QATAR UNIVERSITY

COLLEGE OF ENGINEERING

A FRAMEWORK FOR TIME-DRIVEN ACTIVITY-BASED COSTING FOR ORTHOPEDIC PROCEDURE

BY

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ABSTRACT

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Title: A Framework for Time-Driven Activity-Based Costing for Orthopedic Procedure

Supervisor of Thesis: Prof. Shaligram Pokharel.

The study uses Time-Driven Activity-Based costing (TDABC) approach to examine healthcare costs. Three multivariable regression models have been proposed to predict the cost of healthcare: multiple linear regression, Ridge regression, and Lasso regression. The models are based on TDABC. These models are used to analyze healthcare costs in Knee Arthroplasty Department in a hospital in Qatar. The study focuses on the primary knee arthroplasty consultation process by considering the human resource. The results show that the lasso regression method is more accurate and predicts better costs than other methods. The actual cost obtained from the data is $180,048, and the model predicted it to be $175,932. The model is statistically significant for use, and its results are validated with different samples of costing used by the hospital.

DEDICATION

This research was possible because of the God's grace.

I would like to express my special thanks of gratitude to my family who gave infinite support to me along the journey, My dad, Mom, and brothers.

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ACKNOWLEDGMENTS

PRAISE AND THANKS TO ALLAH (SWT) THE ALMIGHTY

I would like to express my gratitude and thanks to Prof. Shaligram Pokharel for his continuous support and assistance during the study.

I would like to direct my greetings to the best family that was the first place to raise and educate me.

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CHAPTER 1: INTRODUCTION

The costing of medical care is a complex task as the service provided to each person can be unique. Various models from simple accounting to activity-based methods are adopted in different organizations. Kaplan and Porter (Kaplan & Anderson, 2004) developed a costing method called the time-driven activity-based costing (TDABC) primarily for business processes to show an alternate and more representative method for costing. This method has been improved and used in many industries, including healthcare.

There are a few methods that are used in evaluating healthcare costs. The traditional cost accounting method (TCA) was the first method used in healthcare. The method depends on allocating an organization's overhead to a specific output depending on a cost driver (for example, cost of medical personnel or medical equipment set up cost) or percentage rate predetermined by expertise (Paulus, Raak, & Keijzer, 2002). This method has been used widely in healthcare and has gained acceptance; the main reason is that it required a small investment of financial cost and managerial efforts (McKenzie, 1999). Nevertheless, this method has its limitations, for example, it cannot address the differences in the services lines (Velmurugan, 2010), which affect the accuracy of the true cost (McKenzie, 1999).

Another costing method that improves the TCA is the Activity Based-Costing (ABC) method. The method identifies the main activities and resources significant to providing patient care (Namazi, 2009). Then, the cost driver is used to allocate the indirect expenses to activities. The cost driver is selected carefully to reflect the resource pool usage. On the one hand, the ABC method helps the decision-maker to make an accurate mix of decisions related to different services and resources (Horngren, et al., 2010), on the other hand, when applying the ABC method in a complex environment, it becomes a resource-intensive method (Moisello, 2012). The cost driver requires a considerable amount of financial investment and managerial time. Also, the information collected needs updates from time to time for different reasons. The information could become outdated in a short period of time, and the subjectively assigned cost driver may not have the ability to reflect the changes in healthcare. Healthcare providers can adopt the TDABC method to avoid this type of problem.

The TDABC method uses time as the main cost driver. It is presumptively assumed that most resources have capacity that can be measured in terms of time(Namazi, 2009). Since time is a significant variable, there is no need to identify individual activities; also, personal preferences associated with cost estimation are reduced because of the elimination of managerial interference in costing. There are opportunities to enhance time, cost, and resources calculations, making the TDABC method more effective. Therefore, the focus of this thesis is to study the accuracy of cost with TDABC in the healthcare industry. The proposed model is expected to reduce the uncertainty and inaccuracy of cost in meeting a particular healthcare procedure.

1.1 Research Problem

It is found that the major issues in the patient care-delivery process are the time and cost associated with human resources. Although various methods are used to obtain the cost based on activity, time and resources, the nexus between the cost, resources, time, efficiency, and capacity is still being explored to utilize the constrained resource in healthcare service.

A better way to organize costing could be to develop a model representing a unique healthcare service with the right variables. The uniqueness of the costing method based on a particular type of healthcare can be more representative, and its analysis can lead to a better method for costing.

In this thesis, it is assumed that the accuracy of cost data and capacity rates and analyzing them with models can improve both the total cost accuracy and resource utilization.

1.2 Research Objective

The main objective of this thesis is to propose a costing model that can determine the significant resources and total cost needed in a department for healthcare service delivery. The specific objectives are mentioned below.

The objectives of this research are:

- Understand and analyze the significant resources and cost uncertainties in a particular healthcare service;
- Propose an enhanced model for costing, and;
- Analyze the results to show the effectiveness of the model for a particular healthcare service.

1.3 Research Scope

The models are developed by studying the pre-hospital healthcare process in knee arthroplasty at a hospital in Qatar. The particular process and the hospital were chosen due to the access to the data and the process. The study examines only the resource wages based on two areas of pre-hospital procedure: pre-operational office and pre-operational testing and consulting, as illustrated in Figure 1. Also, the analysis will include the patient-care time associated with each resource and will exclude the equipment and indirect costs.

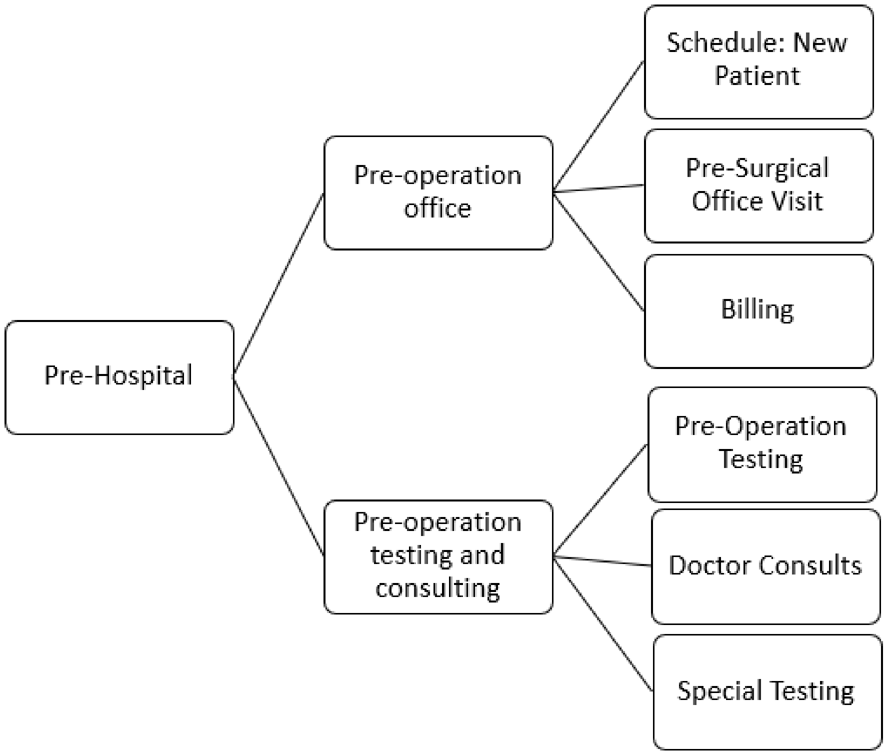

Figure 1. The area of study

1.4 Research Assumption

This research assumes that the time given by the healthcare from the electronic medical records is the exact time consumed by the human resources while delivering care to patients. Also, the wages of human resources obtained from the financial departments are considered accurate. This research hypothesis assumes a significant difference between the total time of patient care delivered by different human resources.

1.5 Research Methodology

The research follows a systematic approach while analyzing each chapter in the study. The process followed to synthesize results in the literature review chapter is as follows. First, the research question is defined, and the related literature is reviewed to understand the current development in the costing models. Research framework, sampling, the hypothesis are developed, and new models are proposed. The insights of the method are also discussed.

1.6 Research Questions

Based on the importance of cost-reduction and accuracy in healthcare, the following research questions are considered in this research:

RQ1: Does the cost of human resource significantly affect the total cost of the knee arthroplasty service?

RQ2: What methods are available to resource cost based on care delivery time handling with the TDABC method?

1.7 Contribution of the Research

This thesis focuses on providing the model that depicts the actual costing situation and provides the utilization impact of the current costing model. The closeness of the models is tested for the three models to find the best model for the chosen healthcare service costs. Three statistical models developed here for costing human resources utilization are the multiple linear regression analysis, ridge regression, and lasso regression. Since the TDABC method focuses on studying the relationship between the dependent variable (cost) and independent variable (time) to provide the general cost, the accuracy data on each service segment becomes important (DiGioia, Greenhouse, Giarrusso, & Kress, 2016).

1.8 Thesis Structure

This research comprises five chapters. In the second chapter, the literature review is provided, and the gap in the current literature in terms of costing methods is discussed. The research framework is discussed in the third chapter, followed by the analysis and result in the fourth chapter. The conclusions, limitations, and potential future research are discussed in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

Access, delivery, and service pricing are important in healthcare service design. The focus here is on the pricing part of health service delivery to reflect the activities carried out in healthcare. It is mentioned that the current cost system may not use enough information for service pricing decisions (Skinner & Chandra, 2012). Service-based pricing can provide a true picture of pricing and promotes competitiveness (Cooper & Kaplan, 1988; Manivannan, 2019).

The literature search and analysis use the systematic review to select and critically assess the literature to answer the research questions (Dewey & Drahota, 2016). As seen in Figure 2, the review starts by developing the research question. The literature search used the terms traditional accounting method, ABC method, TDABC method, healthcare accounting, opportunities for cost, cost price for healthcare, healthcare quality, healthcare cost-effectiveness, human resource cost in healthcare, human resource utilization, and healthcare direct and indirect cost. The search is done using different journals and books from databases at Qatar university library: ScienceDirect, Google Scholar, Scopus, Springer, Healthcare Finance, Clinical Orthopedics and Related Research, BioMed Central, and JAMA Internal Medicine.

The selected literature was evaluated based on the critical time interval and care cycle criteria. Following that, a content analysis of the literature was done. The publications that did not relate to the research questions or in duplicates (obtained from different databases) were excluded from the analysis.

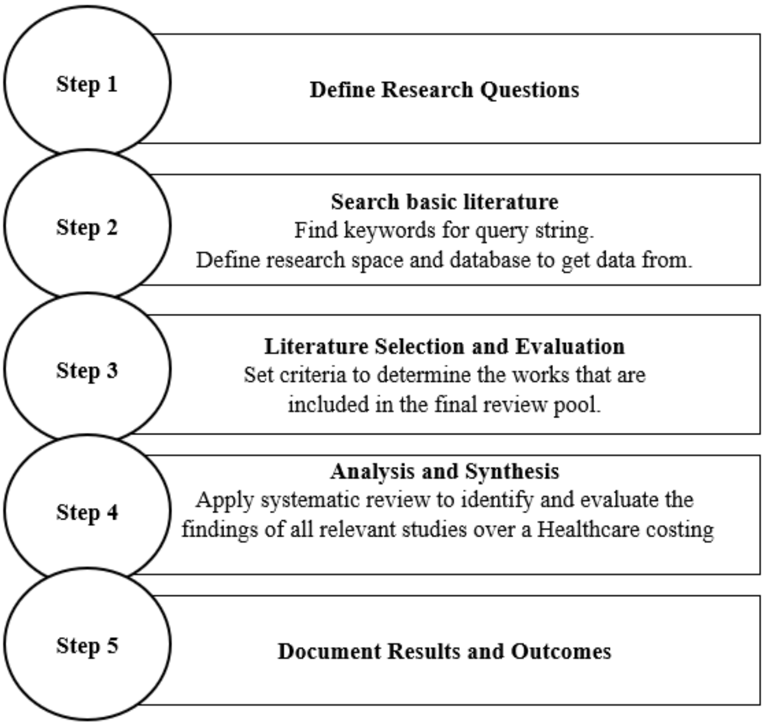

Figure 2. Analysis approach

The publications included in the literature review focused on the following:

- Apply TDABC framework as discussed by Kaplan and Anderson (Kaplan & Anderson, 2004).
- Focus on healthcare departments in general and orthopedic departments in specific.
- Traditional cost accounting, ABC, and TDABC case studies, journals, or methodological papers focus on cost-effectiveness compared to actual cost.

The literature search terminated when no further results were produced or case studies were introduced. The procedure for the systematic literature review is given in Figure3, and it shows that a total of 58 publications were found useful for the review. While Table 1 shows the relevant studies that focused on the TDABC methods with different factors and criteria.

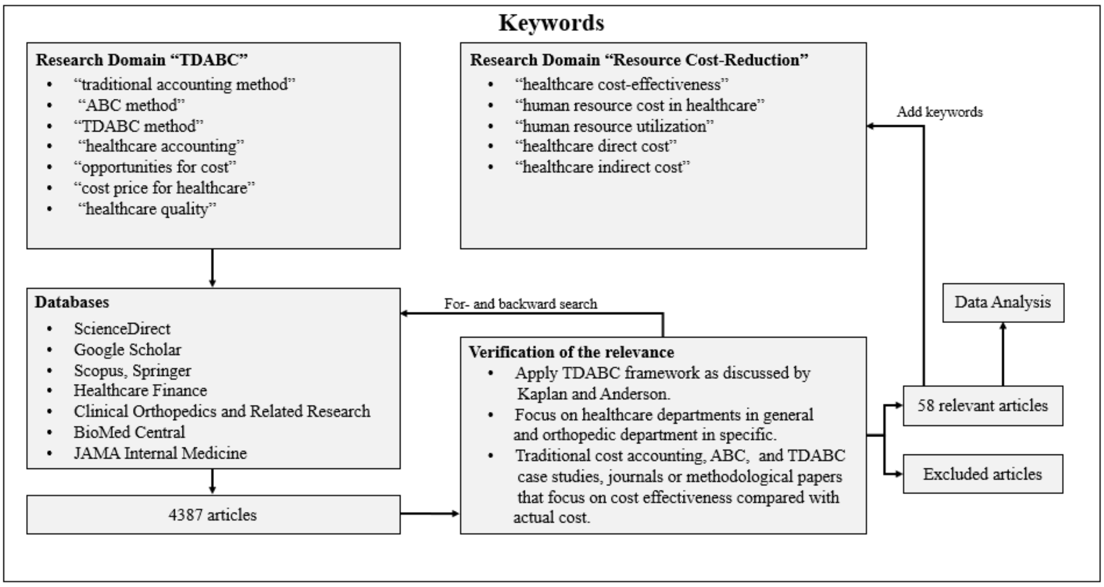

Figure 3. The procedure of the systematic literature review

Table 1. Synthesis of Different Authors on TDABC

Factors	Criteria	Author
Value of time as a cost driver	Time element	Kaplan & Anderson (2004); (Etemadi, Mohammadi, Akbarian Bafghi, PM, & Tasavon, 2018); (Keel, et al., 2020)
Allocating costs	Objective method	(Kaplan, et al., 2014); Kaplan & Anderson (2004); (Ozyurek & Dinc, 2014); Keel, Savage, Rafig and Mazzocato (2017); Martin et al. (2018); Najjar, Strickland, and Kaplan (2017)
Determination of costs	Considers entire system or process	(Ana, et al., 2019); (McLaughlin N. , et al., 2014)

From the final list, 27 are case studies, and 15 publications provided a methodological approach to performing the TDABC framework in different healthcare departments. The remaining 16 publications are published as review articles. Figure 4 shows a time-based evolvement of the publications on the TDABC method in healthcare.

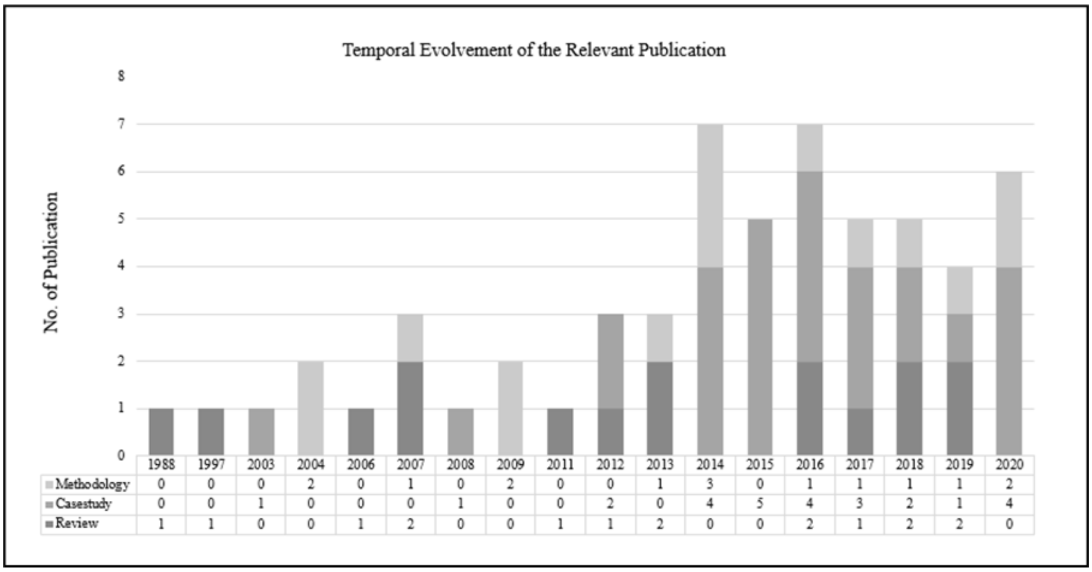

Figure 4. The reviewed research publication in different years

Figure 5 provides an overview of the different articles related to the TDABC method, methodology, and review articles. Of the 27 case studies included in the research, six case studies focused on knee arthroplasty services. The pediatric and urology services were studied in three case studies. The cases in urology, eye, and pediatric department related services were studied in 3, 2, and 2 case studies. Other five healthcare services case studies included oncology surgery, epidemiology of acute appendicitis, adenotonsillectomy, and plagiocephaly. The remaining six case studies were focused on healthcare improvements and ABC application.

The literature review is presented in four sections: traditional cost accounting in healthcare, the ABC method in healthcare, the TDABC model in healthcare, and the summary of literature review and research gaps. The review provides the advantages and disadvantages of these methods to build a costing model proposed in the thesis. The review also shows the current practice, research, and gaps mentioned in the literature.

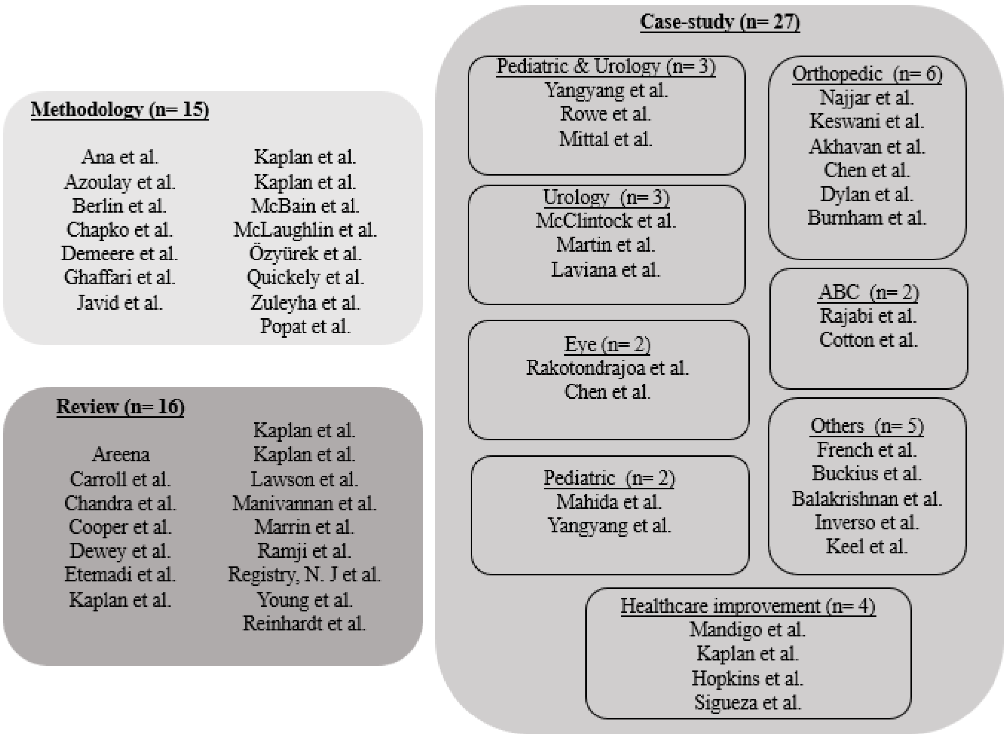

Figure 5. Overview of the analyzed studies

2.1 Framework of the review

Figure 6 shows a general flow followed in this review. The review focuses on TCA, ABC, and TDABC methods only as they are the most popular costing methods adopted in the healthcare service industry. The three methods are compared based on their features and applications in different healthcare departments. The comparison is done based on criteria such as application purpose, cost estimation, methodology of data collections such as time interval and care cycle, direct and indirect cost, and the application of the methodology to service output. Then, advantages and limitations are stated. This classification guides sections and subsections in the review and shows the gaps in the current costing methodology for exploration.

It is seen from the review that most healthcare systems rely on a bottom-up or top-down approach in calculating the healthcare cost delivery. Top-down approaches rely on a pre-determined metric in assigning the total healthcare costs to the specific services. In contrast, the bottom-up approaches rely on a sum of the resources used to deliver an individual service or activity (Chapko, et al., 2009). Compared to the top-down cost accounting methods, bottom-up approaches tend to be more reflective of the service costing (Quickely, O'Donell, & Doyle, 2020). The individual contributors or the specifics to costs should be identified and accounted in a bottom-up approach.

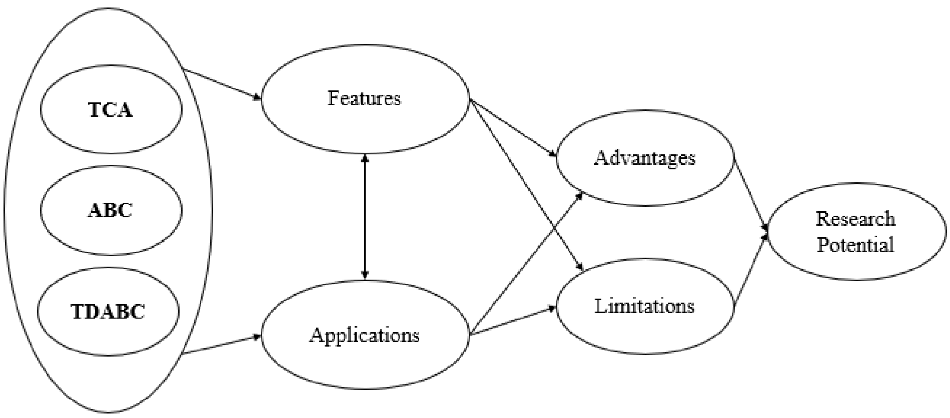

Figure 6. The focus of contents for the review

2.2 Traditional Cost Accounting (TCA) method

Keswani, Sheikholeslami, and Bozic (2018) mention that the TCA methods utilize the top-down approach. TCA focus on assessing costs at the departmental level (Lawson, 2017) and relies on the cost drivers for allocating the overhead cost; where they apply relative value units (RVU) or ratio of cost to charge (RCC) to provide estimates as well as assign support and indirect costs. The TCA methods are easy to use, but they may not be applicable in all cases that might have the complexity of services (Keswani, Sheikholeslami, & Bozic, 2018). It is also possible that this method may omit some of the cost drivers for specific care (Zuleyha C. , David, Jeffrey, Rinad, & Geoffrey, 2020). The TCA method allocates overhead cost based on a pre-determined percentage or cost driver based on expert advice or management experience (Chapko, et al., 2009).

The steps to perform the TCA are given in Figure 7. The first step requires identifying overhead costs by splitting down departmental costs for procedural level cost; this step is followed by estimating the service period (Carroll & Lord, 2016). In the next step, cost drivers are identified for the provided service. The next step involves identifying and computing the pre-determined overhead rate for the service, This aids in determining how much each service will cost and what important areas need to be prioritized is for enhancing service quality and lowering total expenses.. The overhead rate is applied to the service rendered in the last step.

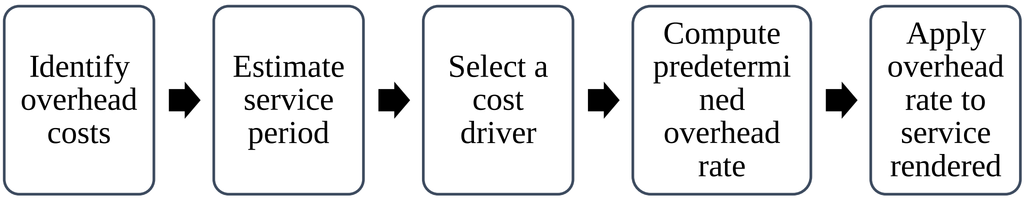

Figure 7. Traditional cost accounting framework

The TCA through RCC is a parametric method based on medical procedure costs aggregated at the departmental level and using a ratio to identify the cost for a particular service or procedure. The challenge with this approach is its reliance on aggregate information, which may not accurately depict the actual costs. Using RVU in the TCA, the number of resources, physician work, and expertise required to provide care is important. As a result, the method captures the depth of competence, experience, and time required to provide a specific service (Azoulay, et al., 2007). A service with six total RVUs implies that the resources required to provide that service are six times higher than those required by a medical procedure having only one RVU. The TCA method is not expensive to manage (Carroll & Lord, 2016) due to its simplicity (Sigueza-Guzman, Abbeele, & Cattrysse, 2014).

The review also highlights some limitations of the method. For example, the method cannot be used commonly for all care services Michelson (2014). It may not identify the use of resources and services for patient care (McBain, et al., 2017). The method assumes that all providers and all types of patient care are the same (McBain, et al., 2017); therefore, the method fails to link the variations in-service requirements for the patients (McBain, et al., 2017). Due to the focus on aggregation, specific healthcare interventions for a patient care service cannot be identified (Najjar, Strickland, & Kaplan, 2017). There is no correlation between resource use and the patient care service in TCA (Reinhardt, 2006); therefore, the true costs may vary by 10-50 % (Akhavan, Ward, & Bozic, 2016).

The TCA method is appropriate for understanding the cost drivers. Still, it does not capture the variations in the services across different patients (McClintock, Shah, Chang, & Haleblian, 2019). As mentioned earlier, It does not give enough information on the resources that were used to provide the service (Javid, Hadian, Ghaderi, Ghaffari, & Salehi, 2016). Some of these limitations can be avoided with the activity-based costing discussed next.

2.3 Activity Based Costing (ABC) Model

Berlin and Smith (2004) refer to Kaplan and Cooper (1998), who provided an activity-based costing method, which focuses on the costs involved in delivering a particular healthcare service. The fundamental characteristic of the ABC method is that it aims to minimize the errors caused by the inconsistent allocation of indirect costs by identifying the cost depending on the activity level. According to the ABC model, services require activities, activities require resources, and resources require charges. As a result, understanding ABC involves understanding of activities, resources, and cost drivers(Cotton, Jackman, & Brown, 2003).

As mentioned in Figure 8, the ABC method involves evaluating resource consumption, including manpower, materials, and machines. McBain et al. (2017) mention that activities are the cost drivers in this method. The ABC model assumes that all activities are aimed at supporting the production and delivery of services, all indirect costs are traceable and allocated to the specific services (Sigueza-Guzman, Abbeele, & Cattrysse, 2014), and the cost of a service is the total sum of all the resources and activities involved in the delivery of a service.

Figure 8. Activity based-costing framework

The ABC model uses the cost pool sum divided by the cost driver to get the cost driver rate of the activity. The cost driver rate measures overhead and indirect costs associated with a specific activity (Javid, Hadian, Ghaderi, Ghaffari, & Salehi, 2016). For this method, activities are defined and split into cost pools containing costs associated with each activity. Each cost pool is assigned with an activity cost driver, like hours. Determination of the cost driver needs gathering information and interviewing key employees interviewed in a variety of areas such as procurement, production, quality control, and accounting are collected. Then, the average overhead of each cost pool is computed by dividing the estimated overhead costs by the estimated activity cost driver. Finally, the cost driver rate (CDR) is multiplied by the total number of cost drivers (McBain, et al., 2017).

This method provides a relationship between the resources and the goals to be achieved (Carroll & Lord, 2016) due to a shift from functional to cross-functional cost accounting (Sigueza-Guzman, Abbeele, & Cattrysse, 2014). Due to activity orientation of this method, it can support the efficiency of resource use (Carroll & Lord, 2016), better cost planning for a particular patient care service (Marrin, Johnson, Beggs, & Batalden, 1997), and identifying on value-adding activities (Lawson, 2017). Unlike the

TCA method, the ABC model allows organizations to use the information gathered for controlling the costs and improving the management of an organization's performance and decisions (Lawson, 2017). It depicts the true cost of delivering services (Kaplan & Anderson, 2004).

Despite the benefits the ABC methodology provides, it also has certain drawbacks. Kaplan and Anderson (2004) and Javed et al. (2016) mention that the time and cost demands for developing and maintaining the ABC system are major impediments to adopting this method. However, when the frequency of updating is low, this method may not yield accurate cost results. The method needs consistency in identification of the cost drivers to avoid personal bias from the managers, which can otherwise lead to unprofitable services, inefficient processes, and poorly utilized resources (Carroll & Lord, 2016) which has a direct bearing on the performance of a particular department in the hospital (Zuleyha C. , David, Jeffrey, Rinad, & Geoffrey, 2020).

ABC method is a resource-intensive cost accounting method (Rajabi, 2008). It requires significant management and financial resources to collect, measure, and input the data for each component of hospital activities (Kaplan and Anderson, 2004). There might be a higher cost of adoption due to the specific expertise required to use and update the accounting model.

2.4 Time-Driven Activity Based-Costing (TDABC)

The TDABC method focuses on estimating resource costs used for providing patient care. It requires identifying all activities in the ABC method and resource utilization time (Kaplan & Anderson, 2004). The activities are added together to calculate the overall cost of the care episode or service. Adopting the time-driven activity-based costing (TDABC) approach is one way of enhancing costing efficiency in recent decades. Notably, the TDABC method can help estimate resource use and the associated costs (Zuleyha C. , David, Jeffrey, Rinad, & Geoffrey, 2020).

2.4.1 Development of TDABC

The TDABC method was first applied in the manufacturing industry. This method was introduced to the healthcare sector by Kaplan et al. (2004). The TDABC addresses the limitations of TCA and ABC methods. It uses a bottom-up approach to provide a more accurate estimation of the costs (Demeere, Stouthusyen, & Roodhooft, 2009). The TDABC develops the "costs of resources consumed as a patient moves along a care process" (Martin, Mayhew, & Urman, 2018).

The TDABC differs from the traditional costing model by involving time as the main driver for cost objects resources such as human resources (Kaplan & Anderson, 2004). The TDABC method simplifies determining the costs largely by eliminating the need to conduct a survey or interview the employee before allocating the costs to their respective activities (Kaplan & Porter, 2011). It depends on the historical medical records (Kaplan, et al., 2014).

Compared to the traditional costing model, TDABC accommodates the complexities of service delivery and considers the variations in the usage of different resources (Areena, 2019). The underlying principle behind the TDABC differs from traditional healthcare models; this attributes to the fact that it measures all the costs of resources expended in treating the medical condition over the entire cycle of care (Ana, et al., 2019).

The costing methodology makes it easier to obtain accurate measurements of the outcomes and associated costs at the patient's level. Table 2 shows the comparison between the three costing methods with different characteristics: cost driver, data collection, complexity, process map, data accuracy, efficiency, and cost-saving.

Table 2. Comparison between three costing methods

Characteristics	TDABC	ABC	TCA	Reference
Cost driver	Time	NA	NA	(Kaplan & Anderson, 2004)
Data Collection	Historical data. Electronic medical records.	Interviewing and surveying (Resource Intensive)	Use common cost center, common basis, and units to allocate the cost.	(Kaplan R. S., 2014) (Yangyang Y. , et al., 2017) (Lawson, 2017)
Complexity	Handle complexity of service delivered and consider variations in the usage of different resources.	Cannot handle the complex services and resources used on a large scale.	Cannot handle the complex services and resources used on a large scale.	(Areena, 2019) (Najjar, Strickland, & Kaplan, 2017)
Process Map	Applicable	NA	NA	(Yangyang R. Y., et al., 2016) (McBain, et al., 2017)
Data Accuracy	*Identify idle capacity for activities. *Model development. *Eliminate unnecessary interventions. *Done at a patient level.	Provide a more precise breakdown of indirect costs.	Not accurate; *The overhead burden rate applies arbitrarily and identically to all services. *The cost overhead of the services that utilize the overhead activities are not assigned.	(Balakrishnan, Goico, & Arjmand, 2015) (Lawson, 2017)

Characteristics	TDABC	ABC	TCA	Reference
Efficiency	Test alternative staffing models by minimizing unused personnel capacity.	Allows for an efficient operational cost challenge to identify better methods to allocate and eliminate overhead	Ideal in case of low indirect costs as opposed to direct costs	(Balakrishnan, Goico, & Arjmand, 2015) (Berlin & Smith, 2004)
Cost Saving	Save cost through resource allocation.	More costly to implement.	This results in significant underestimating and overestimating of costing.	(Mandigo, O'Neil, Misty, & al, 2015) (Carroll & Lord, 2016)

2.4.2 Implementation of TDABC Method

The core and prerequisites of the TDABC method require a detailed process map that can be adjusted continuously (Yangyang Y. , et al., 2017). Process map offers a suitable approach to examining certain processes. It breaks down the flow of activities right from initiation to completion. Different healthcare providers have adopted process maps required to apply the TDABC model to identify the costs incurred in delivering care.

Kaplan and Anderson (2004) developed a framework for implementing the TDABC model as described in Figure 9. Only two parameters must be estimated in the model: the unit cost of supplying capacity and the time required to complete an activity (Kaplan & Anderson, 2007). The activities in each step are mentioned below.

1. Determination of the care processes included in the study.

2. Mapping the process, which depicts the distinct activity and duration of healthcare resources, personnel, and equipment.

3. Identifying relevant resource objects and activities. The resources may include energy costs, wages, or maintenance costs. Then, calculating the total activity costs based on the consumption of the resources per activity. Instead of surveying the staff to identify how they spend time, the resources supplier's practical capacity can be estimated as a fraction of the theoretical capacity.

4. Estimating the capacity of each resource.

5. Estimate the time of each resource.

6. Calculating the unit cost of the capacity supplied. This is determined by establishing the total cost for specific activities and associated practical capacity. Then, calculating the activity rates for the activities supplied (Kaplan & Anderson, 2013). This is obtained by multiplying the activity rate with the observed activity time for each activity.

Multiplying the activity cost rate by the activity unit time and adding all the applicable activity costs to arrive at the product/service cost.

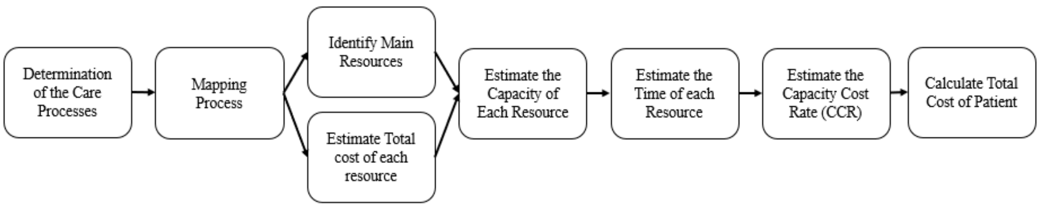

Figure 9. The TDABC framework

The application of the TDABC method for different services such as urology, pediatric, eyes, and orthopedic is also mentioned in the literature as described below.

2.4.3.1 Urology related care

A study on pediatric urology of children's hospital of Philadelphia, USA, determines the true cost of applying the new technology using a robot-assisted laparoscopic pyeloplasty (RALP) performed on children (Laviana, et al., 2016). Authors evaluate it to the TCA and develop TDABC to reduce cost and enhance the efficiency of time flow (Bodar, Srinivasan, Shah, Kawal, & Shukla, 2020). The problem was associated with defining the actual cost in the hospital in an adequate way since TCA does not exclude room capacity and idle personnel in its calculation; thus, labor costs were overestimated. The study investigates some accounting methodologies like 'relative value unit' (RVU) and 'ratio to cost charge'(RCC) (Rowe, et al., 2012; Mahida, et al., 2015) which are based on consumption to examine the cost of RALP and create more visibility into organizational cost drivers and processes (Young, 2007).

The study includes pediatric patients who received RALP surgery in a year. It started by executing the TDABC framework (Kaplan & Porter, 2011). The study starts with structuring the process map with the help of the expert of the stakeholder's team to develop step-by-step process maps of all activities involved in delivering the care cycle to the patient. During the observation of three cases, the method maps were validated to eliminate bias. Then, the intervention was defined based on the American Urological Association (AUA) practice guidelines. The study mentions the interval based on a daily routine that begins with the patient's entry into the pre-operative unit to the post-anesthesia unit discharge. Follow, the time spent on each task is quantified. Electronic medical record (EMR) in RALP cases is used to obtain retrospective time details (Bodar, Srinivasan, Shah, Kawal, & Shukla, 2020). After that, the capacity cost rate is determined for all resources used in the care-delivery process. In the next step, the total cost is determined to compare the treatment interventions for caring for a patient starting from the diagnosis up to 12 months follow-up. The overall cost of care for each intervention was summarized by the cost of each stage in the treatment route. However, this is the first study in the urology children's department that includes indirect costs in the final calculations.

The overall RALP cost that resulted from TDABC, compared to current traditional hospital cost accounting, showed several key cost savings, such as the TDABC with actual robot cost was $15,319 (5.0 percent) in comparison with traditional expenses when using the TDABC approach to analyze direct and indirect expenses with the robot's real usage capability. The lowest cost RALP scenario is $ 10,698, compared with $ 17,588, a difference of $ 6890, according to the cost computed by TDABC. The default deviation was set as $1302 in this computation. The present rate of use for robots of 22% effectively increases the overall cost of RALP TDABC by 16%. If used to the maximum capacity of the robot's accessibility, TDABC's costs are projected at 13,179$ (18%), representing a decrease of $2,979 (18%). These cost reductions result from increasing robot utilization, reducing the operating room turnover time, and enhancing pre-operative holding time (Bodar, Srinivasan, Shah, Kawal, & Shukla, 2020).

Another study mentions that TDABC can also be used to explore the processes, for example, detection of the trans peritoneal procedure of laparoscopic partial robot-assisted nephrectomy, as it would add to service costs compared to the cost of retroperitoneal laparoscopic partial nephrectomy robotic-assisted service (McClintock, Shah, Chang, & Haleblian, 2019). Each operational episode needs accurate cost accounts as a starting point to assess equal compensating allocation between different healthcare team members (French, Guzman, Rubio, & Frenzel, 2016). The TDABC analysis could lay the foundation for comparing realistic value and optimizing benefit in each value-driven model, such as bundled payments in urological applications (McClintock, Shah, Chang, & Haleblian, 2019).

The TDABC method is also used to differentiate long- and short-term prostate cancer treatments (Laviana, et al., 2016). The costs can change due to the hospital charges, maintenance fees, salaries, and length of stay (Laviana, et al., 2016). The study used the historical time archived by the hospital and the interviews of the staff involved in a specific procedure to obtain the maximum and the minimum time. In studying cancer services, the application of the TDABC is viable, and it gives insights into cost reduction techniques in a value-centered period. We reveal significant cost differences between competing medicines by tracking all stages of treatment from diagnosis to treatment to follow-up for low-risk prostate cancer for 12 years..

Urology encompasses a wide range of complex diseases; therefore, the TDABC application can be useful. For example, urolithiasis (is a phrase used for the description of urinary tract calculi or stones, which includes the growth of urinary calcifications, generally in the kidneys or ureters but occasionally in the bladder and urethra) management requires a large degree of variation in terms of management methodology such a method of surgical operation, observation, or timing of intervention, this has a major impact on the use of high-cost resources including MRI machines, emergency care, and operating room time.. The TDABC method compares different paths across a given process map in terms of cost and health results, allowing for the best practices to be portrayed and standardized. In addition, a further precise definition of the care cycle shows ways to further use practitioners at the topmost of their abilities. Midlevel physicians, for example, could treat not difficult post-operative patients instead of a high-cost capacity surgeon. These procedures will improve understanding of true resource use, improving the potential profit margins beneath bundled reimbursement models.

TDABC provided accurate costing in the Urology Department. But It should be noted that a correct reflection of cost can help the management identify the measures that can be applied for streamlining activities and providing the right resources for the ultimate care of the patient.

2.4.3.2 Pediatric Appendicitis care

The application of the TDABC method with a dynamic value measurement in pediatric appendicitis care has been mentioned in (Yu, et al., 2017). The authors create a pre-intervention process map and collect timings for each process for six months. The direct cost was calculated for each personnel and consumables for each part of the process map. The study identified higher costs due to long waiting times. Considering the diversity of care provided, the authors divided the process maps into three cases. The first case was the pre-intervention focused on identifying the levels of care. The pre-intervention case was analyzed for 149 patients between the age of 12.5 ± 4.2 years. The second was the post-intervention case, in which the process map was revised by studying the care processes of 58 patients of age between 11.3 ± 3.5 years. The third part was the same-day discharge cases, which refer patients who can be discharged on the same day after post-anesthesia care. The care process for 19 patients was studied for same-day discharge cases. In the pre-intervention cases, the revised process map included 41 processes and 20 staff kinds, whereas the post-intervention cases included 6 stages of care, 33 processes, and 19 human types. Due to these detailed process maps, the authors could reevaluate the time required for patient care. The analysis helped them reduce waiting time from 31 to 15 minutes and the emergency department duration from 269 minutes to 229 minutes by sending them to the holding area during the pre-operative phase. For the same discharge case, cost evaluation could be focused only on the discharge processes, thus eliminating the counting of operative phase processes, which was normally considered in the earlier accounting method. The authors found that this detailed process mapping following the TDABC method made the time calculations more accurate, and the service cost could be reduced by more than $300 for a patient.

Buckius et al. (2012) studied the use of TDABC for appendectomy in a pediatric department. The time data was retrieved from timestamp data from the electronic medical records. If the timestamp data were not available, observational data were used. The authors developed a process map through interaction with employees directly involved in the treatment. The study focused on inpatient and their interaction with the healthcare system and staff. The authors could correctly identify the activities and cost accounting with process maps. These maps resulted in finding the needed time in surgery (which has the highest cost), emergency department, and post-operative observation. The method was also useful to disaggregate the cost of personnel and the cost of consumables.

The two case examples show the effectiveness of TDABC in identifying the bottlenecks in processes and any undue charges accounted. The method helps drive efficiency and effectiveness (by finding the right processes and timing) in the patient care process.

2.4.3.3 Eye related care

Rakotondrajoa et al. (2020) demonstrated using the TDABC method for eye-related care to examine the cost drivers that led to a 200% cost increase in the past five years. The authors followed a six-step method of the TDABC framework created by Kaplan and Anderson (2007) to determine the cost for the staff, capacity utilization, cost/time for the care. The authors used the fixed costs for consultation, cataract operation, and the sale of glasses. The proportion of the cost was based on the time spent by the ophthalmologist on these activities. It was assumed that the evaluation activities were distinct and did not overlap (Chen J. , 2014). Rakotondrajoa et al. (2020) found that the increase in costs was due to consultation (for all patients) and cataract (for the patient who can afford it). Higher costs were incurred if a patient came directly to the hospital instead of through its referral center/camp. The costs were cheaper for referred patients as some of the care-related work was already done in the camp. The cost of ophthalmologists to the acuity and refractions tests in a hospital is more expensive than an allied staff who performs these in the camps. (Rakotondrajoa, et al., 2020).

The TDABC model revealed that the hospital gains more profit if patients accept operation and deflective errors through cataract surgery. The process also highlighted that those costs could be reduced if imported consumable surgical items could be reduced.

2.4.3.4 Orthopedic related cases

The need for orthopedic care, mainly for hip and knee replacements, and its cost have increased substantially over the years (Registry, 2013). Although most orthopedic procedures are expensive, the TDABC method may help streamline the service cost.

Cost can increase due to diagnostic procedures as well (McClintock et al., 2019).

The cost of the total knee replacement (TKR) process in a London teaching hospital was evaluated by Alvin, Sanjeeve, Kashif, Navnit, and Chinmay (2015). The authors studied the time taken for 20 patients with no complications such as infections and developed the process maps for the service. The study also included the indirect cost by considering departmental ward overheads during the TKR process until discharge. This calculation was created by dividing the number of beds per year in the orthopedic ward by annual overhead expenses on all wards to provide a unit cost for one single bed-day in one year. The direct inpatient cost was calculated based on personnel, consumables, and corporate overhead. It was found that the operating theatre consumables contribute about 34.4% of the total cost (staff salaries, overall ward cost) and implant, 30.5% by the corporate overheads, 3.3% by the operating theatre turnaround time, 3% for pre-assessment\joint school, 12.1% for admission and operating theatre staff, 11.1% forward care, and the remaining for orthopedic ward overheads. It shows that the overhead is a major cost contributor to the costs, and therefore, further analysis could be done to analyze the overhead attributed to the orthopedic wards (Chen, Sabharwal, Akhtar, Makaram, & Gupte, 2015).

A review of research on the applications of the TDABC method used in processes for the orthopedic department is done by Koolmees et al. (2020). Their review shows that the TDABC method provided a realistic breakdown of the costs and the processes (Dylan, David, & Eric, 2020). Similar findings were also obtained by Burnham et al. (2017) to use TDABC in orthopedic surgeries. The authors mention that recent advances in technology can help better cost accounting to implement TDABC (Burnham, Meta, Lizzio, Makhni, & Bozic, 2017). Most research articles show that the workforce is a high-cost item in inpatient care. Higher costs are incurred mainly from the services provided by the orthopedic surgeons. Other costs were incurred from the patient outcome and the healthcare facilities.

Anzai et al. (2016, 2017) provided a direct cost breakdown for delivering an abdomen and pelvis computed tomography (APCT) in the orthopedic department. The author found that 80% of the costs are related to labor like radiologist interpretation (40%), support staff (40%), materials (14%), and equipment (6%) contribute to this direct cost. Bodar et al. (2020) mention that the robot laparoscopic pyeloplasty process increases direct and indirect costs.

Morris et al. (2017) studied the TDABC method application in the endoscopy center in Brigham Women's Hospital. The patients had to wait for 14 days to 3 months at the ambulatory unit and the hospital. For cost accounting, costs of consumables, medical equipment, and staff were significant. The data showed that the reallocation of resources could cut waiting time from 3 months to 3 weeks and save almost US$ 102,000 in yearly cost reductions. As in Najjar et al. (2017), the costing technique enhanced investment return by lowering the medical time and number of visits to the hospital required by the patients.

By studying detailed processes, Martin et al. (2018) the use of ambulatory units can help them lower the operational cost, reduce waiting times, and relieve congestion in pre-operative clinics. The authors noted that a shift of about 50 to 75 percent of colonoscopy volume from hospital to the ambulatory facility could lower the waiting time from to less than six weeks and save up to US$102,000 per year (Martin, Mayhew, & Urman, 2018). Studies by Bodar et al. (2020), Balakrishnan et al. (2015), and Martin et al. (2018) in different settings also mention that the TDABC method helped them to provide more accurate estimates on the costs.

McBain et al. (2017) note that although costs may be accurate, the service providers are likely to give approximate estimates, translating to misleading information on resource use. Another factor can be time inaccuracies (McLaughlin N. , et al., 2014). For instance, the doctor may perform only a few observations when time is restricted, which might be a problem for carrying out the care procedures. By studying the details of a process, the time can be estimated more accurately (Najjar, Strickland, & Kaplan, 2017). It can lead to more patients being serviced within a given period.

2.4.3.5 Effectiveness of the TDABC method

The effectiveness of the TDABC method has been mentioned by many authors, as mentioned in Table 3.

Table 3. Effectiveness of the TDABC method

Effectiveness as cited by different authors	Author(s)
• Can be embedded in a functional system. • Supports cost control to deliver value-based care.	(Mandigo, O'Neil, Misty, & al, 2015)
• Can be used for complex services. • Eliminates personal preferences and managerial discretions.	(Areena, 2019)
• Effectively applied for appraisal purposes in a variety of specialties. • Identify the idle capacity to explore personnel decisions. • Identify areas to increase the data accuracy of cost. • Model development in clinical effectiveness in the context in outpatient clinics	(McLaughlin N. , et al., 2014) (Balakrishnan, Goico, & Arjmand, 2015) (Donovan, Hopkins, Kimmel, Koberna, & Montie, 2014) (Inverso, Lappi, & Flath-porn, 2015)
• Reduced the waiting times of patients by resource allocation	(Yangyang Y. , et al., 2017)

Table 4. Effectiveness of the TDABC method

Effectiveness as cited by different authors	Author(s)
• Eliminate unnecessary interventions by identifying the resources required for particular procedures. • Identify the relationship between enhancement of patient health and utilization resources to eliminate wastes	(Laviana, et al., 2016) (Najjar, Strickland, & Kaplan, 2017)
• Utilize the staff time by providing a comprehensive understanding of personnel costs and ways and testing alternative staffing models to increase efficiency. • Allocates time to the specific condition to determine the degree of resource capacity. • Enabled the calculation of per minute and per case personnel costs	(McLaughlin N. , et al., 2014) (Balakrishnan, Goico, & Arjmand, 2015) (Popat, Gracia, Guzman, & Feeley, 2018)
• Determine the cost of providing care for specific conditions or diseases. • Data collection is done at a patient level. • Have room for updates to reflect the ongoing changes in the operating conditions by estimating the required unit time for every new activity.	(Kaplan & Anderson, 2004) (Keel, et al., 2020)
• Provides an opportunity to identify process steps for changes in the number of staff.	(Balakrishnan, Goico, & Arjmand, 2015)

2.4.3.6 Limitations of TDABC

Although the TDABC model overcomes the limitations of the TCA and the ABC method, it does have its limitations, as mentioned in Table 4. The TDABC costing method has been adopted to measure costs accurately over the entire life cycle. Its implementation will automatically lead to increased profits and reduced costs for patients. (Ana, et al., 2019). Likewise, the model allows clinicians to access actionable plans that redesign effective care systems for patients' treatment. The TDABC model can help the healthcare industry achieve cost-effective processes, a significant challenge in the current era. Therefore, the TDABC model becomes a good investment when weighing the pros and cons.

Table 5. Limitation of TDABC method

Limitation	Author(s)
• TDABC's reliance on time may not be relevant for complex organizations with different departmental outputs because it fails to capture other time-driven areas and relate indirect costs of the staff work time. • The system is expensive to acquire and maintain.	(Ghaffari, Mohamadzadeh, Akbari, Salem Safi, & Yousefi, 2013) (Carroll & Lord, 2016) (Ramji, Koehler, & Shah, 2018)
• It requires a comprehensive information technology platform which is costly and time-intensive.	(Ramji, Koehler, & Shah, 2018)
• It relies on a single activity with a one-time relationship, which does not show the correlation between involved costs and outcomes	(Ozyurek & Dinc, 2014)

2.5 Summary of Literature Review and Research Gap

Identifying the total cost of care delivery is important, but the outcomes are based on the methods used, which may or may not reflect costs correctly. When costing is not done as per the service, the organization might be overcharging to its patients, thus losing competitiveness, undercharging (thus being less efficient), randomizing the charge, thus losing the effectiveness of the costing process. When calculating the cost of healthcare delivery, service time and overhead cost become important.

Service time needs to be evaluated based on the study of process maps for care, but overhead cost calculations can be challenging to overgeneralize the cost process.

Figure 10 shows that to get an effective healthcare cost, developed based on the BLOC-ICE system concept method by Pokharel (2021), where the focus of the study, inputs, outputs, methods (constraints), and components of costs have to be considered (Pokharel, 2021). Figure 10 also shows that costing depends on the accounting method, type of service offered, and the regulations/policy from the government or the healthcare organizations become important. If the time interval of the care cycle can be correctly assessed and an appropriate costing model is used, then all aspects of the health care process can be outlined and evaluated to get the right cost of service. Also, it shows that such a costing method should consider the service personnel, service equipment, pharmacy requirements, facilities, and auxiliary service to support the care becomes important.

The indirect cost evaluation can be a big task as the general thumb rule of using percentage, generally done in the organization, may not reflect the actual indirect cost. Therefore, the focus should be on adding the processes and evaluating each of them for a particular service provided to the patient.

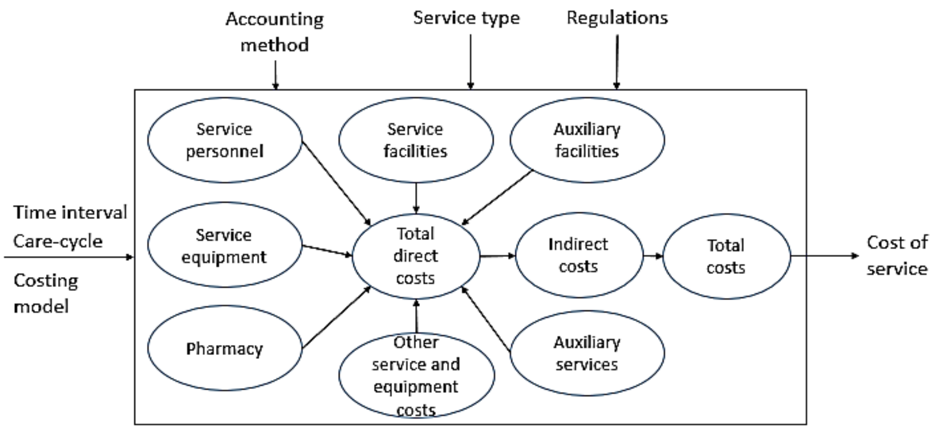

Figure 10. The main elements in healthcare costing

In this chapter, three costing methods applied to healthcare services were discussed. The first method, the traditional cost accounting (TCA) method, uses a cost driver established through management experience or expert advice. This method is simple to implement and use. It applies RBRVS or RCC, which overlooks resources in a particular process. Therefore, it may predict inaccurate and unrealistic costs of the service.

The second method, activity-based costing (ABC), uses activities in a hospital setting as a basis for measurement. Cost drivers allow the allocation of indirect expenses to reflect a specific resource pool. It enhances organizational efficiency by enabling managers to identify costs incurred in healthcare services. Contrary to TCA, ABC has a higher level of accuracy and depicts the actual costs of delivering services. Its main advantage is that it allows hospital administrators to focus on value-added activities. However, identifying the cost drivers is not easy due to the detailed processes, timing, and resources required to be used for a service.

The third method, the TDABC method, is increasingly used in the healthcare sector. The method uses a bottom-up approach to provide the estimation of costs. This method assumes that most of the resources, including labor and facilities, can be measured in terms of time used. Some researchers have shown the applicability of the method in services like urology, orthopedics, and eye care.

Below are some gaps in TDABC implementation that were identified after reading and analyzing the literature:

- **Gap 1:** Most research focuses on including the direct and indirect costs for the overall activities. There is no explicit consideration of human resources utilization which directly affects the costs.

- **Gap 2:** The current research focuses on identifying activities and linking costs to each based on the timing and resource use. Also, current research needs to show how the cost accounting methods can support more accurate costs associated with Capacity Cost Rate (CCR) by emphasizing segmentation rather than studying the entire system.

CHAPTER 3: METHODOLOGY

This chapter provides the methodology followed in this research paper. The research strategy, sampling design, process map of care-delivery, research question and hypothesis, methodology framework, TDABC method, sensitivity analysis, multiple linear regression model, ridge regression model, and lasso regression model are also discussed in this chapter.

3.1 Research Strategy

The research will follow the quantitative design model as described in the below Figure 11 to comprehend the relationship between time and cost variables which are independent variable (and dependent variable of human resources respectively, as well as how they may influence the total cost of the healthcare department.

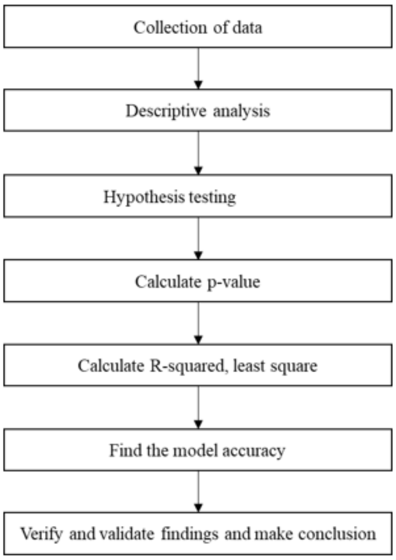

Figure 11. The methodology for quantitative analysis

A scientific research process will be followed in this research , shown below in Figure 12. The eight steps mentioned in step 1 on the left side of the research process are based on Kaplan and Anderson TDABC framework (Kaplan & Anderson, 2004). The right side of the model, step 2 to step 4, is proposed in this thesis to complete the cost evaluation.

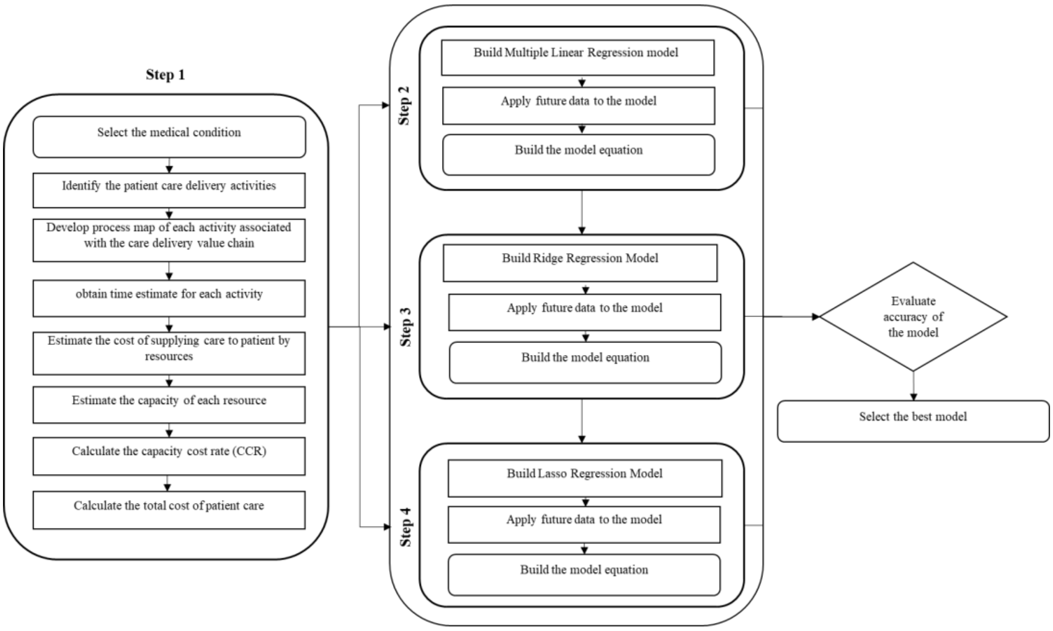

Figure 12. Research process

3.2 Sampling Design

The research will use random sampling to survey patients who visited the orthopedic department (knee arthroplasty) during the fiscal year 2019 in two areas which are pre-operation office and pre-operation testing and consulting . The fiscal year is chosen to match the financial records used for the patient-certain pre-treatment records rather than the part-year financial records and to normalize the records for this research. The formula in equation 1 is being used to obtain the sample size for this study.

$$\boldsymbol{n_o = \frac{z^2 \times p(1-p)}{e^2}} \qquad (1)$$

Where:

z^2 - Z value corresponding to the confidence level obtained from the Normal Distribution table.

p- Variability of the patient population who suffer from knee arthroplasty problems.

e- The confidence level interval (margin of error).

The confidence level is chosen at 95% for this study and z=1.96 from the Standard Normal Distribution Table. The Z score and margin of errors depend on the confidence interval. A 50% standard deviation has been used. The margin of error is expected to be 5%. These assumptions provided a minimum sample size required for the study to be about 383 patients, as shown below. Therefore, to increase the accuracy of the study and ensure that different cases are included, 1000 patients are used in this study.

$$\boldsymbol{n_0 = \frac{(1.96)^2 \times 0.5(1-0.5)}{(0.05)^2} \approx 383}$$

3.3 Process Map of Care Delivery

Miro application (Hauser, Hawkins, Queiroga, & Prater, 2020) was utilized to create a thorough flow diagram of the patient's care. This process map helps develop a common standardized language ensuring that participants understand the design flow. The process map indicates all activities each patient encounters during its care flow and shows each patient's resources and associated time during each activity. The data incorporated in the process map for the different components such as activities, time, cost, and resources are obtained from the electronic medical records and other different creditable supplies.

3.4 Research Questions and Hypotheses

In this section, research questions are proposed. They are used to develop hypotheses to evaluate the importance of the relationship between the overall time of patient care and the cost of human resources responsible for delivering specific care.

3.4.1 Research Question

The following research questions are discussed in this research.

RQ1: Does the cost of human resource significantly affect the total cost of the knee arthroplasty service?

The literature discussed the TDABC method considers time as the main cost-driver. Delivering care to patients needs a human resource responsible for activities when delivering care to patients. These patient-care activities cost healthcare in different aspects; one of these aspects is the time the human resources consume with patients. The purpose of this study topic is to see how much the cost of human resources affects the total cost of a knee arthroplasty procedure.

RQ2: What methods are available to resource cost based on care delivery time handling with the TDABC method?

This research question aims to study the accuracy of the total cost of the Arthroplasty department by using the two main variables (time and cost) when applying the TDABC method through three different cost-based models. The accuracy of the model for the given data is also analyzed. The following hypotheses are built to test the two-research questions.

3.4.2 Research Hypothesis

The literature discuss that time is the main cost driver when applying the TDABC method. In healthcare, human resources consider as the main aspect, and managing it contributes as a key success factor for the whole healthcare system and can improve the healthcare cost models. As a result, each human resource needs to be tested separately based on the time consumed when delivering care to patients and see how the cost changes compared to the actual cost. Therefore, the study proposes the following hypotheses:

$\boldsymbol{H_{o1}}$: There is no statistically significant difference between the total time of patient care delivered by a patient access specialist and the total cost.

$\boldsymbol{H_{o2}}$: There is no statistically significant difference between the total time of patient care delivered by a nurse and the total cost.

$\boldsymbol{H_{o3}}$: There is no statistically significant difference between the total time of patient care delivered by security and the total cost.

$\boldsymbol{H_{o4}}$: There is no statistically significant difference between the total time of patient care delivered by a physical therapist and the total cost.

$\boldsymbol{H_{o5}}$: There is no statistically significant difference between the total time of patient care delivered by X-ray specialist and the total cost.

$\boldsymbol{H_{o6}}$: There is no statistically significant difference between the total time of patient care delivered by an orthopedic consultant and the total cost.

$\boldsymbol{H_{o7}}$: There is no statistically significant difference between the total time of patient care delivered by a patient schedule coordinator and the total cost.

$\boldsymbol{H_{o8}}$: There is no statistically significant difference between the total time of patient care delivered by a pharmacist and the total cost.

3.5 Research Framework

Based on the research hypotheses, the focus of the study is to apply and test the TDABC method cost reduction in the knee arthroplasty service covering the two main variables, time and cost, as shown in the conceptual framework model developed for the hypotheses in Figure 13. Because the mere application of TDABC would not add value without some means of comparison, the researcher develops a methodology framework that follows along the research works as described in Figure 14.

Data were collected from different sources using interviewing the hospital staff and financial and HR reports. The activities used to complete the patient care delivery were collected from the hospital staff, and time data were collected from the electronic medical records and verified with the resources who do the associated job. Also, to verify the time data, the time was collected for different fiscal years (2017 and 2018) and combined with the fiscal year 2019 by calculating the mean time from three years. Once the data were collected from different sources and electronic sources, the data was analyzed using Microsoft Excel software.

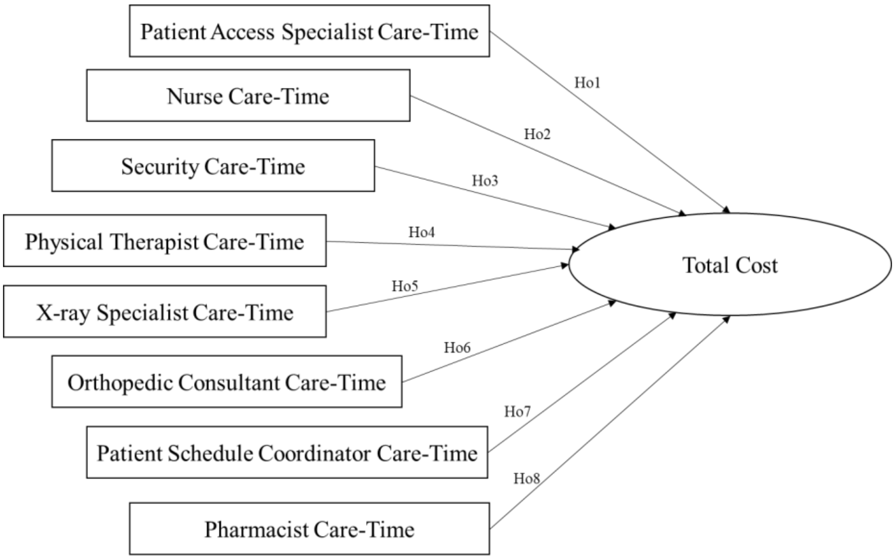

Figure 13. Conceptual framework of the model

After that, the TDABC method, as Kaplan’s framework mentioned earlier, is applied, following the Multiple Linear Regression (MLR) Analysis Model to test the hypothesis built, show which human resources are affecting the total cost and who can be ignored (Cohen, West, & Aiken, 2014). Then, the accuracy of the model is obtained. Then, based on the results, the Ridge Regression (RR) and Lasso Regression (LR) models are created to investigate the cost model's accuracy.. The outputs are verified and validated with 200 patients' data selected randomly from the historical data used for the three regression models. Finally, a comparison is done between the actual cost and the models' outputs on the total costs.

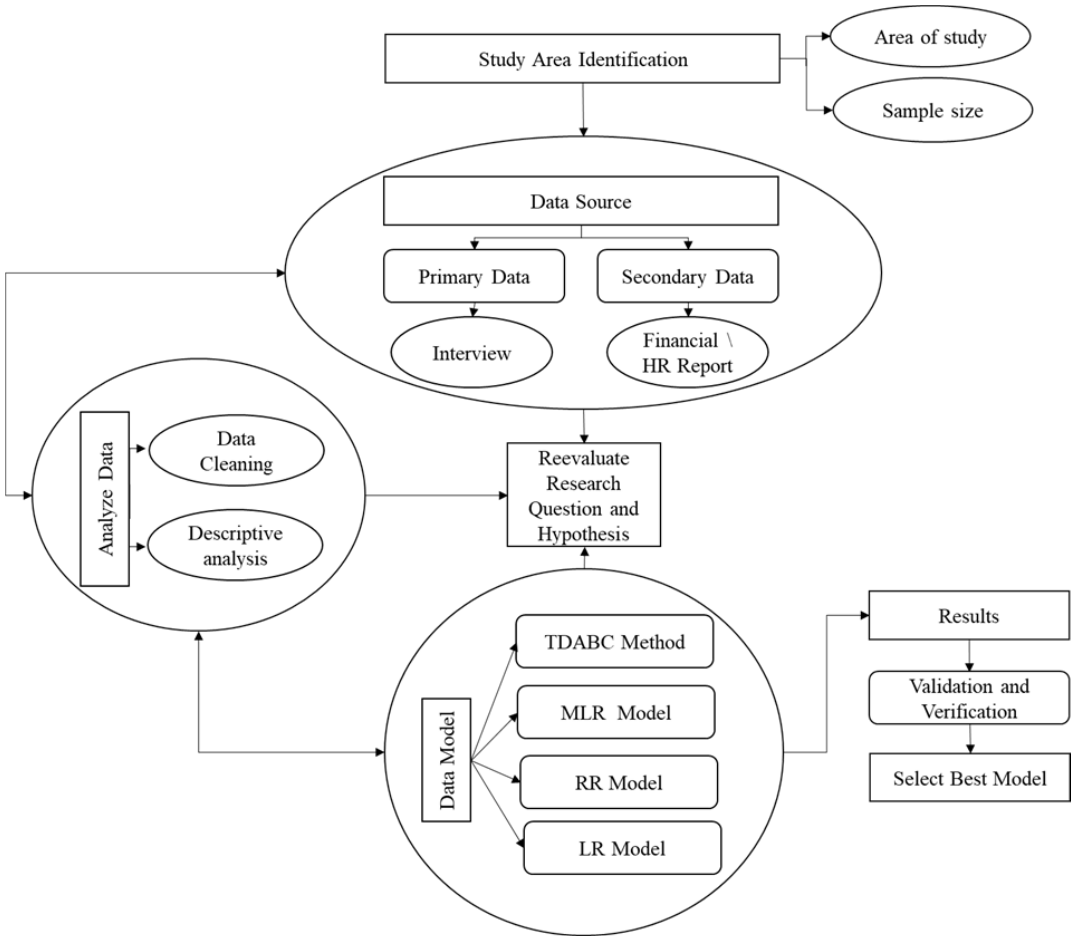

Figure 14. Methodology framework

3.5.1 TDABC Method

The following eight-step framework of the TDABC model will be applied in this research.

1- Select the medical service for examination.

2- Identify the activities in the care cycle of the medical service and draw the process map to examine the details and flow of processes.

3- Identify relevant resources for each activity.

4- Calculate each resource's total cost.

5- Calculate the cost of each resource's capacity.

6- Calculate how much time each resource will take.

7- Calculate the Cost of Capacity (CCR).

8- Determine the patient's overall cost.

The equations to be used for the TDABC framework applications are discussed below:

1. The overall cost of any resource is estimated based on the sort of work performed and the wages received.Equation 2 yields the following estimate of each resource's capacity cost:

$$\boldsymbol{Capacity\ of\ Resource/Week} \\ \boldsymbol{= daily\ working\ hours \times working\ days\ per\ week} \quad (2)$$

2. The estimation of time of each resource depends on the time the patient consumes with the resource; the researcher used the information of the two previous years in the hospital electronic medical records, which were confirmed with the clinicians during individual meetings. After that, all the time obtained were used to find the mean time needed for each activity of the care cycle.

3. To calculate the CCR; two equations are used:

$$\boldsymbol{CCR}_{\boldsymbol{Resource}} = \frac{\boldsymbol{Resource\ wage}}{\boldsymbol{Practical\ Capacity}} \quad (3)$$

$$\boldsymbol{Practical\ capacity} = \boldsymbol{Available\ Capaciy} * \boldsymbol{shift\ hour} * \boldsymbol{working}\frac{\boldsymbol{days}}{\boldsymbol{month}} * \boldsymbol{60\ min} \quad (4)$$

4. Calculating the total cost of the patient:

$$\boldsymbol{Total\ cost} = \boldsymbol{Mean\ time} \times \boldsymbol{cost} \quad (5)$$

Where:

Mean time is minute/patient

Cost is $/minute

Before analyzing the data, data cleaning was applied to the collected data to ensure consistency and validation of the used data. The steps followed in data cleaning were to remove unwanted values, fix structural errors, fill missing values, and manage outliers.

3.5.2 Regression Models

Different regression models are built in this study to minimize the error and enhance cost accuracy. The three models used are Multiple Linear Regression (MLR), Ridge Regression (RR), and Lasso Regression (LR).

3.5.2.1 Multiple Linear Regression

An MLR model is developed after identifying the required data using the TDABC method. This method will provide the relation between the cost as a dependent variable and several independent variables representing time spent to provide the care.

As shown in equation 6, the outcome depends on many linear variables (Xi). The coefficients associated with the time variable in the equation are called the capacity cost rate (CCR) and will be obtained by analyzing historical data. The intercept ‘a’ in the equation is considered the cost of assets.

Healthcare cost equation

$$\begin{aligned} \boldsymbol{y} = \boldsymbol{a} + \boldsymbol{CCR_1 x_{ST}} + \boldsymbol{CCR_2 x_{PST}} + \boldsymbol{CCR_3 x_{NT}} + \boldsymbol{CCR_4 x_{PTT}} + \boldsymbol{CCR_5 x_{XT}} \\ + \boldsymbol{CCR_6 x_{CT}} + \boldsymbol{CCR_7 x_{PSCT}} + \boldsymbol{CCR_8 x_{PT}} \end{aligned} \tag{2}$$

Where:

$\mathrm{y} = \text{dependent variable (cost)}$

$X_{ST} = \text{independent variable (time) of Security Resource}$

$X_{PST} = \text{independent variable (time) of Patient Specialist Resource}$

$X_{NT} = \text{independent variable (time) of Nurse Resource}$

$X_{PTT} = \text{independent variable (time) of Physical Therapist Resource}$

$X_{XT} = \text{independent variable (time) of X} - \text{Ray Specialist Resource}$

$X_{CT} = \text{independent variable (time) of Orthopedic Consultant Resource}$

X_{PSCT}

$= \text{independent variable (time) of Patient Schedule Coordinator Resource}$

$X_{Pt} = \text{independent variable (time) of Pharmacist Resource}$

$\mathrm{a} = \text{Asset Cost}$

MLR applied in the study go along with the following sequence:

1. Hypothesis testing (null/alternative):

Hypothesis testing uses statistics to determine if the model acts naturally or not. Type I error (null hypothesis) tests if the variable is laid outside the confidence interval and less than the specified p-value. The usual process of hypothesis testing consists of four steps (Raftery, 1995):

1. Measure both the null hypothesis H_o (that the data are the result of pure chance) and the alternative hypothesis H_a (that the observations are not the result of pure chance) (commonly, the observations show a real effect combined with a component of chance variation).
2. Apply ANOVA testing procedure to identify the parameters.

3. Calculate the p-value, which is the chance of the null hypothesis being rejected or not, by identifying the least significant p-value. The lower the p-value, the stronger the evidence against the null hypothesis and the more likely it is that the alternative hypothesis should be accepted.
4. Compare the p-value to an acceptable significance value (sometimes referred to as an, and typically equal to 0.05). When p=, the observed effect is statistically significant, the null hypothesis is rejected, and the alternative hypothesis is accepted.

2. R^2:

For linear regression models, the R-squared is considered a measure of the goodness of fit. R-squared measures the strength of the association between the model and the dependent variable. This will measure how each resource affects the total cost depending on its value, greater or below 0.05. Also, it will be used to compare the obtained cost of TDABC with the predicted cost, which helps find the gap.

3. Coefficient:

Coefficients are used to fit the data points best and be used as CCR values for each resource. This coefficient will be used to minimize the predicted total cost of resources for the knee arthroplasty service, and then it used to build the equation of the model.

The used variables are:

x_{ST}: Time consumed by Security Resource

x_{PST}: Time consumed by Patient Specialist Resource

x_{NT} : Time consumed by Nurse Resource

x_{PTT}: Time consumed by Physical Therapist Resource

x_{XT}: Time consumed by X-Ray Specialist Resource

x_{CT}: Time consumed by Orthopedic Consultant Resource

x_{PSCT}: Time consumed by Patient Schedule coordinator Resource

x_{PT}: Time consumed by Pharmacist Resource

4. Accuracy (train/test data)

The model is trained to reduce the loss and best fit the data into a model to increase accuracy and minimize risk. Equation 7 is a Root Mean Square Error (RMSE) which is used to calculate the difference between the actual and predicted values of the model (errors):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} ||(y_i - y^\wedge{}_i||^2}{N}} \quad (7)$$

Where

N: is the number of sample size

y_i: Actual data

$y^\wedge{}_i$: prediction data

After calculating the errors, the mean absolute percentage error (MAPE) is obtained using equation 8 to see how accurate the new model is with the actual model.

$$\boldsymbol{MAPE} = \frac{\mathbf{1}}{\boldsymbol{n}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \frac{|\boldsymbol{A}_{\boldsymbol{i}} - \boldsymbol{F}_{\boldsymbol{i}}|}{\boldsymbol{A}_{\boldsymbol{i}}} \quad (8)$$

Where

A_i: is the actual value

F_i: is the forecast value

n: is the total number of observations

4. Multicollinearity

Multicollinearity is applied by using the correlation coefficient as a parameter to measure the dependency of the variables. The equation used to test the correlation is:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (9)$$

3.5.2.2 Ridge Regression Model

Ridge regression is used to minimize the unbiased results from the least-squares and large variance that impacted the predicted values far from the actual values. This problem could be solved by adding a penalty cost of the coefficient to the linear regression equation.

After generating a ridge regression using the time and cost data, a new CCR of each resource is obtained. Then, the model is tested for accuracy using the value of R-squared. Then, the data was split into training (70%) and test data (30%). After that, the model is tested for validation using the MAPE and RMSE. Following that, the total cost is obtained through equation 9. In the end, the utilization of each resource is obtained and examined.

As shown in equation 9, the outcome depends on many linear variables (Xi) plus the penalty cost multiplied by the summation of the squared values of the coefficients. The coefficients associated with the time variable in the equation are called the capacity cost rate (CCR) and will be obtained by analyzing historical data. The lambda ‘λ’ in the equation is considered the penalty term. Since selecting the value of penalty (λ) is critical, λ was obtained through Python programming by doing a loop iteration by iterating between the following digits ($10^{-5}\ to\ 10^{5}$) to find the optimum value that will produce a higher score (R-squared) and give a solution that is not overfitting data. The intercept ‘a’ in the equation is considered the cost of assets.

$$\boldsymbol{y = a + CCR_1 x_{ST} + CCR_2 x_{PST} + CCR_3 x_{NT} + CCR_4 x_{PTT} + CCR_5 x_{XT}} \\ \boldsymbol{+ CCR_6 x_{CT} + CCR_7 x_{PSCT} + CCR_8 x_{PT}} + (\lambda \times \sum_{i=1}^{8} CCR_i^{\,2}) \quad (9)$$

3.5.2.3 Lasso Regression Model

Lasso Regression stands for “Least Absolute Shrinkage and Selection Operator.” This type of regression is used to obtain a more accurate value prediction than the normal linear regression by shrinking the values towards the mean. Lasso regression method is used to find the subset of predictors that gives the minimum amount of prediction error for a quantitative response variable. The method imposes a constraint on the parameters to lead some regression coefficients towards zero. This constraint, called penalty, forces the reduction of the size of the variables, thereby providing an opportunity to developed a more relevant model that can be used for prediction. The model adds a penalty to the coefficient of the linear regression equation, which helps to reduce the number of insignificant variables. This penalty is equal to the absolute values of the CCR. This method can be used for a small number of predictors.

After generating a lasso regression using the time and cost data, a new CCR of each resource is obtained. Then, the model is tested for accuracy using the value of R-squared. Then, the data was split into training (70%) and test data (30%). After that, the model is tested for validation using the MAPE and RMSE. Following that, the total cost is obtained through equation 10. In the end, the utilization of each resource is obtained and examined.

As shown in equation 10, the outcome depends on many linear variables (Xi) plus the penalty cost multiplied by the summation of the absolute values of the coefficients. The coefficients associated with the time variable in the equation are called the capacity cost rate (CCR) and will be obtained by analyzing historical data. The lambda 'λ' in the equation is considered the penalty term. Since selecting the value of penalty (λ) is critical, λ was obtained through a loop iteration by iterating between the following digits (10^{-5} to 10^{5}) to find the optimum value that will produce a higher score (R-squared) and give a solution that is not overfitting data. The intercept 'a' in the equation is considered the cost of assets.

$$\boldsymbol{y = a + CCR_1 x_{ST} + CCR_2 x_{PST} + CCR_3 x_{NT} + CCR_4 x_{PTT} + CCR_5 x_{XT}} \\ \boldsymbol{+ CCR_6 x_{CT} + CCR_7 x_{PSCT} + CCR_8 x_{PT}} + (\lambda \times \sum_{i=1}^{8} |CCR_i|) \quad (10)$$

3.5.3 Sensitivity Analysis

Sensitivity analysis examines the utilization of human resources involved in the care delivery process. The analysis is done to analyze the utilization of the resources and the actual working hours for each activity performed. Each scenario represents a case with increased utilization of 5%, starting from 70% to 90%, and working hours with a step increase of 1 hour from a minimum of 6 hours to 10 hours.

To demonstrate consistency in cost evaluation, the study, the knee arthroplasty service, is considered in this thesis. The data is analyzed by studying the relationship between the dependent variable (cost) and independent variable (time) for human resources providing care to the patients. This analysis will follow different steps as the TDABC method, MLR model, RR model, and LR model to increase the accuracy of the cost model and hence cost reduction. All CCRs obtained from the regression models are used to obtain each resource's utilization and compared with TDABC CCR and utilization.

CHAPTER 4: RESULTS AND ANALYSIS

This study used quantitative techniques to analyze data collected from the case hospital located in Qatar. The result analysis consists of different stages. Section 4.2 describes the test instance of the chosen case study. The data cleaning process is then elaborated in Section 4.3, followed by the descriptive analysis in section 4.4, then the TDABC method is analyzed in section 4.5. Regression models in Section 4.6 and Sensitivity analyses build in Section 4.7. Finally, the conclusion is in Section 4.8.

4.1 Test Instances

The proposed process was conducted as a case study at the hospital (knee arthroplasty) department to assess the process effectiveness by accurately determining the human resource cost reduction in patient care delivery. The data collection followed the application requirements of the TDABC method. Analyzed data in this study include the time required for patients and the human resource performing and activity on the patient, working hours for each human resource, the cost of each human resource, and the total cost for the department.

The knee arthroplasty service consists of four main activities: registration and verification, clinician visit, patient consulting and plan-care discussion, and finally, patient check for medication. These main activities consist of different sub-activities managed by a specific human resource who cares for patients, described in Section 4.5. Some activities at the hospital are merged, which does not allow the identification of resource utilization and real-time consumption. Consequently, the study separated some activities from being as one to be in different steps. This procedure is done based on the defining activities in Qatar's private hospitals and the literature. The sequence of main and sub-activities is emphasized by a process map, as shown in Appendix A.

Activities are different according to their purpose and time. The time of each activity is retrieved from the electronic medical records in the hospital and then verified following two different stages: the first stage, by checking it with the electronic medical record of the two previous years, and the second stage by asking the human resources who are responsible for giving the patientcare about the time he\she consumed with one patient treatment. All responses were then collected to calculate the mean of the time spent with the patient in each activity.

4.2 Data Cleaning

Data cleaning was applied to clean some errors encountered while reviewing the data sets collected for this research. The steps followed for cleaning are:

- Remove unwanted values.

The high volume of data associated with patients creates a problem while cleaning. So, the research study considers 1000 patients based on the sample size evaluated earlier. Also, the duplicated patient ID and repeated data or mixing data for different patients are removed to keep the data collected unique. In addition, some collected data showed that a resource might perform two different jobs simultaneously. The duplication of such works was also removed for consistency.

- Structural error fixing

The error in formatting the time values, such as mixing the values between hours and minutes and by time reporting in text or number format, had to be fixed. Also, the format of the resource title had to be adjusted to the correct format for this study. In addition, fixing the attribute dependencies between activities was undertaken, for example, patients take a token for medicine and get the medicine from the pharmacy. Some records did not have the obvious dependency.

- Filling missing values

Filling the resource titled in the required cells because some of the resources responsible for a specific activity were missed and not written. In addition, some activity times were missing, so it is filled following the method described earlier in this chapter.

- Manage outliers

Identify the data outliers by identifying the maximum and minimum values and removing them because it will skew the results. These outliers result from specific reasons, such as comorbidities of patients that make the activities longer than usual or emergency conditions that make the process faster.

4.3 Descriptive Statistical Analysis

The time study was done along with the practical resource capacity; in other words, the time was collected while the resources were involved in delivering the care to patients. The intervals, time consumed by patients in each activity, and the number of patients are given in Appendix B.

Multiple tools are used to analyze the data, such as Histogram, boxplot, and normal distribution, as shown in Appendix B. The results obtained are visualized in Table 5. The minimum time, maximum time, the mean time, and variations are being studied to know how much time resources spend with a patient while delivering the care and indicate if there is a possibility for enhanced utilization and cost reduction.

Table 6. Descriptive statistical results

Activity	Resource Responsible	Min Time (Min)	Max Time (Min)	Mean Time (Min)	Variation (Min)
Take Token	Security	0.10	1.00	0.48	0.29
Ask for Information	Patient Access Specialist	14.00	18.00	16.00	1.40
Patient Registered	Patient Access Specialist	1.00	3.00	2.00	0.80
Check Vital Sign	Nurse	6.00	10.00	7.98	1.40
Blood Test	Nurse	10.00	13.00	11.51	1.10
Physical Examination	Physical Therapist	35.00	45.00	38.70	3.13
X-Ray	X-Ray Specialist	25.00	30.00	27.47	1.70
Diagnose by Consultant	Orthopedic Consultant	25.00	30.00	27.50	1.70
Discuss Plan-care	Orthopedic Consultant	18.00	20.00	19.00	0.80
Schedule Next Visit	Patient Schedule Controller	9.00	11.00	9.96	0.82
Take Medicine	Pharmacists	14.00	16.00	15.01	0.82

After analysis, as shown in Figure 15, all activities revealed that a significant amount of time is squandered but compensated without actual labor, and that this time might be used to assist many more patients. The frequency distribution shows the minimum and maximum allowable time for care service. However, a boxplot is used to know if patients' time is distributed symmetrically around the mean or skewed and any outliers that may affect the time data.

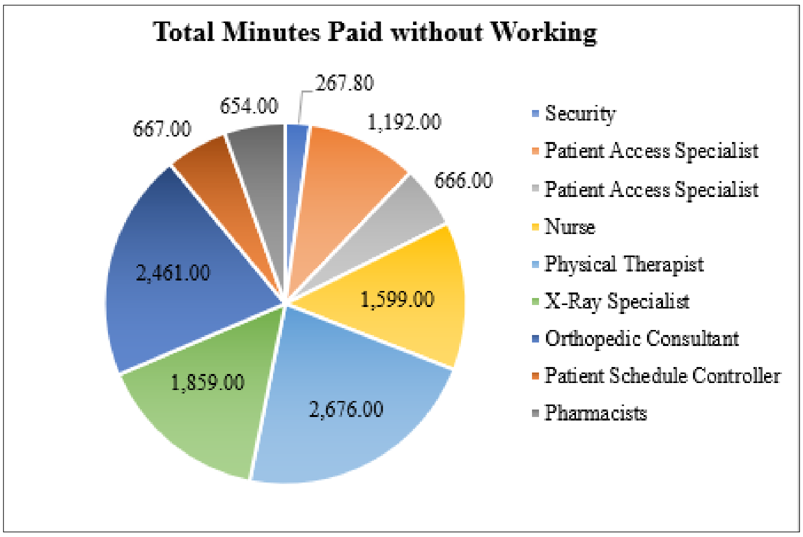

Figure 15. Total minutes paid without the actual working

4.4 TDABC Method

The data were collected meeting the TDABC requirements and included the following sequence:

1. Select the medical condition

Identify patients who suffer from knee problems and are transferred to the department of knee arthroplasty.

2. Identify the care cycle and draw a process map

The care cycle starts from the patient's initial visit to the knee arthroplasty in the orthopedic care center, registration and verification, clinician visit and radiologic imaging, a patient’s consulting and plan-care discussion, check for next appointment and check medication. The study focuses on the consulting path of the care cycle, starting from the patient's entrance in the center until they are being diagnosed with an illness, as described in Table 6.

Table 7. Patient care-delivery activities

Main Activity	Sub-Activities	Assigned Resource
Registration and Verification	Patients go to admission.	NA
	Patients take a token and check-in.	Security
	Staff asks the patient for data.	Patient access specialist
	Patient registered.	Patient access specialist
	Patients wait in the waiting room.	NA
Clinician Visit	Nurses check the vital sign of the patient.	Nurse
	Patients are asked for an initial physical examination.	Physical Therapist
	Patients are asked for an X-ray.	X-ray specialist
	Patient gets a blood test.	Nurse
	Patient wait to see the consultant.	NA

Table 8. Patient care-delivery activities

Main Activity	Sub-Activities	Assigned Resource
Patient Consulting and Plan-Care Discussion	Patients are being diagnosed by a consultant.	Consultant
	Consultant discusses a plan of care with patient.	Consultant
	Patient discusses with the administration to schedule the next visit.	Patient schedule coordinator
Patient Check for Medication	Patient takes a token and wait.	Security
	Patient takes medicine.	Pharmacist

The process map shown in Appendix A was obtained by meeting and interviewing different clinicians individually to identify each activity and time of the care cycle. In addition to that, the sequence of activities information available in different literature and private hospitals in Qatar was considered to obtain a symmetric sequence of the processes and thus accurate resources and time used during the treatment process. After patients complete the previously mentioned four stages in the care cycle, they enter the next process by getting the remaining care on the same day or leaving the system. In this case, they are two possibilities; patients are done or schedule another appointment. Also, depending on doctor consultation, the patient may collect their medication.

3. Identify relevant resources of each activity

Each activity is assigned to a specific resource responsible for delivering care to patients, as shown in the earlier mention Table 6.

4. Estimate the cost of each resource

The cost of each resource was obtained from the financial department in the hospital, as illustrated in below Table 7.

Table 9. Resource cost (wages)

Resource Type	Cost ($/month)
Patient access specialist	3,173
Nurse	5,388
Security	824
Physical Therapist	5,334
X-ray specialist	4,475
Orthopedic Consultant	18,055
Patient schedule coordinator	3,814
Pharmacist	8,973

5. Estimate the capacity of each resource

Human resources work 8 hours per day, and 6 days per week, which means the total capacity for each resource is calculated using equation 2, equal to 48 hours/week, 208 hours/month, and 2496 hours/year. This data is utilized to compute each human resource's capacity cost rate.

6. Estimate the time of each activity

The researcher used available information and data of the two previous years in the hospital's electronic medical records, which were confirmed with the clinicians during individual meetings. After that, all the time obtained were used to find the mean time needed for each activity of the care cycle, as shown in Table 8 and stated in the process map.

Table 10. Activities mean-time

Activity	Mean Time
Patient goes to admission	2.506
Patient takes a token and check-in	0.488
Staff ask patient for data	16.054
Patient registered	2.001
Patient wait in the waiting room	20.015
A nurse checks the vital sign of the patient	7.984
The patient is asked for the initial physical examination	38.734
The patient is asked for an X-ray	27.478
Patient gets the blood test	11.510
The patient waits to see the consultant	23.523
The patient is being diagnosed by a consultant	27.557
The consultant discuss a plan of care with the patient	19.017
Patient requests the administration to schedule the next visit	9.969
Patient discusses with the administration to schedule the next visit	0.500
Patient takes a token and wait	15.017
Patient takes the medicine	2.506

7. Estimate the Capacity Cost Rate (CCR)

After identifying the dependent variable, the cost, and independent variables, the time, resources CCR are calculated using equation 3 and equation 4. The values are shown in Table 9.

Table 11. Resource's CCR

Resource Type	CCR ($/min) of service
Patient access specialist	0.32
Nurse	0.54
Security	0.08
Physical Therapist	0.53
X-ray specialist	0.45
Orthopedic Consultant	1.81
Patient schedule coordinator	0.38
Pharmacist	0.90

The CCR is calculated for each resource to know how much $ it cost per minute while delivering the care. In this study, the CCR is used to calculate the cost of each activity when serving 1000 patients, and then find the total cost of the whole activities depending on the resource base, then compare it with the actual cost.

8. Calculate the total cost of patient

The total cost for 1000 patients resulting from the TDABC method using equation 5 equals $199,702, while the actual cost for the same number of patients equals $180,048 as given by the finance department. This high difference between the two costs results from taking the mean time of activities, considering a fixed utilization rate of all resources, 80%, and using wages to determine the CCR.

A line graph builds to compare the actual cost with the TDABC cost for the whole sample, 1000 patients. The graph depicts a discrepancy between TDABC and actual costs. TDABC costs are overstated in comparison to actual costs, as seen in Figure 16, and TDABC does not mimic with actual cost data.

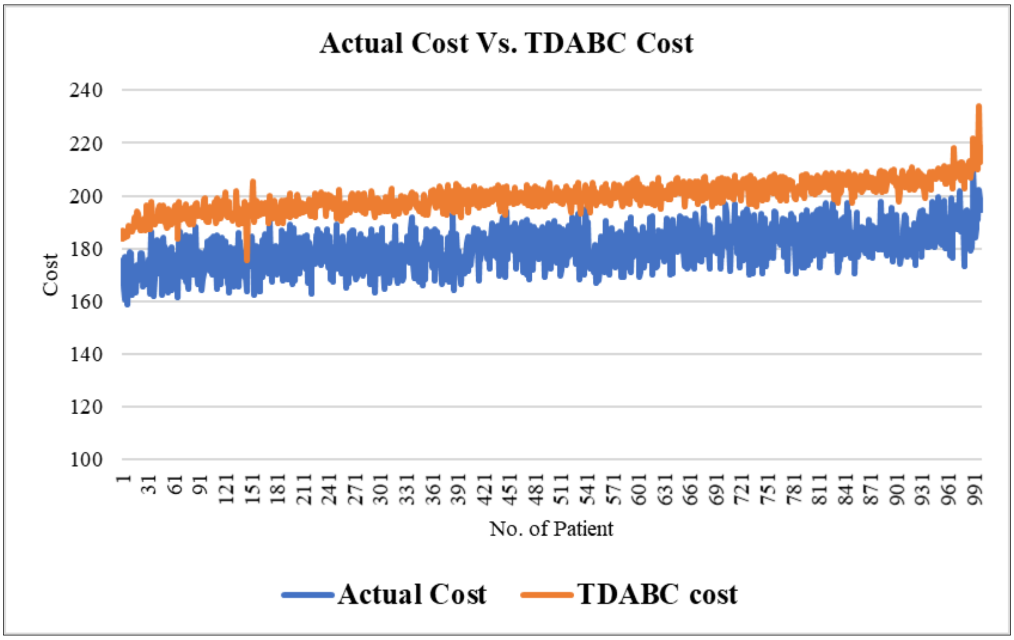

Figure 16. TDABC cost vs. Actual cost

In other words, Table 10 shows a sample of resource care delivery to ten patients with actual cost and TDABC cost. As shown, the TDABC cost is more than the actual cost, which indicates a problem in accuracy and that the utilization of resources is not considered enough in TDABC.

Table 12. Resources care-delivery (Actual cost vs. TDABC cost)

Patient No.	Actual Cost	TDABC Cost	Patient No.	Actual Cost	TDABC Cost
1	172	140	6	173	142
2	175	143	7	159	140
3	165	141	8	175	144
4	161	140	9	166	144
5	177	142	10	179	143

To conclude, as shown in Table 11, the TDABC method assumes that all human resources are within the same utilization level, 80%. The gap between the actual cost and TDABC total cost is due to the capacity cost rate in the two models.

Table 13. Results of TDABC method

TDABC Method	CCR	Utilization	Total Cost
Security	0.08	80%	$ 199,702
Nurse	0.54	80%	
Patient Access Specialist	0.32	80%	
Physical Therapist	0.53	80%	
X-Ray Specialist	0.45	80%	
Orthopedic Consultant	1.81	80%	
Patient Schedule coordinator	0.38	80%	
Pharmacists	0.9	80%	

4.5 Regression Model

Different regression models are developed to estimate the total cost better. The three regression models are Multiple Linear Regression, Rigid Regression, and Lasso Regression.

4.5.1 Multiple Linear Regression Model

The multiple linear regression model developed for the analysis is shown in equation (11) below. The correlation test of the resources for this model is given in Table 12, which shows that except for the security, all independent variables show a high correlation with the dependent variable.

$$\boldsymbol{y = 11.31 + 0.44x_{PST} + 0.47x_{NT} + 0.67x_{PTT} + 0.59x_{XT} + 1.98x_{CT} + 0.52x_{PST} + 0.68x_{PT}} \quad (11)$$

Table 14. Correlation Test of Resource TDABC model

Resource	P-value
Patient access specialist	0.015
Nurse	0.001
Security	0.336**
Physical Therapist	<0.001
X-ray specialist	< 0.001
Orthopedic Consultant	< 0.001
Patient schedule coordinator	0.002
Pharmacist	0.015

The MLR model provides R^2 as 0.3971, showing lower predictability, and that is due to the significance of human resources in the model, which has a huge impact on the total cost of the hospital. This leads to conclude that there is still a missing gap even when calculating the cost by TDABC presented by this result, which results in a poor estimate of the cost for knee arthroplasty.

Table 13 shows the p-value for each resource. The p-value for security resource is greater than 0.05, which indicate that the security resource does not affect the total cost. The intercept value also shows that it is greater than 0.05, representing the hospital's cost even if there is no patient. The costs could be attributed to the software and other related utilities associated with resources. However, patient access specialist, nurse, physical therapist, X-Ray specialist, orthopedic consultant, patient schedule coordinator, and pharmacist all significantly affect the total cost. Therefore, to fit the data to actual costs, the resource utilization fixed by the hospital may have to be revisited.

Table 15. Regression model p-values of Resources

Resource	p-value
Intercept	0.134
Security	0.286
Patient special	< 0.001
Nurse	< 0.001
Physical Therapist	< 0.001
X-Ray Specialist	< 0.001
Orthopedic Consultant	< 0.001
Patient Schedule Coordinator	0.020
Pharmacist	0.003

The correlation between the human resources is shown in Table 14. If the correlation coefficient value is greater than 0.7, collinearity exists between the two variables (Bae, Yoo, Mayberry, He, & Lillard, 2014). Table 14 shows that the results of the variables are independent. So, all variables can be included in the linear regression model.

A line graph builds to compare the actual cost with the MLR cost for the whole sample, 1000 patients. The graph depicts a discrepancy between MLR and actual costs. As seen in Figure 17, the MLR cost is exaggerated when compared to the actual cost. However, as compared to TDABC, it is better to simulate with real data.

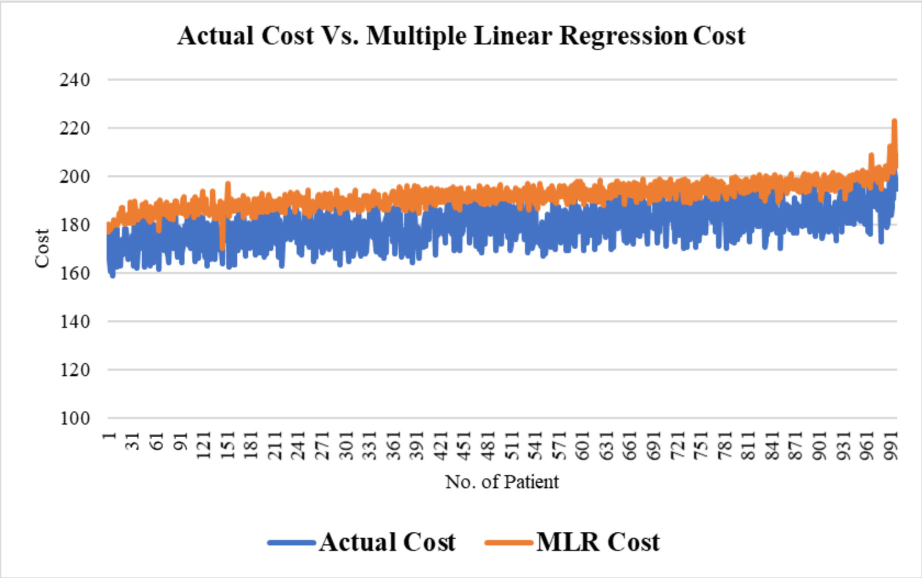

Figure 17. Actual cost vs. multiple linear regression cost

The MLR model shows that there is a difference in human resource utilization. Since the wages are fixed, the utilization rates can be obtained from the TDABC CCR and MLR model CCR. In TDABC, all the resources have 80% utilization, while the MLR model shows that each resource has different utilization.

Table 16 Correlation coefficients between human resources

	security	patient special	nurse	physician	x-ray	consultant	schedule coordinator	pharmacist
security	1							
patient special	-0.016	1						
nurse	0.020	-0.008	1					
physician	0.048	-0.046	0.004	1				
x-ray	0.010	-0.033	-0.002	0.023	1			
consultant	-0.013	-0.019	-0.010	0.027	0.060	1		
schedule coordinator	-0.053	0.028	-0.059	0.051	-0.005	0.064	1	
pharm	-0.017	0.002	0.005	0.022	-0.018	-0.002	0.016	1

Table 15 shows that some of the resources are below the theoretical utilization of 80%, and some are above. This has resulted due to the higher wages of the human resources. This issue may be resolved by reallocating resources in other possible activities during working hours.

Table 17. Results of MLR model

MLR Model	CCR	Utilization	Total Cost
Security	0.16	39%	$ 191,350
Nurse	0.47	92%	
Patient Access Specialist	0.44	58%	
Physical Therapist	0.67	64%	
X-Ray Specialist	0.59	61%	
Orthopedic Consultant	1.98	73%	
Patient Schedule coordinator	0.52	59%	
Pharmacists	0.68	106%	

4.5.2 Ridge Regression Model

The ridge regression model for the data is given in equation (12). The RR model provides R^2 as 0.3854.

$$\begin{aligned} \boldsymbol{y} = \mathbf{11.31} + \mathbf{0.35}\boldsymbol{x}_{\boldsymbol{PST}} + \mathbf{0.39}\boldsymbol{x}_{\boldsymbol{NT}} + \mathbf{0.61}\boldsymbol{x}_{\boldsymbol{PTT}} + \mathbf{0.42}\boldsymbol{x}_{\boldsymbol{XT}} + \mathbf{1.59}\boldsymbol{x}_{\boldsymbol{CT}} \\ + \mathbf{0.25}\boldsymbol{x}_{\boldsymbol{PST}} + \mathbf{0.20}\boldsymbol{x}_{\boldsymbol{PT}} + (\mathbf{0.1} \times \mathbf{3.4601}) \end{aligned} \tag{12}$$

The RR model CCR for each resource, as shown in Table 16, is used to draw the best fit of data points. A penalty cost is added to the equation using $\lambda = 0.1$, with the summation of the squared values of the CCRs for all resources, which equals 3.4601.

The total cost for 1000 patients resulting from the RR model equals $152,511.

The model shows that security resource is insignificant (Table 16). However, the model underestimates the cost, as illustrated in Figure 18.

Table 18. Results of RR model

RR Model	CCR	Utilization	Total Cost
Security	0.08	80%	$152,511
Nurse	0.39	111%	
Patient Access Specialist	0.35	73%	
Physical Therapist	0.61	70%	
X-Ray Specialist	0.42	85%	
Orthopedic Consultant	1.59	91%	
Patient Schedule coordinator	0.25	122%	
Pharmacists	0.2	359%	

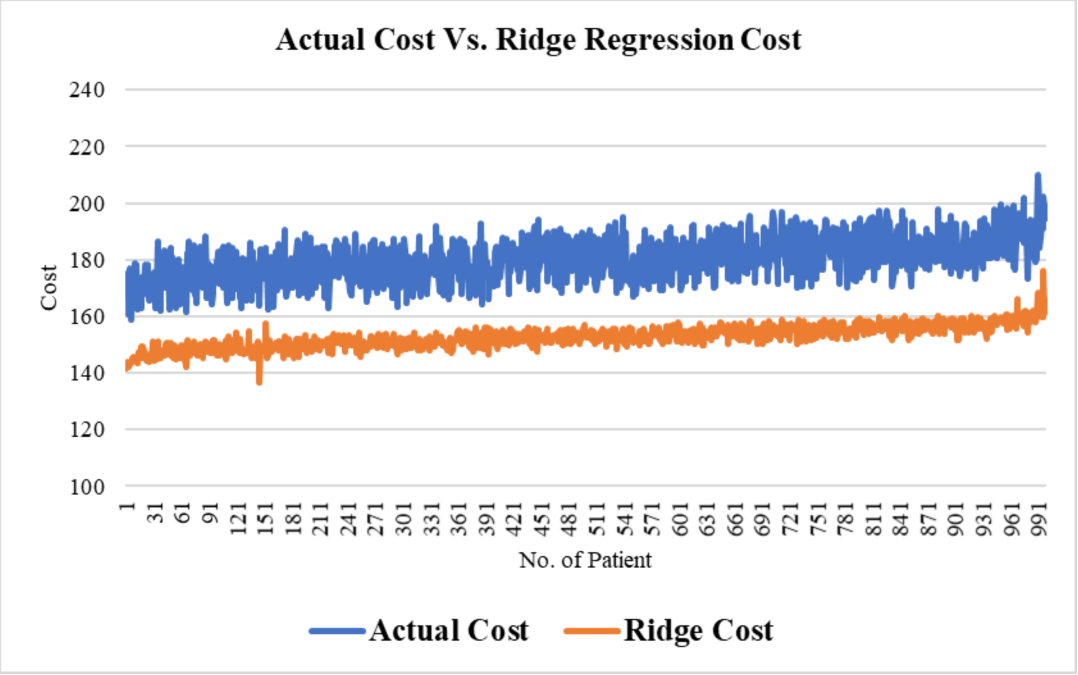

Figure 18. The actual cost vs. ridge regression cost

Table 16 shows that compared with the other two models, the RR model results in increased utilization of the resources for some resources, which could be due to the adjustment made by the model to match the wages for each resource. The model underestimates the total cost since some of the resources have been overutilized in the results.

4.5.3 Lasso Regression Model

The Lasso Regression model developed in equation (13) provides R^2 as 0.4053. The LR model coefficient for each resource is shown in Table 17. A penalty cost will be added to the equation using $\lambda = 0.1$, with the summation of the absolute values of the CCRs for all resources, which equals 5.11. As seen in Table 17, the nurse and the pharmacist have more than 80% utilization. The model adjusts these rates to minimize the costs and adjust the gap between the actual and the prediction to a minimum, thus resulting in high utilization of some resources. In the model, the impact of the security staff is found insignificant as it has a *p*-value of <0.05. The resulting total cost estimated by the LR model is given in Figure 19.

$$\boldsymbol{y = 11.31 + 0.47x_{PST} + 0.53x_{NT} + 0.65x_{PTT} + 0.65x_{XT} + 2.04x_{CT} + 0.43x_{PST} + 0.38x_{PT} + (0.1 \times 5.11)} \tag{13}$$

Table 19. Results of LR model

LR Model	CCR	Utilization	Total Cost
Security	0.11	60%	$175,527
Nurse	0.53	81%	
Patient Access Specialist	0.47	54%	
Physical Therapist	0.65	66%	
X-Ray Specialist	0.65	72%	
Orthopedic Consultant	2.04	71%	
Patient Schedule coordinator	0.43	71%	
Pharmacists	0.38	189%	

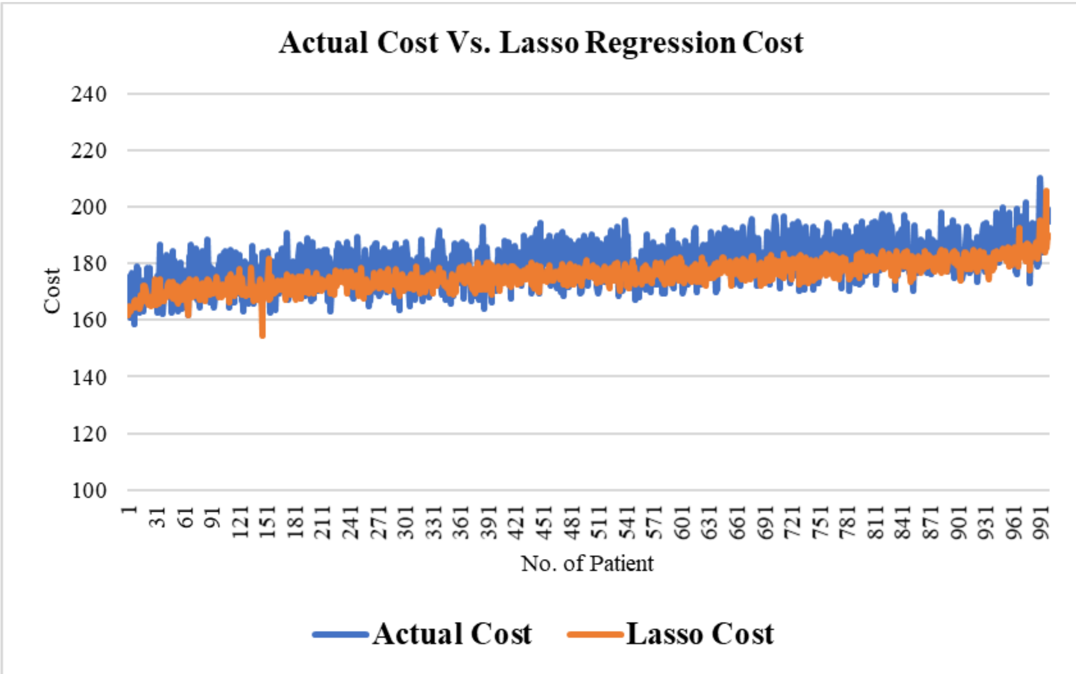

Figure 19. Actual cost vs. Lasso regression cost

Table 17 shows that the total cost for 1000 patients obtained from the LR model is $175,932. Compared to the result of the other two models, this value is closer to the actual cost. Like in earlier cases, the adjustments may be made in the utilization of the resource so that they are utilized to the optimum levels.

4.6 Sensitivity analysis

Sensitivity analysis was done for all available human resources, and the analysis was performed between the utilization of the human resources and the actual working hours. Each scenario illustrates a case with a 5% increase in utilization, from 70% to 90%, and a 1-hour increase in working hours from 6 to 10 hours. As Table 18 shows that when the utilization of the patient scheduler coordinator increased the CCR will be decreased, and when the working hours increased the CCR will be decreased, which indicate the strong relationship between the cost and the utilization of human resources. The results of other human resources that are involved in the care-delivery cycle of the patients are given in Tables 18 to 25 as they compares the CCR of each resource when both utilization and working hours differ.

Table 20 Sensitivity of the Patient Specialist utilization

Patient Scheduler Coordinator				**Utilization**				
			0.382011	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.382011	**Working Hours**	**6**	0.582112	0.543305	0.509348	0.479387	0.452754
Utilization	0.8		**7**	0.498953	0.46569	0.436584	0.410903	0.388075
Working hours	8		**8**	0.436584	0.407479	0.382011	0.35954	0.339566
Wage	3814		**9**	0.388075	0.362203	0.339566	0.319591	0.301836
			10	0.349267	0.325983	0.305609	0.287632	0.271652

Table 21 Sensitivity of the Security utilization and working hours

Security				Utilization				
			0.082532	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.082532	**Working Hours**	**6**	0.125763	0.117379	0.110043	0.10357	0.097816
Utilization	0.8		**7**	0.107797	0.100611	0.094322	0.088774	0.083842
Working hours	8		**8**	0.094322	0.088034	0.082532	0.077677	0.073362
Wage	824		**9**	0.083842	0.078253	0.073362	0.069046	0.065211
			10	0.075458	0.070427	0.066026	0.062142	0.058689

Table 22 Sensitivity of the Nurse utilization

Nurse				Utilization				
			0.539663	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.539663	**Working hours**	**6**	0.822344	0.767521	0.719551	0.677225	0.639601
Utilization	0.8		**7**	0.704867	0.657875	0.616758	0.580478	0.54823
Working hours	8		**8**	0.616758	0.575641	0.539663	0.507919	0.479701
Wage	5388		**9**	0.54823	0.511681	0.479701	0.451483	0.426401
			10	0.493407	0.460513	0.431731	0.406335	0.383761

Table 23 Sensitivity of the Physical Therapist resource utilization

Physical Therapist				Utilization				
			0.534255	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.534255	**Working Hours**	**6**	0.814103	0.759829	0.71234	0.670437	0.633191
Utilization	0.8		**7**	0.697802	0.651282	0.610577	0.574661	0.542735
Working hours	8		**8**	0.610577	0.569872	0.534255	0.502828	0.474893
Wage	5334		**9**	0.542735	0.506553	0.474893	0.446958	0.422127
			10	0.488462	0.455897	0.427404	0.402262	0.379915

Table 24 Sensitivity of the X-Ray Specialist resource utilization

X-Ray Specialist			Utilization					
			0.448217	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.448217	**Working Hours**	**6**	0.682998	0.637464	0.597623	0.562469	0.53122
Utilization	0.8		**7**	0.585426	0.546398	0.512248	0.482116	0.455332
Working hours	8		**8**	0.512248	0.478098	0.448217	0.421851	0.398415
Wage	4475		**9**	0.455332	0.424976	0.398415	0.374979	0.354147
			10	0.409799	0.382479	0.358574	0.337481	0.318732

Table 25 Sensitivity of the Orthopedic Consultant resource utilization

Orthopedic Consultant			Utilization					
			1.808393	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	1.808393	**Working Hours**	**6**	2.755647	2.571937	2.411191	2.269356	2.143281
Utilization	0.8		**7**	2.361983	2.204518	2.066735	1.945163	1.837098
Working hours	8		**8**	2.066735	1.928953	1.808393	1.702017	1.607461
Wage	18055		**9**	1.837098	1.714625	1.607461	1.512904	1.428854
			10	1.653388	1.543162	1.446715	1.361614	1.285969

Table 26 Sensitivity of the Pharmacist resource utilization

Pharmacist			Utilization					
			0.898738	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.898738	**Working Hours**	**6**	1.369505	1.278205	1.198317	1.127828	1.065171
Utilization	0.8		**7**	1.173862	1.095604	1.027129	0.96671	0.913004
Working hours	8		**8**	1.027129	0.958654	0.898738	0.845871	0.798878
Wage	8973		**9**	0.913004	0.852137	0.798878	0.751885	0.710114
			10	0.821703	0.766923	0.71899	0.676697	0.639103

Table 27 Sensitivity of the Patient Scheduler coordinator utilization

Patient specialist				Utilization				
			0.317808	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
CCR	0.317808	**Working Hours**	**6**	0.48428	0.451994	0.423745	0.398819	0.376662
Utilization	0.8		**7**	0.415097	0.387424	0.36321	0.341844	0.322853
Working hours	8		**8**	0.36321	0.338996	0.317808	0.299114	0.282496
Wage	3173		**9**	0.322853	0.30133	0.282496	0.265879	0.251108
			10	0.290568	0.271197	0.254247	0.239291	0.225997

The results obtained from the sensitivity analysis show that the CCR will decrease as resource utilization increases. Accordingly, the total cost will decline because the resource will meet the required work in the care delivery cycle and satisfy the wage paid as the working hours increase for the same utilization.

4.7 Result analysis

Table 26 summarizes R^2 values and the total costs obtained from the three models. The table shows that the R^2 of the LR model is better, and the total cost obtained by the LR model is closer to the actual cost, $180,048.

Table 28. Comparison between regression models

	MLR Model	RR Model	LR Model
R^2 value	0.3971	0.3854	0.4053
Total Cost	$191,921	$152,798	$175,932

As illustrated in Figure 20, the TDABC method is tested and validated with 200 patients selected randomly from the historical data. The resulting accuracy using the

MAPE value of the TDABC model is equal to 11%, which indicates a good model. At the same time, the RMSE value was equal to 19, which indicates a high difference between the two models, which in turn leads to inaccuracy in cost calculations.

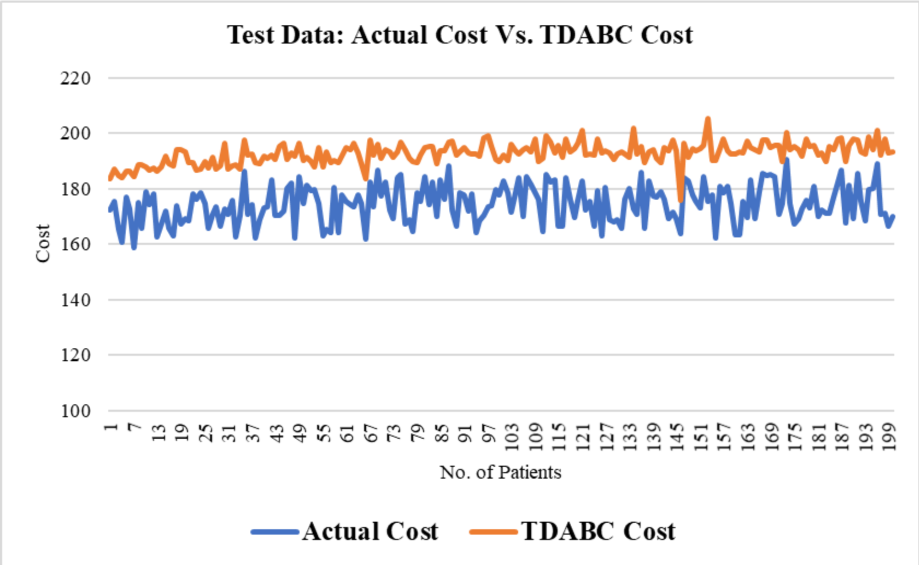

Figure 20. Test data: Actual cost vs. TDABC cost

A comparison of the total costs from the models and actual costs of randomly selected 200 patients is also conducted. The comparison for the MLR model is given in Figure 21, the RR model in Figure 22, and the LR model in Figure 23.

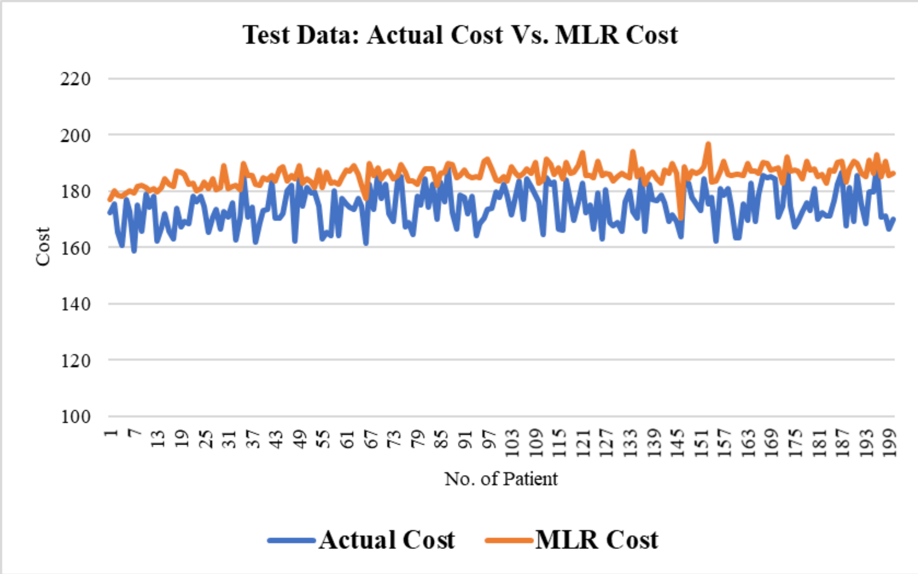

Figure 21. Test data: Actual cost vs. MLR cost

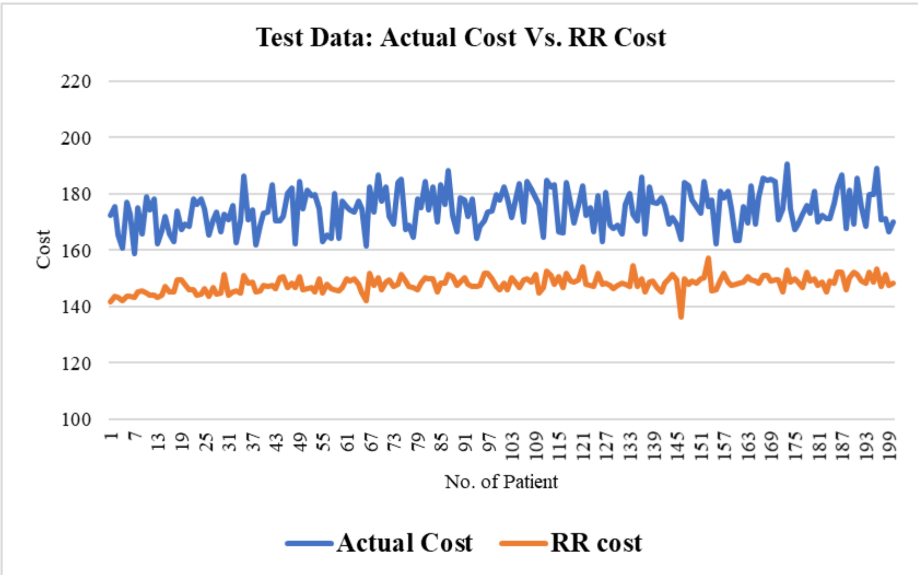

Figure 22. Test data: Actual cost vs. RR cost

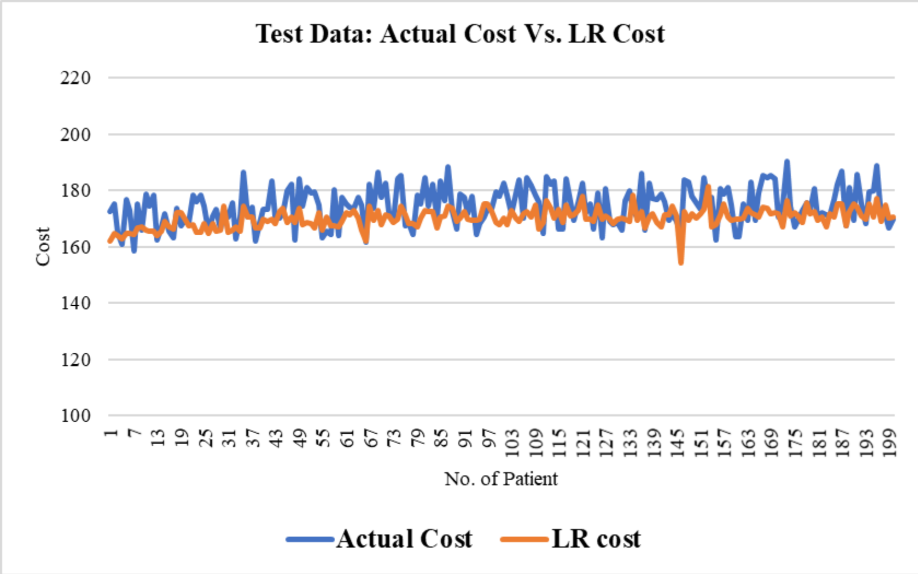

Figure 23. Test data: Actual cost vs. LR cost

The MAPE and RMSE values for the models are given in Table27. The data shows that the LR model is closer to the actual costs and has lower MAPE and RMSE.

Table 29 Data validation

	TDABC	MLR	RR	LASSO
MAPE	10%	6%	15%	3%
RMSE	19	12	27	7

The R^2 from a regression of actual prices on the projected values on the raw scale and the related metric of root mean squared error measures of goodness of fit for the estimation sample (RMSE) (Jones, 2010). Cross-validation was done between the models using Python Scikit-learn (Sklearn) library using five cross-validation rounds. R^2 for MLR, RR, and LR are 0.38, 0.38, and 0.40, respectively. Kan et al. (2019) used the penalized linear regression for predicting future health care expenses and their R^2 values with more than 81,000 data also provides a maximum regression of just over 17%. Therefore, it is considered that the R^2 values obtained here are consistent, and among the methods, the LR model represents the best fit.

4.8 Testing for hypothesis

The results of the hypothesis obtained from the LR analysis model are demonstrated in Table 28. It has been proven that the time spent by the seven human resources involved in the patient care delivery cycle has a substantial impact on the total cost. On the other hand, it showed that the security resource and the intercept (which are other expenses) are not significant, meaning that they have an insignificant impact on the total cost.

Table 30 Verification of the results

Hypothesis	p-value	Result
H1: There is no statistically significant difference between the total time of patient care and patient access specialist cost (Actual cost).	<0.001	Unverified (Accept H_A)
H2: There is no statistically significant difference between the total time of patient care and nurse cost (Actual cost).	<0.001	Unverified (Accept H_A)
H3: There is no statistically significant difference between the total time of patient care and security cost (Actual cost).	0.286	Verified (Reject H_A)
H4: There is no statistically significant difference between the total time of patient care and physical therapist cost (Actual cost).	<0.001	Unverified (Accept H_A)
H5: There is no statistically significant difference between the total time of patient care and X-ray specialist cost (Actual cost).	<0.001	Unverified (Accept H_A)
H6: There is no statistically significant difference between the total time of patient care and orthopedic consultant cost (Actual cost).	<0.001	Unverified (Accept H_A)

Table 31 Verification of the results

Hypothesis	p-value	Result
H7: There is no statistically significant difference between the total time of patient care and patient schedule coordinator cost (Actual cost).	0.020	Unverified (Accept H_A)
H8: There is no statistically significant difference between the total time of patient care and pharmacist cost (Actual cost).	0.003	Unverified (Accept H_A)

CHAPTER5: CONCLUSION AND RECOMMENDATION

This chapter summarizes the main findings in the thesis. The answers to the research questions are given. In addition, limitations and future works are provided.

5.1 Conclusion

The major objective of the health organization is to offer a quality service. Hospitals, clinics, and healthcare providers must make certain that they can maintain this care for the long term with the costs they incur and charge for the service delivery. A good costing method can help in increasing the satisfaction of patients. It helps engage and educate all stakeholders and delivers the right service at the right time (Kurzban, Duckworth, Kable, & Myers, 2013). Therefore, assessing the services by continuously updating the service record can help understand the impact of a particular resource or process in the financial return of the healthcare institution (Wang, et al., 2003).

This research study used the TDABC method to study the cost of healthcare services to develop a model that can accurately predict the total costs. Three statistical models were developed, and the LR model obtained the best results.

The study looked into eight hypotheses based on the two primary research questions, which are:

RQ1*: Does the cost of human resource significantly affect the total cost of the knee arthroplasty service?*

Literature showed that human resource cost has a significant impact on the total cost for healthcare delivery. The analysis here shows that the time used by a resource, the total working hours available, and the wages of the resource have a significant impact on the total healthcare cost for a service. It also shows that if adjustments can be made to the utilization of the resources, the total costs for a service may be reduced.

***RQ2**: What methods are available to resource cost based on care delivery time handling with the TDABC method?*

The TDABC method utilizes a capacity cost rate (CCR), which results in poor prediction of the actual costs. Therefore, three-regression models, namely multiple linear regression, ridge regression, and lasso regression, were developed in this thesis. The outcome of the models shows that no one method can rightly fit the actual cost calculation made in the healthcare institution. However, the LR regression model predicted the best total costs for the given data. It should be noted that some of the resources are underutilized while others would be overutilized compared to the benchmark utilization of 80%. The analysis also shows that the independent variables used in the models are not collinear; therefore, they can be used for the model.

5.2 Limitations

Due to confidentiality reasons, the data on wage and overhead costs provided by the hospitals are the approximated values; however, the relative difference in wages are similar to the actual wages. The time estimation used in the study is based on the data provided and the interviews of the clinicians conducted for this research. As no standard time measurement templates were found, there might have been some inconsistencies in the results. Moreover, the study considers only one department for analysis. Therefore, the results should be taken to understand the relationship between the utilization rates and the CCR used in the model rather than the absolute values.

5.3 Future work

This research can be expected to be extended in the following direction.

1. The model considers point data as obtained from the records provided to the researchers. The suitability of the model is based on data adoption for the analysis. The models have been developed here. Therefore, further research can be done by extending the data points, validating the results obtained with the analysis with the actual utilization and costing so that a more reasonable model can be promoted for cost analysis. The analysis with all three models may show that one model may be applicable to one sequence of services, and the other could be for the other sequence. This requires a large volume of data.
2. The model is based on as-is procedure conditions. Researchers such as (Toussaint & Berry, 2013; Hicks, McGovern, Prior, & Smith, 2015; Tlapa, et al., 2020; Narayanamurthy, Gurumurthy, Subramanian, & Moser, 2018; Barclay, Cudney, Shetty, & Antony, 2021) mention of promoting lean in healthcare services. Therefore, studying the whole process to develop a lean service can be considered for particular healthcare. However, the cost and time of the measures to use the lean practice should also be considered for the analysis.
3. The current LR model shows an R^2 value of 0.40, although other studies with a higher number of data points provided even lower R^2. Another study can be done by including a more detailed process map and a very large number of data to enhance the result of the proposed model.

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APPENDIX A: PROCESS MAP

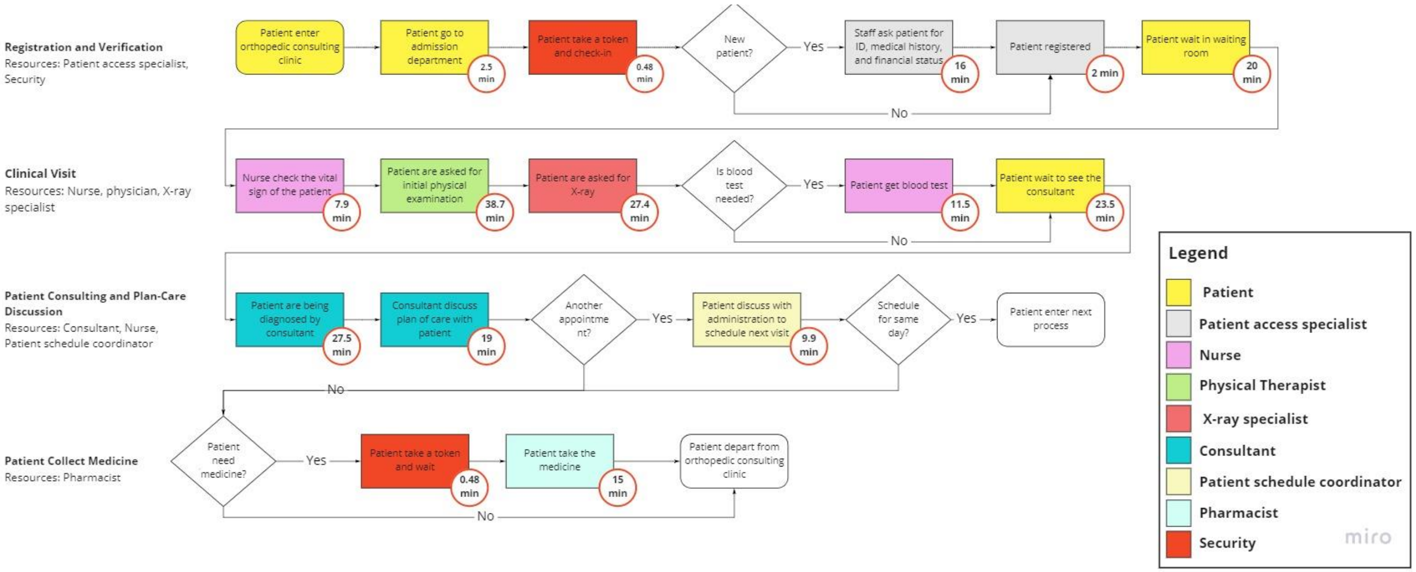
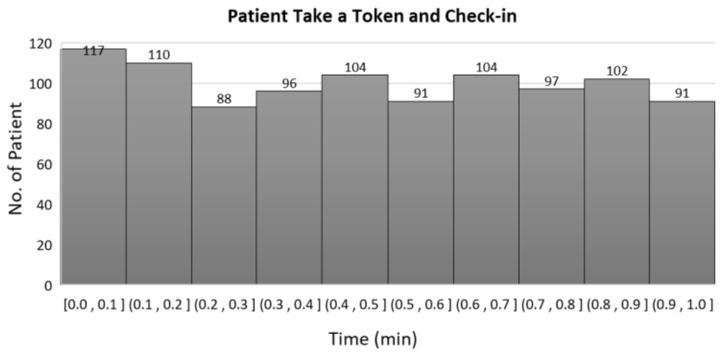
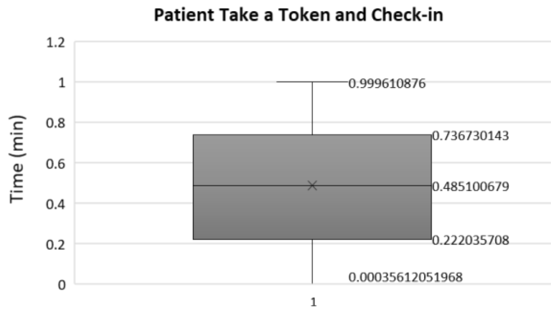


Figure 24. TDABC process map

APPENDIX B: DESCRIPTIVE ANALYSIS

Resource 1: Security





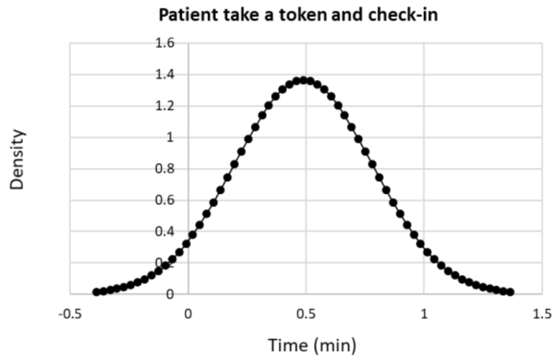


Figure 25 Descriptive analysis of security

Resource 2: Patient access specialist

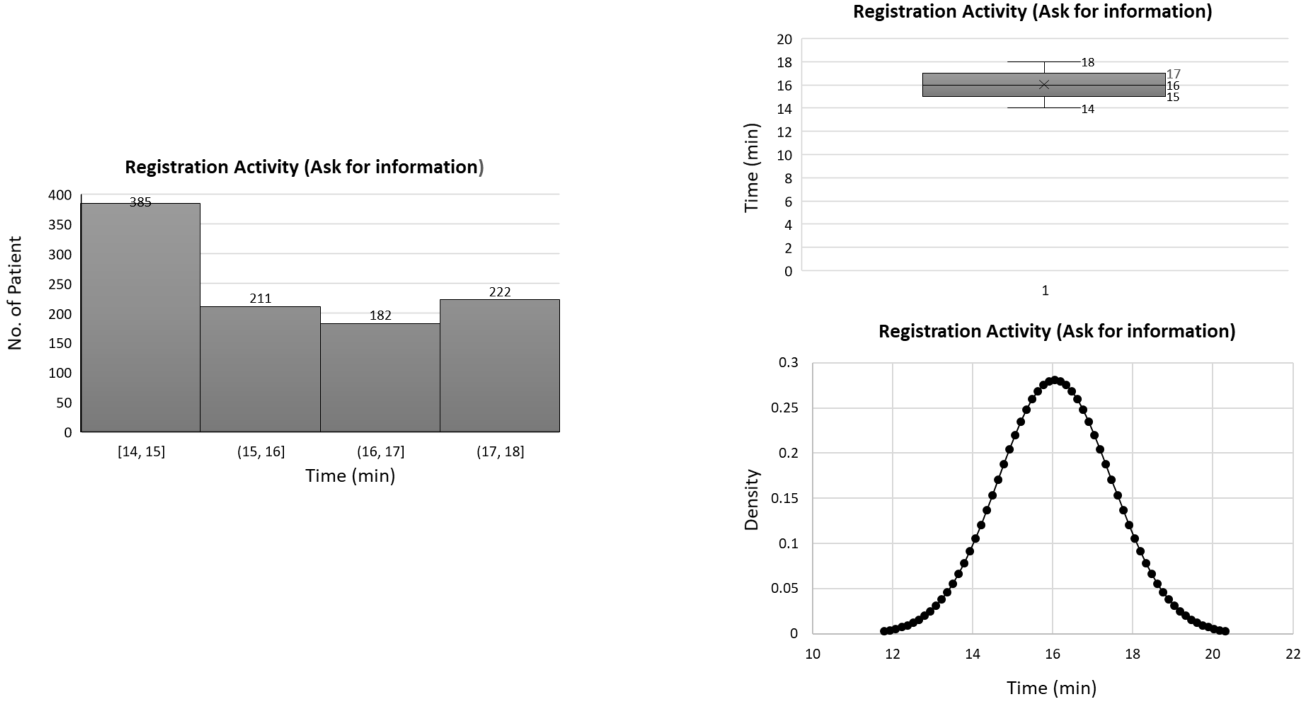
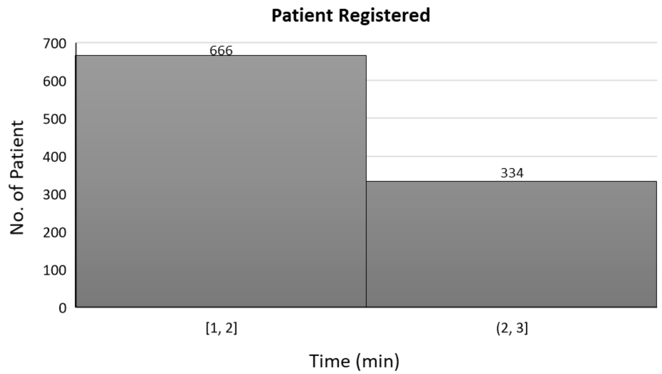
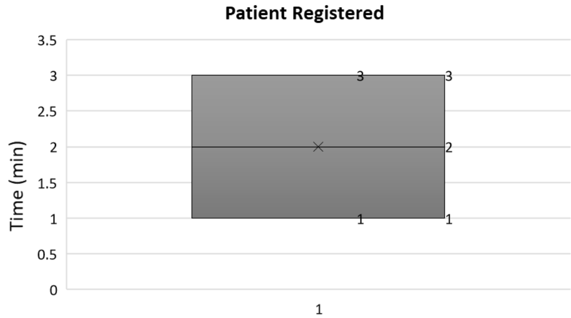


Figure 26. Descriptive analysis of patient access specialist

Resource 2: Patient access specialist





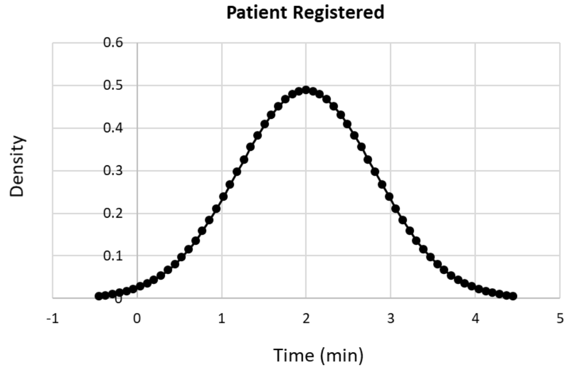


Figure 27. Descriptive analysis of patient access specialist

Resource 3: Nurse

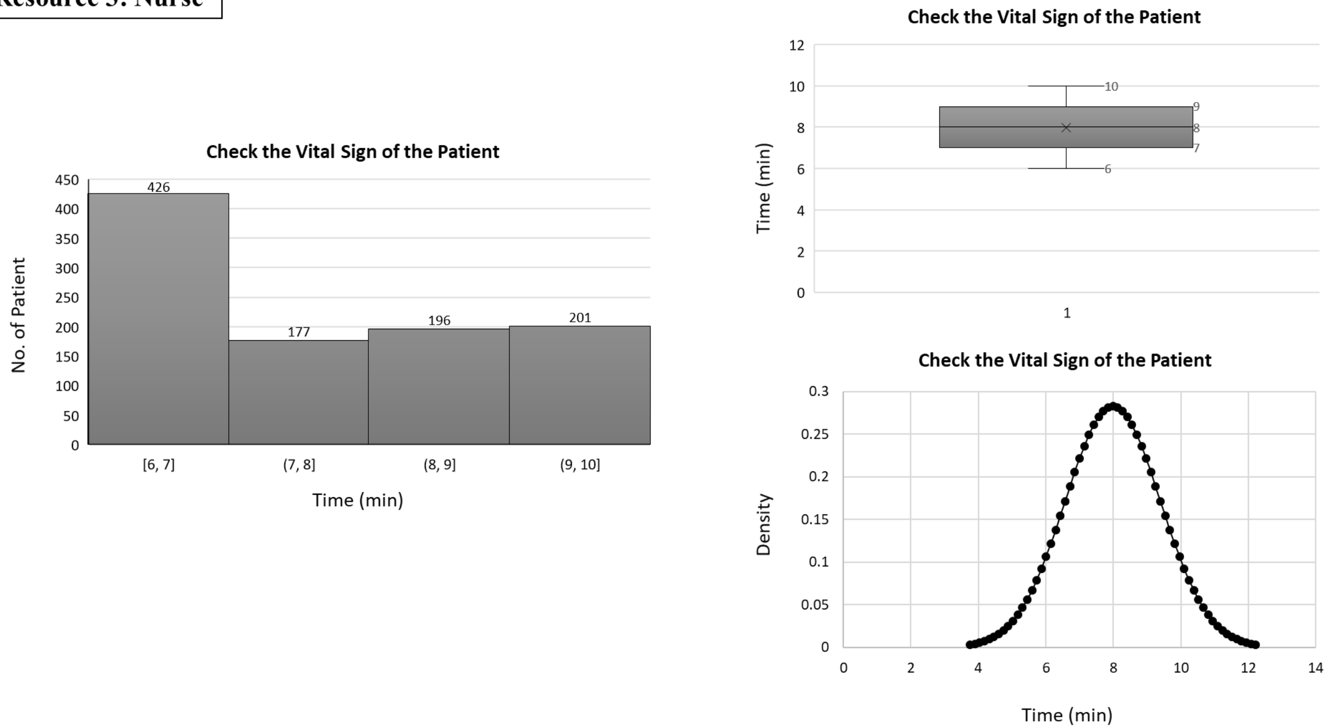


Figure 28. Descriptive analysis of nurse

Resource 3: Nurse

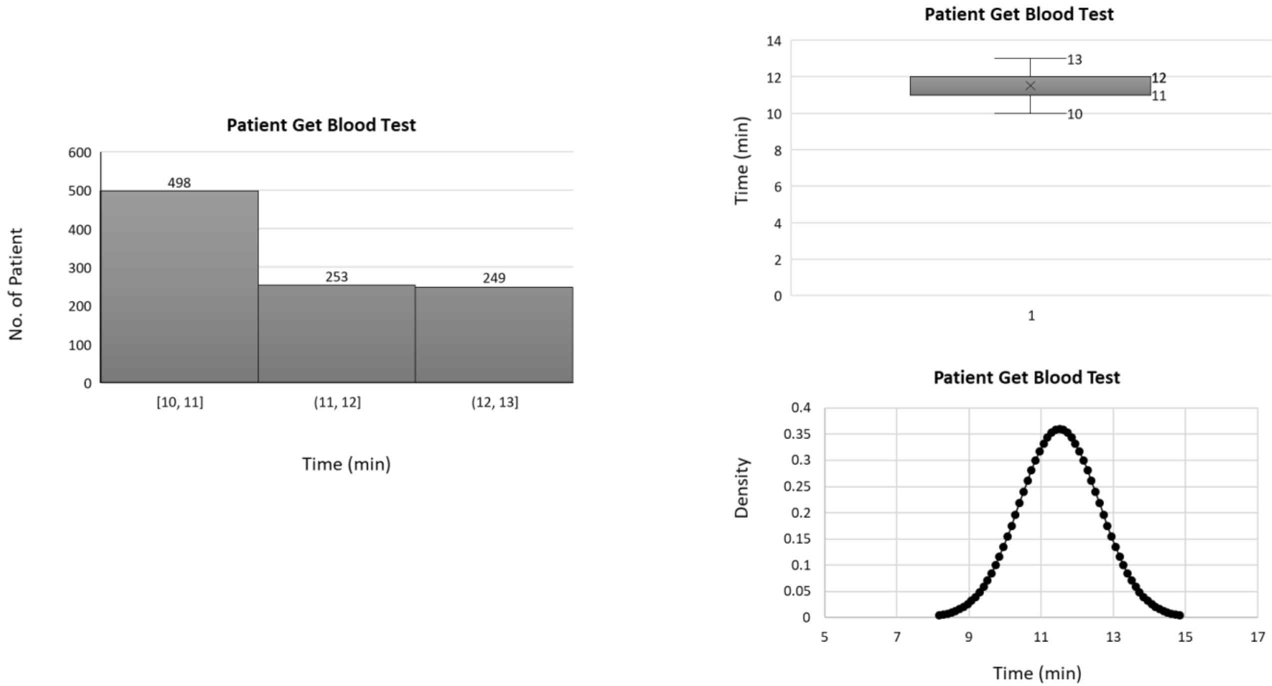
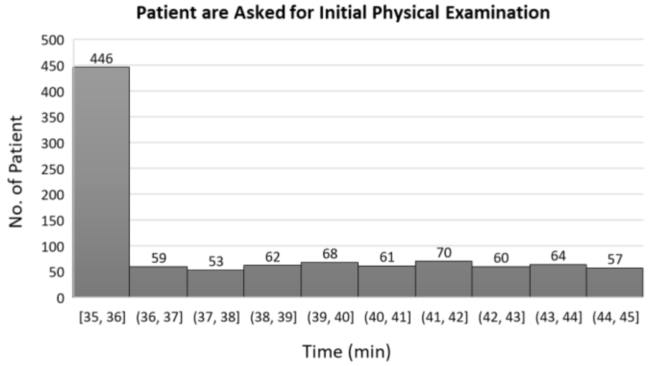
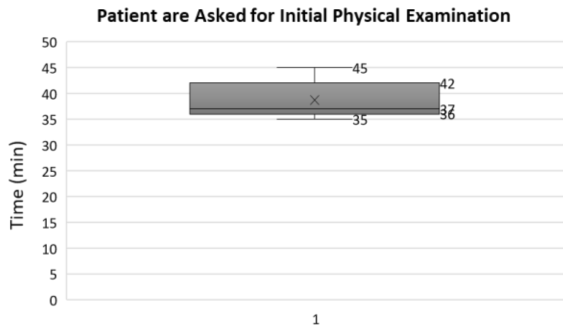


Figure 29. Descriptive analysis of nurse

Resource 4: Physical Therapist





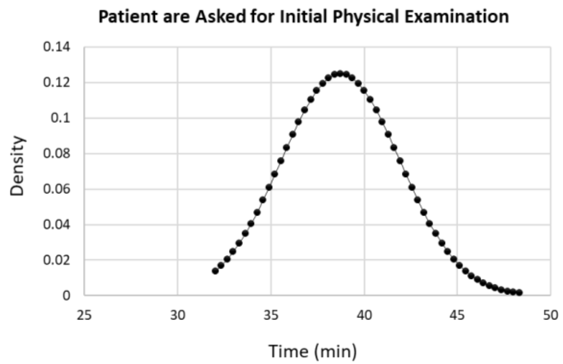


Figure 30. Descriptive analysis of physical therapist

Resource 5: X-Ray Specialist

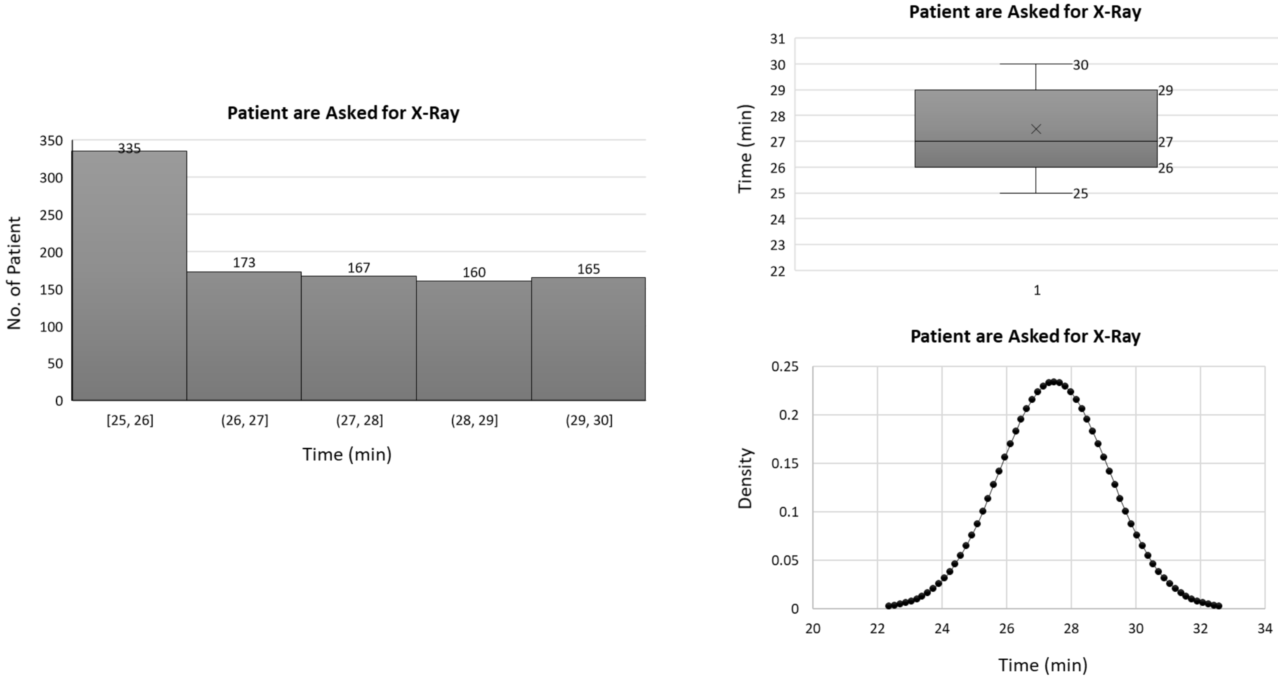


Figure 31. Descriptive analysis of X-ray specialist

Resource 6: Orthopedic Consultant

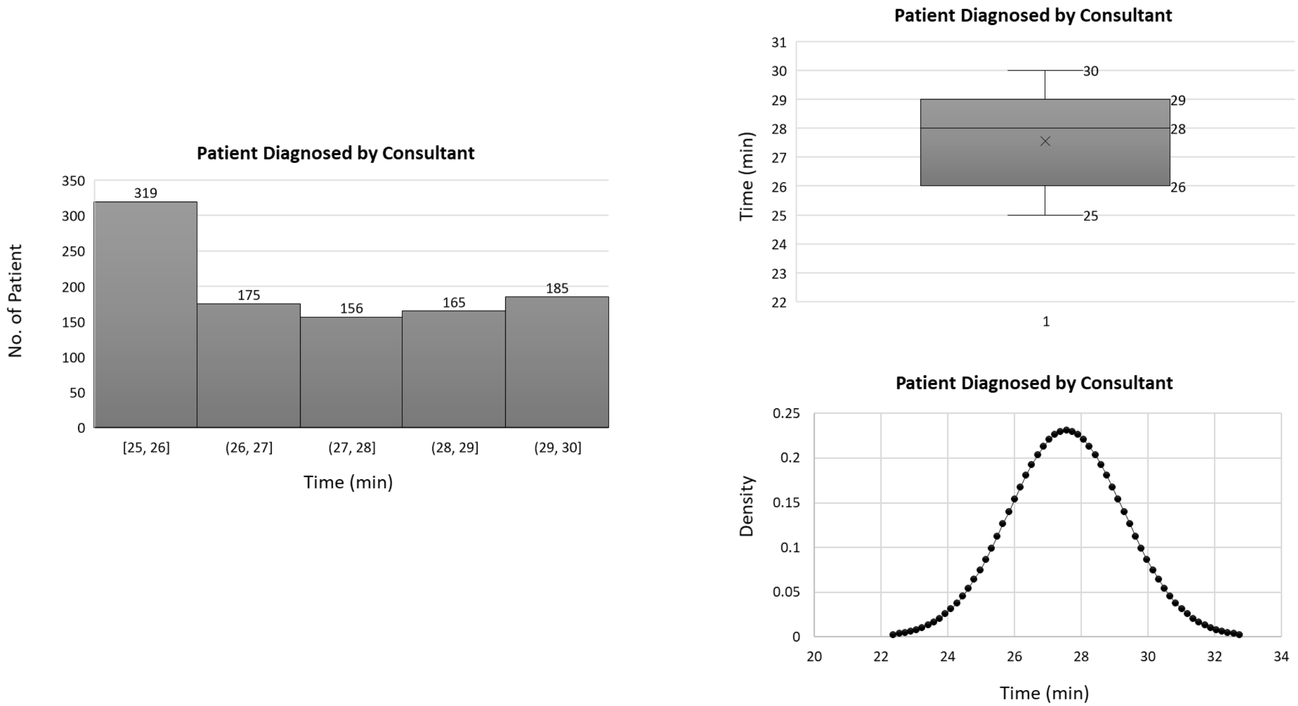


Figure 32. Descriptive analysis of orthopedic consultant

Resource 6: Orthopedic Consultant

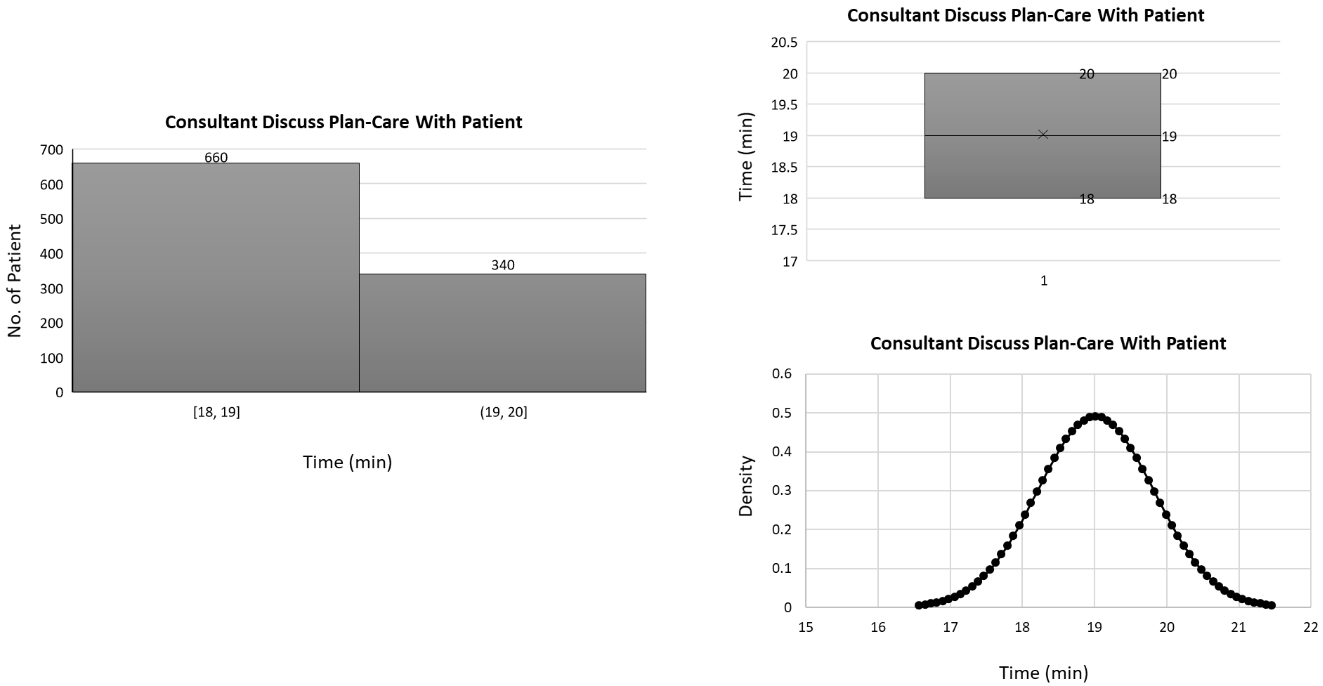


Figure 33. Descriptive analysis of orthopedic consultant

Resource 7: Patient schedule coordinator

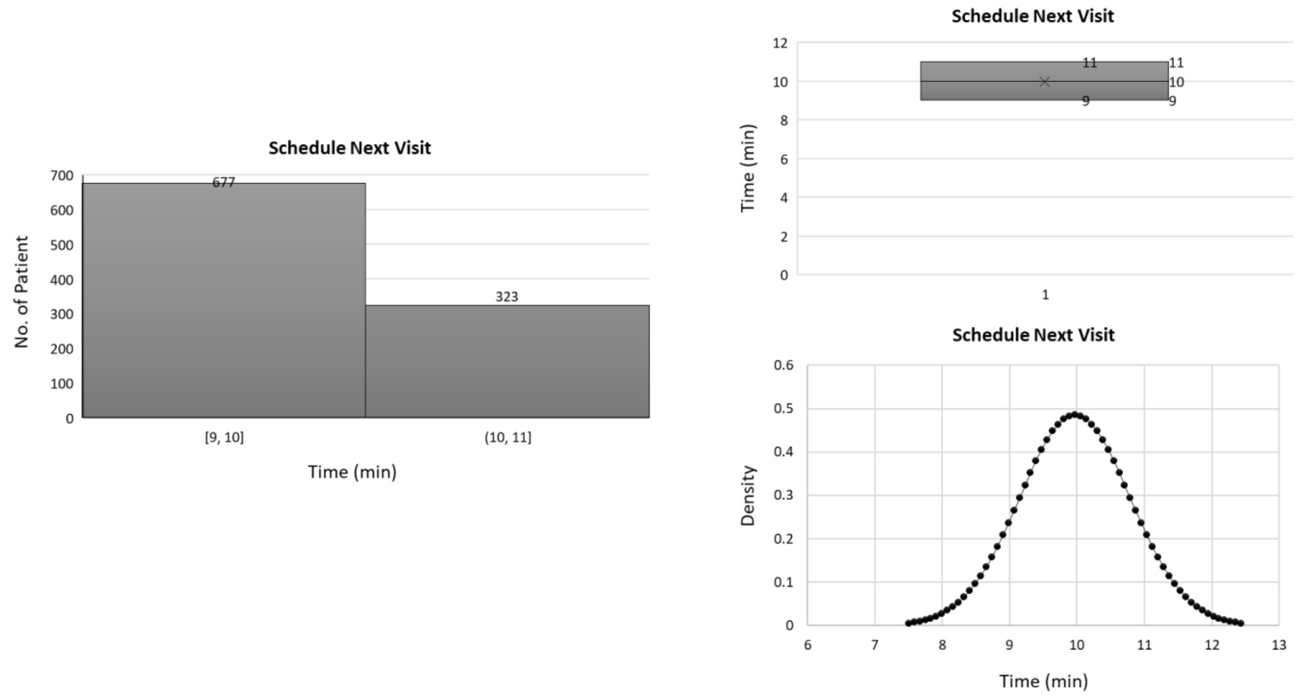


Figure 34. Descriptive analysis of patient schedule coordinator

Resource 8: Pharmacist

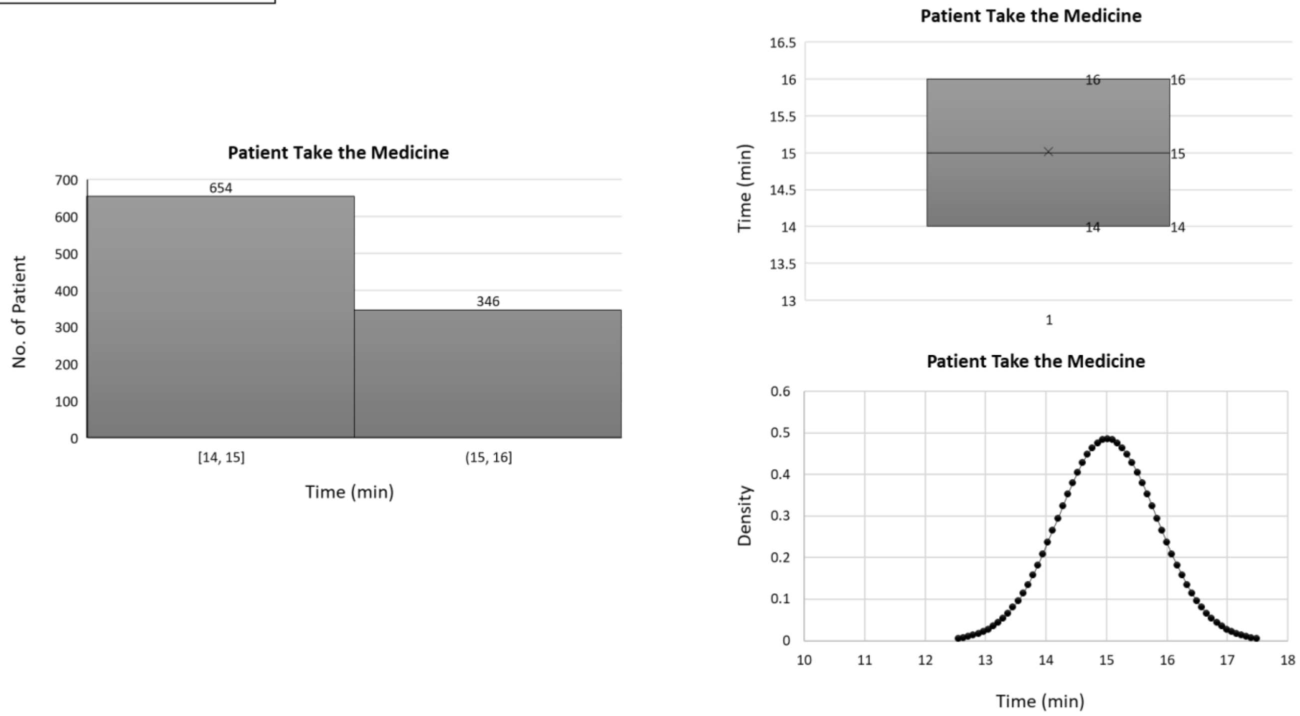


Figure 35. Descriptive analysis of pharmacist