Li}), which are obtained through the following equation. The time required for each department is determined by the total times of available departmental activities, which have been estimated using the fuzzy Delphi method.

$$FT_i = (FTS_i, FTM_i, FTL_i) = (\sum T_{Sj} * F_j, \sum T_{Mj} * F_j, \sum T_{Lj} * F_j) \tag{12}$$

where T_j represents the time needed to perform activity j, F_j denotes the number of occurrences of activity j, and T_i indicates the available activity time j in the department i.

Step 6: Calculation of the final cost of services using the Fuzzy set Method (FCOS)

At this stage, the final cost of services is derived from multiplying the sum of the estimated fuzzy time of each department activities (FT) by the FCCR according to Eq. (13). In this equation, $FCOS_{Si}$, $FCOS_{Mi}$, $FCOS_{Li}$ represent the smallest possible, most possible, and the largest possible values of the final cost of department i services, respectively. Given that the "Capacity cost rate" and "Time Required to Perform Activities" are shown by Triangular Fuzzy Numbers (TFNs), there will be nine different modes that will be examined based on the time parameter in three different relationships (14–16). For example, one relationship is for a mode in which the time is in optimistic condition (smallest possible) and capacity cost rate is in three conditions of optimistic, moderate (most possible), and pessimistic (largest possible), respectively. This mode determines the values for the smallest possible value for the final cost of services ($FCOS_{Si}$). In this equation, $FCOS_{SSi}$, $FCOS_{SMi}$, and $FCOS_{SLi}$ denote respectively the smallest possible, the most possible, and the largest possible values for the final cost of services in a situation where time is in an optimistic condition and capacity cost rate is in optimistic, moderate, and pessimistic conditions.

$$FCOS_i = (FCOS_{Si}, FCOS_{Mi}, FCOS_{Li}) \tag{13}$$

$$FCOS_{Si} = (FCOS_{SSi}, FCOS_{SMi}, FCOS_{SLi}) = (FT_{Si} * FCCR_{Si}, FT_{Si} * FCCR_{Mi}, FT_{Si} * FCCR_{Li}) \tag{14}$$

$$FCOS_{Mi} = (FCOS_{MSi}, FCOS_{MMi}, FCOS_{MLi}) = (FT_{Mi} * FCCR_{Si}, FT_{Mi} * FCCR_{Mi}, FT_{Mi} * FCCR_{Li}) \tag{15}$$

Table 2
Fuzzy costs associated with the laboratory unit.

Resource cost	FRC_{Si}	FRC_{Mi}	FRC_{Li}
Manpower	2,461,008,192	2,652,037,129	2,830,136,925
Consumables	478,563,751	555,913,485	673,525,384
Depreciation	239,213,648	246,730,000	257,254,902
Overheads	101,594,246	122,608,500	139,003,481
Cost allocated from other centers	437,361,507	455,523,672	489,149,027
Total	3,717,741,344	4,032,812,786	4,389,069,719

$$FCOS_{Li} = (FCOS_{LSi},\ FCOS_{LMi},\ FCOS_{LLi}) = (FT_{Li} * FCCR_S,\ FT_{Li} * FCCR_{Mi},\ FT_{Li} * FCCR) \quad (16)$$

Step 7: Determining the exact amount of the final cost of services (COS)

In the proposed FL-TDABC model, the final cost of services is obtained in terms of triangular fuzzy numbers (TFNs). If necessary or for reasons like better decision making, fuzzy outputs can be converted into crisp values. Thus, in this stage, the fuzzy sets of the final cost of the services by Eq. (3) will be defuzzified in order to determine the definitive value of the COS. Accordingly, definitive service costs will be determined as follows:

$$COS_i = (FCOS\_Si + FCOS\_Mi + FCOS\_Li)/3) \quad (17)$$

$$COS_{Si} = (FCOS\_SSi + FCOS\_SMi + FCOS_{SLi})/3) \quad (18)$$

$$COS_{Mi} = (FCOS\_MSi + FCOS\_MMi + FCOS\_MLi)/3) \quad (19)$$

$$COS_{Li} = ((FCOS\_LSi + FCOS\_LMi + FCOSL\_Li)/3) \quad (20)$$

4. A numerical example, results, and discussion

In this section, the application of the proposed method is presented in a numerical example. For this purpose, the data collected by Hejazi et al [19] in the hospital laboratory section were used [19]. A comparison is also made between the results of the proposed model and the results of the standard TDABC model used in their research. Since the determination of the cost of services in hospitals based on the number of treated patients – and regarding various factors, such as the capacity and skill of doctors, technicians, and other healthcare personnel, and the time needed to perform various activities – is associated with uncertainty, not considering the uncertainty conditions in calculating the cost of healthcare service may lead to inaccurate results and often show more or less costs than actual values. Therefore, in this study, we tried to use the proposed model in accordance with the characteristics of hospitals and healthcare centers by examining a numerical example in a laboratory that faces such conditions.

Step 1. In the first stage, activities related to the provision of laboratory services as well as resources used by these activities and their costs are identified. In this regard, laboratory activities were categorized into four groups, i.e., Admission, Sampling, Testing, and Result, which vary according to the type of tests. Also, the cost of activities includes labor costs, consumables, depreciation, overhead costs, and costs allocated from other centers. Table 2 represents the costs associated with the laboratory unit. This information was gathered through direct observation of activities, interviews with key experts and staff, and reviewing the financial and process information of the hospital.

Step 2. At this stage, the Fuzzy Delphi method was used to estimate the practical capacity of the laboratory as a percentage of its nominal capacity. To this end, a team consisting of six experts was selected and asked to determine the capacity of the laboratory as a percentage of its nominal capacity. These experts were asked to provide estimates in form of Triangular Fuzzy Numbers (TFNs). At each stage, the mean of the group (mean of experts' opinion) and the difference of each expert's opinion from the mean of the group were calculated and the achieved information was sent to experts for obtaining new estimates. The results of this method are presented in Table 3. This process was stopped after the second repetition because, in this repetition, the mean of TFNs was approximately equal. Therefore, the second TFN's mean was accepted as a consensus of the experts' opinion and became the basis of determining the amount of practical capacity of the laboratory.

Table 3
Successive estimates of fuzzy practical capacity percentage.

	Round1			Round2		
Staff identity No	$FPCP_{Si}$	$FPCP_{Mi}$	$FPCP_{Li}$	$FPCP_{Si}$	$FPCP_{Mi}$	$FPCP_{Li}$
E1	0.85	0.87	0.9	0.84	0.86	0.89
E2	0.8	0.84	0.86	0.8	0.85	0.87
E3	0.85	0.88	0.91	0.85	0.88	0.91
E4	0.83	0.85	0.89	0.83	0.85	0.89
E5	0.8	0.83	0.85	0.81	0.83	0.85
E6	0.82	0.85	0.9	0.82	0.85	0.89
Mean	0.825	0.853	0.885	0.825	0.853	0.883

Table 4
Fuzzy capacity cost rate.

Resource cost	$FCCR_{Si}$	$FCCR_{Mi}$	$FCCR_{Li}$
Manpower	3563.230984	3839.816909	4097.683061
Consumables	692.9002475	804.8929543	975.1802227
Depreciation	346.3513389	357.2340732	372.4728104
Overheads	147.0957172	177.5217196	201.2595943
Cost allocated from other centers	633.2445695	659.5411049	708.2263986
Total	5382.822857	5839.006761	6354.822087

Given that based on the arbitrary approach, practical capacity in accordance with Eq. (9) is determined as a percentage of nominal capacity, it is possible to determine the practical capacity of the laboratory as follows:

Number of laboratory staff = 6
Average workdays = 30 day
Available time per day = 6.2 hr
Nominal capacity (NC) = 6 * 365 * 6.2 = 13578 h
Fuzzy practical capacity percentage (FPCP) = (0.824, 0.845, 0.875)
Fuzzy practical capacity in hours (FPC) = (11179.22, 11473.41, 11880.75)
Fuzzy practical capacity in minutes (FPC) = (670753.2, 688404.6, 712845)

Step 3. After determining the fuzzy practical capacity of the laboratory, the value obtained through Eq. (10) will be converted into definite value and will be used in the next stages of the model.
Practical capacity in minutes (PC) = (670753.2 + 688404.6 + 712845)/3) = 690667.6

Step 4. Capacity cost rate is determined by dividing the total cost of the laboratory by practical capacity. At this stage, based on a variety of laboratory costs, capacity cost rate is calculated using Eq. (11). The results of this step are presented in Table 4.

Step 5. At this stage, the Fuzzy Delphi method is applied to estimate the time used for performing activities. Using this method, the time spent on the activities performed for each lab service is determined by selecting a group of six experts who were asked to estimate the time spent for activities in the form of triangular fuzzy numbers

Table 5
Successive estimates of time spent on admission activity (serology).

Admission	Round1			Round2		
Staff identity No	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}
E1	0.6	0.8	1.2	0.7	0.9	1.4
E2	0.9	1.1	1.5	0.8	1.1	1.6
E3	1	1.2	1.9	1	1.1	1.8
E4	0.7	0.9	1.3	0.7	1	1.5
E5	0.9	1.2	1.9	0.9	1.2	1.8
E6	1	1.3	2	1	1.2	1.9
Mean	0.85	1.083	1.631	0.85	1.083	1.666

Table 6
Successive estimates of time spent on sampling activity (serology).

Sampling	Round1			Round2			Round3		
Staff identity No	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}
E1	1.3	1.7	2.1	1.3	1.6	2	1.3	1.6	1.9
E2	1.2	1.5	1.7	1.2	1.5	1.7	1.2	1.5	1.7
E3	1	1.3	1.6	1.1	1.4	1.5	1.2	1.4	1.6
E4	1.3	1.5	1.8	1.3	1.5	1.8	1.3	1.5	1.8
E5	1.4	1.6	2	1.4	1.6	1.9	1.3	1.5	1.8
E6	1	1.2	1.5	1	1.4	1.7	1	1.5	1.7
Mean	1.2	1.467	1.783	1.217	1.5	1.767	1.217	1.5	1.75

Table 7
Successive estimates of time spent on testing activity (serology).

Testing	Round1			Round2			Round3		
Staff identity No	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}
E1	60	63	70	58	62	68	57	61	67
E2	53	60	65	55	60	65	55	60	65
E3	50	58	62	53	58	62	54	58	63
E4	65	66	75	62	64	72	60	64	71
E5	58	60	65	56	60	65	56	60	65
E6	50	58	60	55	58	62	57	59	62
Mean	56	60.83	66.167	56.5	60.33	65.67	56.5	60.33	65.5

(TFNs); i.e., the minimum possible time, the most possible and the maximum possible time. At each stage, the mean of the group (mean of the experts' opinion) and the difference in opinion of each expert from the mean of the group were calculated and this information was sent to experts for obtaining new estimates. Tables 5-8 provide examples of the results of this method for serology testing. For this experiment, the fuzzy Delphi process was stopped, depending on various activities, after the second or third repetitions; hence, the mean TFN of the last round was accepted as the consensus of the experts' opinion and considered as the basis for determining the spent time of the lab activities. Table 9 shows the activity time for each type of experiment, based on Eq. (12).

Step 6. At this stage, based on the Eq. (13), by determining the time of activities related to the laboratory services, the final cost of each experiment is determined by multiplying the fuzzy time of the activities related to each experiment (FT) by the FCCR. Given that the "capacity cost rate" and "Time Required to Perform Activities" are shown by TFNs, nine different modes would be obtained that are examined according to the time parameter in three conditions (Eqs. (14) to (16)). Table 10 shows the allocation of human resources costs to a variety of services provided in the laboratory. Other expenses are also allocated to services in the same way. Table 11 shows the final cost of each experiment in the form of triangular fuzzy numbers.Table 12.

Table 8
Successive estimates of time spent on result activity (serology).

Result	Round1			Round1			Round1		
Staff identity No	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}	T_{Sj}	T_{Mj}	T_{Lj}
E1	0.6	1	1.5	0.7	1	1.4	0.7	1	1.5
E2	0.5	1	1.8	0.5	1	1.5	0.6	1	1.3
E3	1	1.3	2	0.8	1.3	1.9	0.8	1.3	1.8
E4	0.7	1	1.2	0.7	1	1.2	0.7	1	1.2
E5	0.5	0.8	1	0.6	0.9	1	0.6	0.9	1
E6	1	1.2	1.5	0.9	1	1.2	0.8	1	1.2
Mean	0.717	1.05	1.5	0.7	1.033	1.367	0.7	1.033	1.333

Step 7. In the proposed FL-TDABC model, the final cost of services is obtained in terms of triangular fuzzy numbers. In the case of any necessity or for better decision making, fuzzy outputs can be converted into crisp values. Thus, in this stage, the fuzzy sets of the final cost of the services by Eqs. (17)–(20) are defuzzified in order to determine the definitive value of the COS. Accordingly, definitive service costs will be determined. Tables 12 and 13 present the exact costs of a variety of services provided by the lab based on the type of activity and its cost, respectively.

4.1. Results

4.1.1. Comparing the FL-TDABC with TDABC for hematology test

The FL-TDABC predicted the cost of the Hematology test to be 635,759,600.5 IRR that is 2.85% more than the TDABC model by the cost of 618,142,765.4 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (2.33%) Consumables (4.98%), Depreciation (2.92%), Overheads (1.21%), and Cost allocated from other centers (3.66%) (Table14).

4.1.2. Comparing of FL-TDABC with TDABC for serology test

The FL-TDABC predicted the cost of the Serology test to be 571560059.9 IRR that is 1.39% more than the TDABC model by the cost of 563699570.7 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (0.89%) Consumables (3.49%), Depreciation (1.46%), Overheads (0.22%), and Cost allocated from other centers (2.19%) (Table15).

4.1.3. Comparing of FL-TDABC with TDABC for biochemistry test

The FL-TDABC predicted the cost of the Biochemistry test to be 1,530,351,334 IRR that is 0.42% more less the TDABC model by the cost of 1,536,755,609 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (0.92%) Consumables (1.64%), Depreciation (0.35%), Overheads (2%), and Cost allocated from other centers (0.37%) (Table16).

4.1.4. Comparing of FL-TDABC with TDABC for hormone test

The FL-TDABC predicted the cost of the Hormone test to be 169112270.1 IRR that is 0.03% more less the TDABC model by the cost of 169167281.6 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (0.53%) Consumables (2.03%), Depreciation (0.03%), Overheads (1.62%), and Cost allocated from other centers (0.75%) (Table17).

4.1.5. Comparing of FL-TDABC with TDABC for blood bank test

The FL-TDABC predicted the cost of the Blood bank test to be 7440431.022 IRR that is 4.75% more less the TDABC model by the cost of 7811911.556 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (5.23%) Consumables (2.79%), Depreciation (4.69%), Overheads (6.27%), and Cost allocated from other centers (4%) (Table18).

Table 9
The activity time for each type of experiment.

Activity	Driver	Type of experiment	T_{Sj}	T_{Mj}	T_{Lj}	F_j	FT_{Si}	FT_{Si}	FT_{Si}
Admission	Patient admission for testing	Hematology	0.85	1	1.6	1485	1262.25	1485	2376
Sampling	Blood sampling	Hematology	1.22	1.5	1.75	1485	1811.7	2227.5	2598.75
Testing	Hematology	Hematology	58	60	67	1672	96,976	100,320	112,024
Result	Finding the test result to deliver it to the patient	Hematology	0.7	1	1.3	1485	1039.5	1485	1930.5
Admission	Patient admission for testing	Serology	0.85	1	1.6	2584	2196.4	2584	4134.4
Sampling	Blood sampling	Serology	1.22	1.5	1.75	2584	3152.48	3876	4522
Testing	Hematology	Serology	56.5	60	65.5	1453	82094.5	87,180	95171.5
Result	Finding the test result to deliver it to the patient	Serology	0.7	1	1.3	2584	1808.8	2584	3359.2
Admission	Patient admission for testing	Biochemistry	0.85	1	1.6	2093	1779.05	2093	3348.8
Sampling	Blood sampling	Biochemistry	1.22	1.5	1.75	2093	2553.46	3139.5	3662.75
Testing	Hematology	Biochemistry	116	120	122	2125	246,500	255,000	259,250
Result	Finding the test result to deliver it to the patient	Biochemistry	0.7	1	1.3	2093	1465.1	2093	2720.9
Admission	Patient admission for testing	Hormone	0.85	1	1.6	2122	1803.7	2122	3395.2
Sampling	Blood sampling	Hormone	1.22	1.5	1.75	2122	2588.84	3183	3713.5
Testing	Hematology	Hormone	142.5	150	151	143	20377.5	21,450	21,593
Result	Finding the test result to deliver it to the patient	Hormone	0.7	1	1.3	2122	1485.4	2122	2758.6
Admission	Patient admission for testing	Blood bank	0.85	1	1.6	21	17.85	21	33.6
Sampling	Blood sampling	Blood bank	1.22	1.5	1.75	21	25.62	31.5	36.75
Testing	Hematology	Blood bank	56	60	54.5	21	1176	1260	1144.5
Result	Finding the test result to deliver it to the patient	Blood bank	0.7	1	1.3	21	14.7	21	27.3
Admission	Patient admission for testing	Parasitology	0.85	1	1.6	5714	4856.9	5714	9142.4
Sampling	Blood sampling	Parasitology	1.22	1.5	1.75	0	0	0	0
Testing	Hematology	Parasitology	18	20	22.5	5714	102,852	114,280	128,565
Result	Finding the test result to deliver it to the patient	Parasitology	0.7	1	1.3	5714	3999.8	5714	7428.2
Admission	Patient admission for testing	Microbiology	0.85	1	1.6	2107	1790.95	2107	3371.2
Sampling	Blood sampling	Microbiology	1.22	1.5	1.75	0	0	0	0
Testing	Hematology	Microbiology	19	20	23	2107	40,033	42,140	48,461
Result	Finding the test result to deliver it to the patient	Microbiology	0.7	1	1.3	2107	1474.9	2107	2739.1

4.1.6. Comparing of FL-TDABC with TDABC for parasitology test

The FL-TDABC predicted the cost of the Parasitology test to be 747109837.3 IRR that is 1.45% more than the TDABC model by the cost of 736422780.6 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (0.94%) Consumables (3.55%), Depreciation (1.52%), Overheads (0.16%), and Cost allocated from other centers (2.25%) (Table19).

4.1.7. Comparing of FL-TDABC with TDABC for microbiology test

The FL-TDABC predicted the cost of the Microbiology test to be 281664183.6 IRR that is 3.72% more than the TDABC model by the cost of 271551067.3 IRR. Cost differences based on the cost values of TDABC were found in all cost categories; i.e., Manpower cost (3.2%) Consumables (5.87%), Depreciation (3.79%), Overheads (2.07%), and Cost allocated from other centers (4.54%) (Table20).

4.2. Discussion

TDABC is a cost accounting system that can be used to calculate actual healthcare services costs. The system is designed for relatively accurate or adequate information that can accurately estimate the cost of services provided to patients. However, estimating the cost and time required for most hospital activities is a subjective and uncertain matter. Because healthcare costs often vary according to the performance of physicians and other healthcare personnel, there are high variations in the cost of healthcare services due to the uncertainty involved their capacity and performance. Such cases also have a significant impact on the time and cost of services provided to patients, making it impossible to estimate accurately the cost and time required for most hospital activities. To address this challenge, the present study used the fuzzy logic in the TDABC model to resolve the inherent ambiguity and uncertainty and determine the best possible values for cost, capacity, and time parameters to provide more accurate information on the costs of the healthcare services. This approach has not yet been tested and used in determining the costs of services of a healthcare setting. This paper aims to present a hybrid model for estimating the costs of healthcare services based on a Fuzzy Logic and TDABC methodology. To examine the proposed model, a set of data related to a laboratory was used. Table 21 illustrates the results of the FL-TDABC model compared to the TDABC model of Hejazi et al [19]. As it is shown, due to uncertainty in the costs associated with each activity, there is a significant difference between the estimated costs of these two systems. For hematology, serology, parasitology, and microbiology tests, the use of the FL-TDABC model has shown higher costs (635,759,600.5, 571,560,059.9, 747,109,837.3, and 281,664,183.6 IRR, respectively) while for biochemistry, hormone and blood bank tests have shown lower costs (1,530,351,334, 169,112,270.1 and 7,440,431.022 IRR, respectively) compared to the TDABC method (618,142,765.4, 563,699,570.7, 736,422,780.6, 271,551,067.3, 1,536,755,609, 169,167,281.6 and 7,811,911.556 IRR, respectively). Also, the highest difference in the prescribed costs was found in the blood bank, Microbiology and Hematology tests at 4.75, 3.72, and 2.85%, respectively, mostly due to uncertainty in the costs of consumables, equipment, and manpower (on average 4.54%, 3.8%, and 3.59%, respectively). The reason for this result is the uncertainty involved in the capacity of technicians and laboratory personnel and the time needed to perform the activities, which is influenced by their skill and performance. Also, these differences are induced by the uncertainty in the cost of laboratory consumables as well as the cost of maintaining and depreciating equipment, which is created depending on the volume of the treated patients and due to uncertainty in the capacity and skill of the technicians to perform laboratory activities. In addition, manpower and consumables have the largest share of the total cost of the laboratory (66% and 14%, respectively) (Fig. 4). Therefore, uncertainty in these costs will also have the greatest impact on the differences in the costs of each test. Fig. 5 compares fuzzy and definitive costs in a blood bank test. In the case of eliminating uncertainty, the standard TDABC uses the most possible values in the calculation and ignores other possible data. Such incomplete information affects the accuracy of the results of the TDABC system and can lead to providing incorrect information by the system. Using the proposed system provides a better perspective about the way the determined costs change in ambiguous

Table 10
The allocation of human resources costs to a variety of experiments.

Type of experiment	Activity	FT_{Si}			FT_{Si}			FT_{Si}		
		FRC_{Si}	FRC_{Mi}	FRC_{Li}	FRC_{Si}	FRC_{Mi}	FRC_{Li}	FRC_{Si}	FRC_{Mi}	FRC_{Li}
Hematology	Admission	4497688.31	4846808.893	5172300.443	5291398.011	5702128.11	6085059.345	8466236.818	9123404.976	9736094.952
Hematology	Sampling	6455505.574	6956596.294	7423772.401	7937097.017	8553192.165	9127589.017	9259946.52	9978724.192	10648853.85
Hematology	Testing	345547887.9	372370084.6	397376912.5	357463332.3	385210432.3	411079564.6	399167387.8	430151649.4	459038847.2
Hematology	Result	3703978.608	3991489.677	4259541.541	5291398.011	5702128.11	6085059.345	6878817.415	7412766.543	7910577.148
Serology	Admission	7826280.533	8433773.859	9000151.074	9207388.863	9922086.893	10588413.03	14731822.18	15875339.03	16941460.85
Serology	Sampling	11233014.41	12104946.01	12917863.89	13811083.29	14883130.34	15882619.54	16112930.51	17363652.06	18529722.8
Serology	Testing	292,521,666	315227849.2	336,397,242	310642477.2	334755238.1	357236009.2	339118037.6	365,441,135	389982643.4
Serology	Result	6445172.204	6945460.825	7411889.12	9207388.863	9922086.893	10588413.03	11969605.52	12898712.96	13764936.94
Biochemistry	Admission	6339166.082	6831226.272	7289983.049	7457842.45	8036736.791	8576450.646	11932547.92	12858778.86	13722321.03
Biochemistry	Sampling	9098567.789	9804818.885	10463269.79	11186763.67	12055105.19	12864675.97	13051224.29	14064289.38	15008788.63
Biochemistry	Testing	878336437.6	946514868.1	1,010,078,874	908623900.9	979153311.8	1,044,909,180	923767632.6	995472533.7	1,062,324,333
Biochemistry	Result	5220489.715	5625715.753	6003515.452	7457842.45	8036736.791	8576450.646	9695195.185	10447757.83	11149385.84
Hormone	Admission	6426999.726	6925877.759	7390990.936	7561176.148	8148091.481	8695283.455	12097881.84	13036946.37	13912453.53
Hormone	Sampling	9224634.901	9940671.607	10608245.81	11341764.22	12222137.22	13042925.18	13232058.26	14259160.09	15216746.05
Hormone	Testing	72609739.38	78245869.06	83500536.57	76431304.61	82364072.7	87895301.65	76940846.64	82913166.52	88481270.33
Hormone	Result	5292823.304	5703664.037	6086698.418	7561176.148	8148091.481	8695283.455	9829528.993	10592518.93	11303868.49
Blood bank	Admission	63603.67307	68540.73183	73143.64263	74827.85067	80636.15509	86051.34427	119724.5611	129017.8481	137682.1508
Blood bank	Sampling	91289.97781	98376.10921	104982.64	112241.776	120954.2326	129077.0164	130948.7387	141113.2714	150589.8525
Blood bank	Testing	4190359.637	4515624.685	4818875.279	4489671.04	4838169.305	5163080.656	4078117.861	4394670.452	4689798.263
Blood bank	Result	52379.49547	56445.30856	60235.94099	74827.85067	80636.15509	86051.34427	97276.20586	104827.0016	111866.7476
Parasitology	Admission	17306256.57	18649606.75	19902036.86	20360301.84	21940713.82	23414161.01	32576482.95	35105142.11	37462657.61
Parasitology	Sampling	0	0	0	0	0	0	0	0	0
Parasitology	Testing	366485433.2	394932848.7	421454898.1	407206036.9	438814276.4	468283220.2	458106791.5	493666060.9	526818622.7
Parasitology	Result	14252211.29	15358499.67	16389912.71	20360301.84	21940713.82	23414161.01	26468392.4	28522927.96	30438409.31
Microbiology	Admission	6381568.531	6876920.093	7338745.477	7507727.683	8090494.227	8633818.209	12012364.29	12944790.76	13814109.13
Microbiology	Sampling	0	0	0	0	0	0	0	0	0
Microbiology	Testing	142,646,826	153719390.3	164,042,546	150154553.7	161809884.5	172676364.2	172677736.7	186081367.2	198577818.8
Microbiology	Result	5255409.378	5663345.959	6043672.746	7507727.683	8090494.227	8633818.209	9760045.988	10517642.5	11223963.67
Sum		2,227,505,390	2,400,409,319	2,561,610,837	2,374,321,552	2,558,621,679	2,730,448,082	2,592,279,581	2,793,498,096	2,981,097,823

Table 11
The final cost of experiments.

Type of cost assigned	Type of experiment	$FCOS_{Si}$			$FCOS_{Mi}$			$FCOS_{Li}$		
		$FCOS_{SSi}$	$FCOS_{SMi}$	$FCOS_{SLi}$	$FCOS_{MSi}$	$FCOS_{MMi}$	$FCOS_{MLi}$	$FCOS_{LSi}$	$FCOS_{LMi}$	$FCOS_{LLi}$
Manpower	Hematology	360205060.4	388164979.4	414232526.9	375983225.4	405167880.7	432377272.3	423772388.5	456666545.1	487334373.1
Consumables	Hematology	70044904.93	81366186.06	98580432.37	73113101.87	84930292.3	102898579.2	82406106.76	95725315.38	115977452.5
Depreciation	Hematology	35012466.36	36112595.98	37653071.54	36546127.4	37694446.32	39302399.77	41191304.97	42485580.4	44297911.98
Overheads	Hematology	14869825.15	17945572.99	20345221.7	15521172.34	18731648.04	21236409.25	17493983.33	21112524.97	23935652.61
Cost allocated from other centers	Hematology	64014345.24	66672647.54	71594217.11	66818383.86	69593128.53	74730279.02	75311301.71	78438728.95	84228834.42
Sum		544146602.1	590,261,982	642405469.6	567982010.8	616117395.9	670544939.5	640175085.3	694428694.8	755774224.6
Manpower	Serology	318026133.2	342712029.9	365727146.1	342868338.2	369482542.3	394295454.8	381932395.8	411,578,839	439,218,764
Consumables	Serology	61842857.61	71838450.84	87036960.77	66673633.42	77450019.63	93835741.75	74269968.12	86274141.58	104526740.1
Depreciation	Serology	30912612.04	31883919.81	33244010.32	33327311.24	34374491.46	35840823.7	37124395.6	38290884.33	39924280.37
Overheads	Serology	13128613.43	15844200.47	17962857.54	14154138.3	17081849.94	19366003.21	15766763.35	19028038.31	21572432.26
Cost allocated from other centers	Serology	56518458.3	58865481.41	63210750.01	60933325.45	63463683.27	68148376.98	67875648.99	70694298.36	75912733.81
Sum		480428674.6	521144082.5	567181724.7	517956746.6	561852586.6	611486400.5	576969171.9	625866201.6	681154950.5
Manpower	Biochemistry	898994661.2	968,776,629	1,033,835,643	934726349.5	1,007,281,891	1,074,926,758	958,446,600	1,032,843,360	1,102,204,829
Consumables	Biochemistry	174817076.4	203072568.7	246035639.5	181765403.9	211143946.7	255814639.5	186378006.2	216502078.8	262306365.5
Depreciation	Biochemistry	87383615.03	90129302.89	93973999.85	90856788.15	93711606.88	97709116.22	93162431.7	96089696.24	100188649.1
Overheads	Biochemistry	37111897.9	44788305.57	50777314.64	38586957.57	46568473.85	52795523.72	39566166.41	47750227.06	54135298.77
Cost allocated from other centers	Biochemistry	159766091.4	166400644.5	178683827.7	166116198.3	173014450.1	185785844.1	170331675.7	177404982.3	190500471.9
Sum		1,358,073,342	1,473,167,451	1,603,306,424	1,412,051,697	1,531,720,368	1,667,031,881	1,447,884,880	1,570,590,344	1,709,335,614
Manpower	Hormone	93554197.31	100816082.5	107586471.7	102895421.1	110882392.9	118328793.7	112100315.7	120801791.9	128914338.4
Consumables	Hormone	18192400.87	21132818.67	25603785.83	20008880.45	23242893.84	28160279.29	21798849.66	25322173.81	30679462.36
Depreciation	Hormone	9093606.798	9379337.776	9779437.524	10001587.61	10315848.33	10755897.34	10896317.03	11238691.11	11718106.36
Overheads	Hormone	3862062.778	4660910.857	5284159.204	4247683.027	5126294.696	5811773.306	4627675.393	5584886.554	6331687.216
Cost allocated from other centers	Hormone	16626114.8	17316541.91	18594795.72	18286203.43	19045568.49	20451453.71	19922064.13	20749361.02	22281014.97
Sum		141328382.6	153305691.7	166,848,650	155439775.6	168612998.2	183508197.4	169345221.9	183696904.4	199924609.3
Manpower	Blood bank	4397632.784	4738986.835	5057237.503	4751568.517	5120395.848	5464260.361	4426067.367	4769628.574	5089937.014
Consumables	Blood bank	855156.6985	993374.7374	1203538.175	923982.4801	1073324.755	1300402.827	860686.0425	999797.7832	1211320.114
Depreciation	Blood bank	427456.4319	440887.5762	459694.7684	461859.5104	476371.6367	496692.4926	430220.3156	443738.3041	462667.1014
Overheads	Blood bank	181541.1214	219091.9806	248388.5535	196152.1389	236725.213	268379.6691	182714.9452	220508.604	249994.6051
Cost allocated from other centers	Blood bank	781531.4503	813985.8454	874071.7744	844431.6334	879498.0633	944419.9026	786584.742	819248.9834	879723.4211
Sum		6643318.486	7206326.974	7842930.775	7177994.28	7786315.516	8474155.253	6686273.412	7252922.248	7893642.255
Manpower	Parasitology	398,043,901	428940955.1	457746847.7	447926640.5	482,695,704	515111542.2	517151666.8	557,294,131	594719689.6
Consumables	Parasitology	77402985.88	89913545.56	108936114.9	87103104.32	101181483.5	122587955.4	100564493.2	116818621.9	141533366.7
Depreciation	Parasitology	38690457.81	39906153.92	41608453.43	43539134.11	44907180.88	46822812.05	50267909.38	51847381.56	54059064.82
Overheads	Parasitology	16431871.35	19830720.51	22482447.65	18491108.42	22315900.32	25299941.09	21348825.18	25764721.28	29209931.98
Cost allocated from other centers	Parasitology	70738927.64	73676479.42	79115050.3	79603908.34	82909593.21	89029724.12	91906330.53	95722893.98	102788863.3
Sum		601308143.7	652267854.6	709,888,914	676663895.7	734009861.9	798851974.9	781239225.1	847447749.7	922310916.4
Manpower	Microbiology	154283803.9	166259656.4	177424964.2	165,170,009	177,990,873	189944000.6	194,450,147	209543800.5	223615891.6
Consumables	Microbiology	30001783.88	34850939.29	42224182.19	32118698.07	37,310,008	45203504.04	37812467.28	43924054.88	53216852.49
Depreciation	Microbiology	14996614.67	15467824.55	16127644.35	16054769.96	16559228.23	17265604.65	18900842.82	19494727.78	20326325.48
Overheads	Microbiology	6369075.397	7686486.307	8714308.986	6818474.877	8228841.789	9329187.236	8027204.515	9687591.015	10982997.7
Cost allocated from other centers	Microbiology	27418761.63	28557371.37	30665388.6	29353418.77	30572368.38	32829126.48	34556979.37	35992015.5	38648835.27
Sum		233070039.5	252822277.9	275156488.3	249515370.7	270661319.4	294,571,423	293,747,641	318642189.7	346790902.5

Table 12
The exact cost of the experiments based on the type of activity.

Activity	Hematology	Serology	Biochemistry	Hormone	Blood bank	Parasitology	Microbiology
Admission	10005508.98	17410259.4	14102040.61	14297434.39	141492.0462	38499312.01	14196368.64
Sampling	12963659.46	22557640.44	18271339.57	18524501.94	183324.4773	0	0
Testing	604089989.5	516452804.1	1,485,715,309	123857782.2	6992577.937	675132862.7	255123146.5
Result	8700442.594	15,139,356	12262644.01	12432551.64	123036.5619	33477662.61	12344668.38
Sum	635759600.5	571560059.9	1,530,351,334	169112270.1	7440431.022	747109837.3	281664183.6

Table 13
The exact cost of the experiments based on the type of cost.

Type of cost assigned	Type of experiment	COS_{Si}	COS_{Mi}	COS_{Li}	COS_i
Manpower	Hematology	387534188.9	404509459.5	455924435.6	415989361.3
Consumables	Hematology	83330507.78	86980657.78	98036291.55	89449152.37
Depreciation	Hematology	36259377.96	37847657.83	42658265.79	38921767.19
Overheads	Hematology	17720206.62	18496409.88	20847386.97	19021334.49
Cost allocated from other centers	Hematology	67427069.97	70380597.14	79326288.36	72377985.15
Sum		592271351.2	618214782.1	696792668.3	635759600.5
Manpower	Serology	342155103.1	368882111.8	410909999.6	373982404.8
Consumables	Serology	73572756.41	79319798.27	88356949.92	80416501.53
Depreciation	Serology	32013514.06	34514208.8	38446520.1	34991414.32
Overheads	Serology	15645223.81	16867330.48	18789077.98	17100544.09
Cost allocated from other centers	Serology	59531563.24	64181795.24	71494227.06	65069195.18
Sum		522918160.6	563765244.5	627996774.6	571560059.9
Manpower	Biochemistry	967,202,311	1,005,644,999	1,031,164,930	1,001,337,413
Consumables	Biochemistry	207975094.9	216,241,330	221728816.8	215315080.6
Depreciation	Biochemistry	90495639.25	94092503.75	96480259.01	93689467.34
Overheads	Biochemistry	44225839.37	45983651.71	47150564.08	45786685.05
Cost allocated from other centers	Biochemistry	168283521.2	174972164.2	179412376.6	174222687.3
Sum		1,478,182,406	1,536,934,649	1,575,936,946	1,530,351,334
Manpower	Hormone	100652250.5	110702202.6	120,605,482	110653311.7
Consumables	Hormone	21643001.79	23804017.86	25933495.28	23793504.98
Depreciation	Hormone	9417460.699	10357777.76	11284371.5	10353203.32
Overheads	Hormone	4602377.613	5061917.01	5514749.721	5059681.448
Cost allocated from other centers	Hormone	17512484.14	19261075.21	20984146.71	19252568.69
Sum		153827574.7	169186990.4	184322245.2	169112270.1
Manpower	Blood bank	4731285.707	5112074.909	4761877.651	4868412.756
Consumables	Blood bank	1017356.537	1099236.687	1023934.646	1046842.624
Depreciation	Blood bank	442679.5922	478307.8799	445541.907	455509.793
Overheads	Blood bank	216340.5518	233752.3403	217739.3847	222610.759
Cost allocated from other centers	Blood bank	823196.3567	889449.8664	828519.0488	847055.0906
Sum		7230858.745	7812821.683	7277612.638	7440431.022
Manpower	Parasitology	428243901.3	481911295.6	556388495.8	488847897.6
Consumables	Parasitology	92084215.46	103624181.1	119638827.3	105115741.3
Depreciation	Parasitology	40068355.05	45089709.01	52058118.59	45738727.55
Overheads	Parasitology	19581679.84	22035649.94	25441159.48	22352829.75
Cost allocated from other centers	Parasitology	74510152.45	83847741.89	96806029.27	85054641.2
Sum		654488304.1	736508577.5	850332630.4	747109837.3
Manpower	Microbiology	165989474.8	177701627.5	209203279.7	184298127.4
Consumables	Microbiology	35692301.79	38210736.71	44984458.21	39629165.57
Depreciation	Microbiology	15530694.52	16626534.28	19573965.36	17243731.39
Overheads	Microbiology	7589956.897	8125501.301	9565931.077	8427129.758
Cost allocated from other centers	Microbiology	28880507.2	30918304.54	36399276.71	32066029.48
Sum		253682935.2	271582704.4	319726911.1	281664183.6

Table 14
The results of FL-TDABC versus TDABC model for hematology test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	415989361.3	406499793.5	2.334458
Consumables	89449152.37	85209484.59	4.975582
Depreciation	38921767.19	37818359.69	2.91765
Overheads	19021334.49	18793224.8	1.213787
Cost allocated from other centers	72377985.15	69821902.79	3.66086
Sum	635759600.5	618142765.4	2.849962

Table 15
The results of FL-TDABC versus TDABC model for serology test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	373982404.8	370697146.3	0.886237882
Consumables	80416501.53	77704621.93	3.489984933
Depreciation	34991414.32	34487491.11	1.461176782
Overheads	17100544.09	17138003.3	0.218573922
Cost allocated from other centers	65069195.18	63672308.14	2.193869015
Sum	571560059.9	563699570.7	1.394446544

Table 16
The results of FL-TDABC versus TDABC model for biochemistry test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	1,001,337,413	1,010,593,139	0.915870667
Consumables	215315080.6	211838042.5	1.641366226
Depreciation	93689467.34	94019666.07	0.351201774
Overheads	45786685.05	46721558.9	2.000947462
Cost allocated from other centers	174222687.3	173583202.4	0.36840254
Sum	1,530,351,334	1,536,755,609	0.416740024

Table 17
The results of FL-TDABC versus TDABC model for hormone test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	110653311.7	111246897.8	0.533575411
Consumables	23793504.98	23319300.46	2.033528042
Depreciation	10353203.32	10349759.73	0.033272139
Overheads	5059681.448	5143146.421	1.622838746
Cost allocated from other centers	19252568.69	19108177.19	0.755652894
Sum	169112270.1	169167281.6	0.032518978

Table 18
The results of FL-TDABC versus TDABC model for blood bank test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	4868412.756	5137228.182	5.232693905
Consumables	1046842.624	1076853.107	2.786868796
Depreciation	455509.793	477937.6184	4.692626083
Overheads	222610.759	237503.4024	6.270496885
Cost allocated from other centers	847055.0906	882389.247	4.004372952
Sum	7440431.022	7811911.556	4.755309012

Table 19
The results of FL-TDABC versus TDABC model for parasitology test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	488847897.6	484282474.9	0.942718951
Consumables	105115741.3	101514098.5	3.547923707
Depreciation	45738727.55	45054804.75	1.51797973
Overheads	22352829.75	22389259.63	0.162711381
Cost allocated from other centers	85054641.2	83182142.83	2.25108216
Sum	747109837.3	736422780.6	1.451212133

Table 20
The results of FL-TDABC versus TDABC model for microbiology test.

Type of cost assigned	FL -TDABC	TDABC	Difference
Manpower	184298127.4	178575984.4	3.20431833
Consumables	39629165.57	37432657.6	5.867892125
Depreciation	17243731.39	16613663.56	3.7924677
Overheads	8427129.758	8255892.551	2.074121075
Cost allocated from other centers	32066029.48	30672869.26	4.541995128
Sum	281664183.6	271551067.3	3.72420419

Table 21
The results of FL-TDABC versus TDABC Model.

Type of experiment	FL -TDABC	TDABC	Difference
Hematology	635759600.5	618142765.4	17616835.14
Serology	571560059.9	563699570.7	7860489.181
Biochemistry	1,530,351,334	1,536,755,609	6404275.701
Hormone	169112270.1	169167281.6	55011.47037
Blood bank	7440431.022	7811911.556	371480.5343
Parasitology	747109837.3	736422780.6	10687056.74
Microbiology	281664183.6	271551067.3	10113116.23

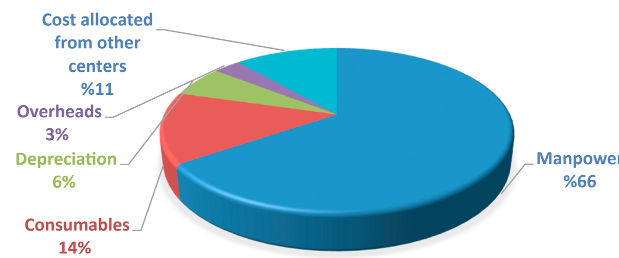

Fig. 4. The Share of Each Resource from Total Laboratory Costs.

and fuzzy circumstances and results in a more closely matching of the determined costs and real costs. Moreover, this system is able to identify the unused capacity of the resources accurately. Tables 22 and 23 illustrate the cost of the resources allocated to the services in question, along with their unused capacity, based on the results of the FL-TDABC and TDABC model. As can be noted, the FL-TDABC model shows more precise information about the unused capacity of the laboratory. Cost of unused capacity derived using FL-TDABC were 80% of costs derived using TDABC for laboratory (IRR 103,543,567 FL-TDABC versus IRR 129,261,799.5 TDABC) accounted for an IRR 25,718,232.58 difference. Cost differences were found in the cost categories with the following TDABC to TA ratios (TDABC/TA): Manpower cost (0.80%) Consumables (82%), Depreciation (80%), Overheads (0.79%), and Cost allocated from other centers (81%). Based on the results of the FL-TDABC system, manpower and consumables have the highest percentage of the total unused laboratory capacity (1.67 and 0.36%, respectively), representing a significant difference in these results compared to the TDABC system (2.17 and 0.45% respectively) (Fig. 6 and Fig. 7). Improper identification of unused capacities in these resources has a significant impact on the decisions made by managers and may lead to incorrect decisions about them. The FL-TDABC system, compared with TDABC, identifies the unused capacity of resources more accurately. This higher accuracy is owing to the fact that, in the TDABC system, all costs are allocated initially to activities and, without the distinction of fixed and variable costs and considering the conditions of uncertainty in them, all costs of activities are divided into the practical capacity to calculate the capacity cost rate. Since in hospital, costs are variable based on the number of treated patients and are depending on factors such as physicians' capacity and skills, the time needed to perform patient-related activities, the allocation of activity costs, including fixed costs, and not considering the uncertainty regarding the cost, and time required for each patient may lead to inaccurate results and show unused capacity and costs often more or less than actual values. Therefore, in the new system, taking into account the uncertainty in the parameters of capacity, time, and cost provides more accurate estimates of the cost of capacity and the time of activities under conditions of uncertainty, which leads to a better understanding the unused capacity of resources. In fact, the difference between the practical capacity determined for an activity and the time required performing that activity represents unused capacity. In the new system, using the TFN method in these parameters, the cost of used and unused capacity resources under conditions of uncertainty can be more accurately identified.

5. Conclusion and recommendations

The present study aimed at developing a new mechanism for the TDABC system through the use of fuzzy set theory for healthcare services costing under conditions of uncertainty and in accordance with healthcare features. Fuzzy Logic, as one of the most effective methods to deal with unreliable data, leads to the creation of the Fuzzy Logic-TDABC system. In this system, fuzzy logic is used to overcome the limitations and deficiencies associated with data estimation or uncertainty in TDABC input data (cost, capacity, and time) to determine the exact cost of healthcare services under. In this regard, we have

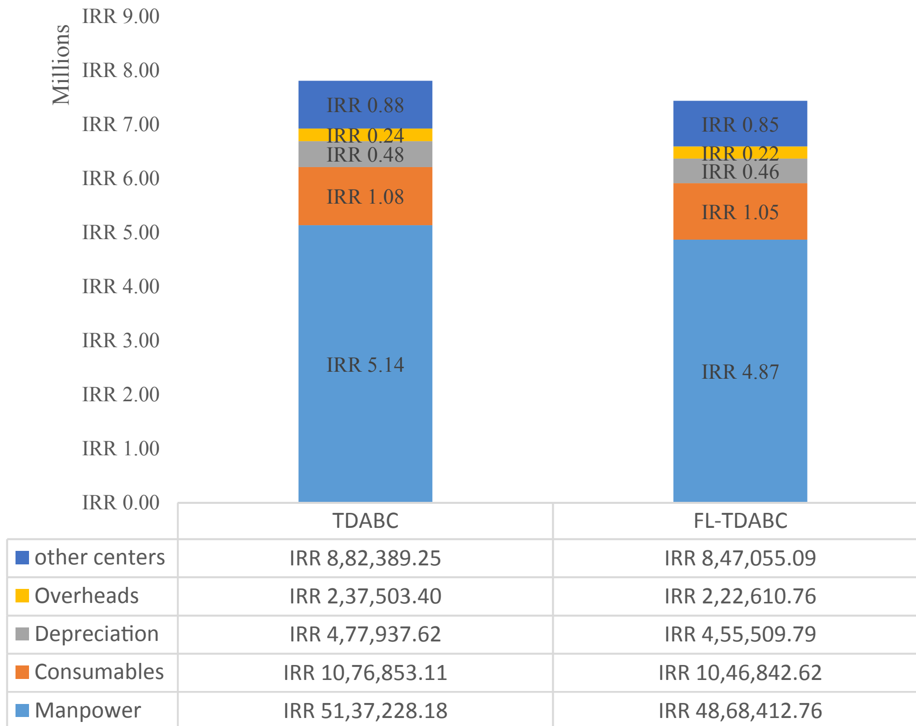

Fig. 5. Graphical comparison between FL-TDABC and TDABC Model for Blood bank test.

Table 22
Summary of resource costs allocation based on the FL-TDABC model.

Type of cost assigned	FRC_{Si}	FRC_{Mi}	FRC_{Li}	RC_i	Allocated cost	Cost of unused capacity	Unused capacity percentage
Manpower	2,461,008,192	2,652,037,129	2,830,136,925	2,647,727,415	2,579,976,929	67750486.58	1.674281364
Consumables	478,563,751	555,913,485	673,525,384	569334206.7	554765988.9	14568217.75	0.360016536
Depreciation	239,213,648	246,730,000	257,254,902	247,732,850	241393820.9	6339029.098	0.156653019
Overheads	101,594,246	122,608,500	139,003,481	121068742.3	117970815.4	3097926.983	0.076557405
Cost allocated from other centers	437,361,507	455,523,672	489,149,027	460678068.7	448890162.1	11787906.54	0.291308199
Sum	3,717,741,344	4,032,812,786	4,389,069,719	4,046,541,283	3,942,997,716	103,543,567	2.558816523

Table 23
Summary of resource costs allocation based on the TDABC model.

Type of cost assigned	Committed cost	Allocated cost	Cost of unused capacity	Unused capacity percentage
Manpower	2,652,037,129	2,567,032,664	85004464.61	2.107820747
Consumables	555,913,485	538095058.7	17818426.31	0.441836189
Depreciation	246,730,000	238821682.5	7908317.468	0.196099296
Overheads	122,608,500	118,678,589	3929911.005	0.097448387
Cost allocated from other centers	455,523,672	440922991.9	14600680.15	0.36204706
Sum	4,032,812,786	3,903,550,986	129261799.5	3.205251679

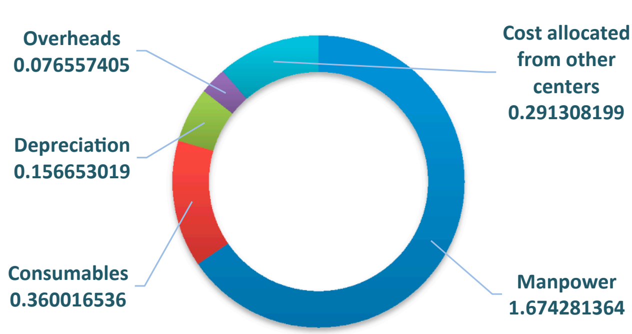

Fig. 6. The Share of Each Resource from Laboratory Unused Capacity based on the FL-TDABC Model.

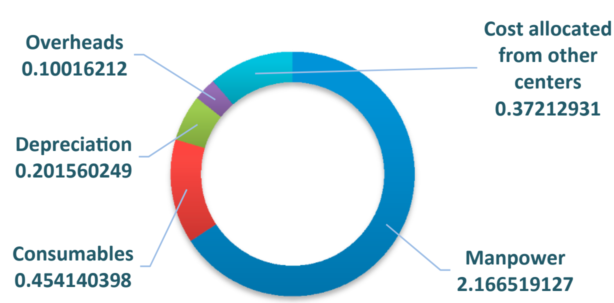

Fig. 7. The Share of Each Resource from Laboratory Unused Capacity based on the Standard TDABC Model.

attempted to analyze the application of such a system in hospitals and healthcare centers to calculate and provide healthcare services costs and other information needed by hospital managers to make decisions. Given that we often encounter ambiguity and uncertainty in determining resource costs and estimating the time required to perform healthcare activities, the use of fuzzy logic in determining these cases will result in more appropriate and precise results. In studies on healthcare services costing so far, information on capacity, time, and cost, even under uncertain conditions of cost estimation, is often taken into account as definitive and conditions of uncertainty in the hospital services costing systems have not been investigated. Incorrect estimates of these parameters may cause a significant deviation in determining the costs assigned to the services compared with the actual values. Therefore, the FL-TDABC model is an appropriate approach accurately to estimate costs in hospitals and other healthcare centers in uncertain conditions. In this paper, the application of the proposed model is shown using the data collected in a laboratory. The results of this study demonstrate that under uncertainty conditions, using the proposed model leads to more accurate and useful results compared to the TDABC system. Hence, hospitals can use this model to reduce the uncertainty of the data and make more accurate and consistent decisions using the cost data obtained from it.

Using the proposed system provides a better perspective about the way the determined costs change in ambiguous and fuzzy circumstances and results in a better matching of the determined costs and real costs. Also, the new model provides a more accurate measurement of the true resources used in hospitals and can be used to accurately identify unused hospital capacities. Compared to the TDABC model, FL-TDABC model is capable of providing additional and more valuable information in a cost-effective manner in the case of uncertainty and imprecise data.

The main limitations of the study include an assumption that all experts' opinion has equal weight in the fuzzy Delphi method. As to future directions, in order to evaluate the efficiency of the proposed model in this paper, it is suggested using different weights appropriate to the importance of the opinions of the experts. It is also recommended using other combined methods with TDABC model such as DEA to AHP to reduce the uncertainty in determining the exact cost of healthcare services in future works. Furthermore, to investigate the accuracy of the results of the present study in the development of the FL-TDABC model and to determine the exact costs of healthcare services under uncertainty conditions, the results of the study can be compared with other methods such as Monte Carlo simulation and interval mathematics.

Conflict of interest

None.

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