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Title: Time-driven activity-based costing in health care: A systematic review of the literature

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Highlights

- TDABC helps to address the challenge of costing conditions in health care.
- TDABC applications varied but generally reflected the seven-step model.
- Future TDABC Applications should consider the methodological recommendations in this review.
- TDABC is yet to overcome challenges with allocating support department costs.
- TDABC's ability to inform bundled payment reimbursement is not well established.

Abstract

Health care organizations around the world are investing heavily in value-based health care (VBHC), and time-driven activity-based costing (TDABC) has been suggested as the cost-component of VBHC capable of addressing costing challenges. The aim of this study is to explore why TDABC has been applied in health care, how its application reflects a seven-step method developed specifically for VBHC, and implications for the future use of TDABC.

This is a systematic review following the PRISMA statement. Qualitative methods were employed to analyze data through content analyses.

TDABC is applicable in health care and can help to efficiently cost processes, and thereby overcome a key challenge associated with current cost-accounting methods. The method's ability to inform bundled payment reimbursement systems and to coordinate delivery across the care continuum remains to be demonstrated in the published literature, and the role of TDABC in this cost-accounting landscape is still developing. TDABC should be gradually incorporated into functional systems, while following and building upon the recommendations outlined in this review. In this way, TDABC will be better positioned to accurately capture the cost of care delivery for conditions and to control cost in the effort to create value in health care.

Keywords: TDABC, Time-driven activity-based costing, value-based health care, hospital costs, costs and cost analysis

Introduction

Value-based health care (VBHC) has been proposed as a strategy to address the challenges facing health care today [1]. Value is defined in terms of the value equation – health outcomes achieved per unit cost expended over the entire care delivery value chain (CDVC) [2]. The CDVC disregards boundaries between departments and organizations, and captures all processes in the care continuum for a medical condition. Fixed bundled payments to reimburse each CDVC hold providers accountable for the full cycle of care. The ability for providers to compare health outcomes and costs is expected to foster improvement through competition on value. There is currently great interest in VBHC, mostly directed at identifying which health outcomes are appropriate to measure for a particular medical condition [3]. Less attention has been paid to developing a standard for cost calculations [4]. The problem addressed in this paper is that valid value-based comparisons are not possible without consensus around how to calculate costs for medical conditions, and if solved, health care providers will be able to understand the cost of care delivery for conditions and control cost.

This paper reviews the empirical application of the cost-accounting tool, Time-driven activity-based costing (TDABC), presented as the solution to the cost-crisis in health care [5]. In modern competitive reimbursement environments, providers and policy makers are looking for cost-accounting solutions capable of informing process improvement and meeting the expectations of cost-control policies [5-7]. However, previous attempts to develop process-oriented cost-accounting methods in health care, such as Activity-based costing (ABC), have proven challenging. One reason is that it is too resource intensive in large or complex organizations [6, 8]. ABC was first applied in health care in the early 1990s [9]. It proved more useful than traditional cost accounting methods [10, 11], but demanded large resource investments, which led to partial or incomplete applications [12]. This was exacerbated by the complexity inherent to health care organizations [13-16]. After peaking in the mid-1990s [12], the subsequent demise of ABC [11] exemplifies the need to find balance between validity in costing and the resources expended to achieve that validity [15, 17].

TDABC was presented by Kaplan and Anderson [8] as a modified version of ABC that sought to find this balance. TDABC has demonstrated some success in the production and service industries [18]. It prioritizes accuracy over precision, i.e. "approximately right rather than precisely wrong" [6]. Accuracy is how close your cost estimate is to actual cost, and precision is the number of decimal places you include in your estimation. TDABC demands fewer resources by requiring only two key parameters: the capacity cost rate (CCR), and the time required to perform activities in service delivery [8] – thus the name "time-driven" ABC. The CCR is the cost of capacity supplying resources divided by the practical capacity of those resources. TDABC has been described as a micro-costing approach well-suited to accommodate the complexity of cost-accounting in health care organizations [5, 19]. In 2011, Robert Kaplan and Michael Porter presented a seven-step approach to the application of TDABC in health care settings (Table 1) as the solution to the cost-crisis, and linked it to the VBHC agenda [5] (hereafter, all references to TDABC will be to this approach).

-- Insert Table 1 here –

Given the increasing interest in VBHC and the need to understand the cost of care delivery for medical conditions, the current empirical evidence of TDABC applications in health care should be investigated. Therefore, the aim is to explore why TDABC has been applied, how its application reflects the seven-step model, and what recommendations can be drawn for future applications in health care.

Materials and methods

This systematic literature review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement [20]. We aimed to investigate how TDABC has been applied, not the quantitative effects of its application. Therefore, we chose a qualitative approach using content analysis [21, 22] to analyze how different applications of TDABC compared to one another and their adherence to the theoretical model. This allowed us to analyze in-depth descriptions in the text.

Search

A comprehensive search strategy was developed in order to capture the maximum number of relevant articles in each database. All possible formulations of the phrase "time-driven activity-based costing" were identified through an iterative discussion among the authors informed by the literature. Seven major databases were searched based on their relevance to health care: PubMed/MEDLINE, EMBASE, WebOfScience, OvidSP, Scopus, CINAHL and Science Direct with search strategies tailored for each. (See Appendix A: Search strategies for each database). All searches were run on June 5th, 2015, and updated on January 21st, 2016.

Eligibility criteria and study selection

Identified records were subjected to three rounds of screening. The first sought to include only those records which explicitly discussed TDABC as a key topic. The titles and abstracts were made visible in the browser and two word searches were run: 1) "driven", and 2) "abc". This comprehensively captured any formulation or abbreviation of TDABC. Any record that did not mention TDABC in the title or abstract was thereby excluded.

In the second round, records outside the context of health care were excluded, e.g. automobile, engineering, or accounting fields. Records not written in English, only available as abstracts, as well as letters, editorials, and commentaries were excluded.

The third round involved a full-text reading to exclude articles that did not explicitly describe empirical applications, i.e. theoretical articles and systematic reviews. Before exclusion, these articles were snowballed to find additional studies.

Data extraction and analysis

Three separate data extraction and analysis processes were employed. These processes were conducted by GK and MR together to improve trustworthiness. Throughout data extraction and analysis, when uncertain about aspects of the analysis, they discussed with PM and CS until consensus was reached.

First, we extracted data on general study characteristics, i.e. publication year, country, medical specialty, and type of organization. Data was stored in Microsoft© Excel 2010.

In the second analysis, we conducted a conventional inductive content analysis [23, 24], because it is suitable for exploring rationales, strengths, and weaknesses [22]. Meaning units were extracted and coded based on their manifest meaning. The analysis was conducted in NVivo qualitative data analysis software; QSR International Pty Ltd. Version 10, 2012.

Third, we used a directed content analysis approach [24], because we wanted to compare empirical applications with an existing theoretical framework [22], i.e. the seven-step model [5]. A coding template was created in Nvivo for each step, and information was extracted from the articles. This provided an overview which we then exported to Microsoft© Excel 2010 and developed further by populating the analysis with examples from each article.

Methodological limitations

We did not appraise the scientific quality of the articles, because we wanted to explore how TDABC has been applied, and not the effects of an intervention. However, the exclusion of quality appraisals may have led to the inclusion of articles with methodological weaknesses or incorrectly reported findings. Yet, the thorough content analysis we performed allowed us to identify questionable applications and make recommendations [22] for future applications of TDABC based on these and other insights drawn from the review.

Analysis of the articles

Study selection and PRISMA flow diagram

A total of 774 records were obtained after executing the search strategies, and six records from subsequent snowballing (Figure 1). After duplicates were removed, 525 records remained. Of these, 374 were excluded because they did not mention TDABC in the title or abstract. After reviewing the abstracts of the remaining 151 records, 117 were excluded because they were not conducted in a health care setting or did not meet other inclusion criteria of the second screening, leaving 34 articles for the final screening. Nine articles were excluded in the third round. Eight of these were excluded because they did not describe empirical applications, and one due to plagiarism found in the discussion around TDABC. In total, twenty-five articles were included in the analysis.

--- Insert Figure 1 here ---

General study characteristics

Over time, the number of articles published on TDABC in health care has increased. Of the 25 articles included in the analysis, 20 (80%) were published in 2013 or later. Fourteen articles described applications in the US, one in Canada, seven in Europe, two in Brazil, and one each in China and India (one article described TDABC in both the US and India).

Twenty-two studies were conducted in a hospital setting. Of these, seventeen were conducted in surgical wards (Table 2). Six studies were conducted in surgical, general, or psychiatric outpatient clinics in hospitals. Two studies were in primary care and one in a cytometry facility without contact with patients.

--- Insert Table 2 here ---

Reasons for applying TDABC

Overall, the articles saw the potential of using TDABC both to support operational improvement [13, 25-41] and to inform reimbursement policy [25, 26, 28-32, 35-43].

All reasons for applying TDABC were based on the expected strengths reported in the literature. Specifically, the method's ability to accurately capture the cost of care [25, 27-31, 34, 35, 38-40, 43, 44] at the level of the care process [25, 26, 29, 30, 32, 33, 35-40, 42, 44-46], and manage the complexity inherent to cost accounting in health care [13, 25, 26, 28, 32, 33, 36, 42, 43, 45, 46]. TDABC was also reported as more efficient [27, 29, 32, 34, 36, 38-41, 43, 44] and simple [13, 25-28, 42-44] than traditional ABC. These strengths were based on successful applications in other industries [13, 27, 29, 38], and/or claims made by the method's creators [5, 6, 8], often with respect to contributions to the VHBC agenda [25, 28, 30, 32, 33, 35-41, 44, 47].

Strengths and limitations of TDABC

The calculation of the total costs was described as simple. This was attributed to the use of multiple time-drivers [44], i.e. CCRs, and direct observations to record time [27]. These made the costs assignments more straightforward than in ABC [33].

Claims of accuracy were implicitly associated with the general thoroughness of TDABC [13, 26-28, 32, 35, 40, 42-44]. While these claims are anecdotal, they make sense because of the inherent accuracy of micro-costing methods [16, 17, 48].

TDABC's ability to clarify how costs are incurred informed improvement initiatives [13, 27, 28, 30, 31, 36, 39-41, 43-45]. Operational improvement was achieved through the reduction of resource waste [26, 31-33, 39-41, 43], redundant human resources [31, 33, 43], non-value adding steps [32, 39, 40], and waiting times [40, 41]. The use of practical capacity, CCRs, and certain data collection tools such as direct observations and interviews allowed for a detailed understanding of the cost of care processes [25, 39].

TDABC was also reported as well-suited for managing the inherent complex costing of hospital settings [13, 25, 28, 40], which made it possible for hospitals to compare their costs against reimbursement tariffs.

Finally, TDABC was reported to provide costing information with the potential to serve as the basis for formal payer reimbursement schemes [30, 33, 39, 42, 44], and performance-based incentives for physicians and administrators [39]. TDABC's potential to accurately capture the cost of care can support the VBHC agenda [30, 31, 38, 44] through the alignment of condition-specific costs and reimbursement models [31, 44].

Applications of the seven steps and consequences for research and practice

TDABC was applied in health care primarily to estimate the cost of clinical procedures and visits in order to inform operational improvement, and to compare against reimbursement tariffs. TDABC applications varied, but generally reflected the seven-step model. The following sections present each step, describe how each step was applied, why deviations from the seven-step method occurred, the consequences of these deviations, and the implications for research and practice.

Step 1. Select the medical condition.

The medical condition is defined as an “interrelated set of patient circumstances that are best addressed in a coordinated way and should be broadly defined to include common complications and comorbidities” [5].

No article adhered to the definition of a medical condition because they did not include comorbidities or complications related to the medical condition. No explanation was provided for this exclusion. One article [26] mentioned the inclusion of complications, but this was not evident in the ensuing cost analysis.

Most articles costed surgical procedures [25, 26, 28-32, 36, 38, 40, 43-46] such as Coronary Artery Bypass Graft (CABG) [32] or Total-Knee Replacement (TKR) [29, 30, 44]. Seven articles costed outpatient visits [13, 33, 35, 37, 39, 41, 47], three of which were condition-specific processes [35, 37, 47]. Four costed outpatient visits that covered a range of medical conditions where the processes were similar for every condition [13, 33, 39, 41]. Three articles did not apply TDABC to a process linked to a medical condition since the focus was on costing a cytometry facility, a primary care intervention, or on unused operating room capacity [27].

The risk of not applying step 1 at the level of a medical condition by merging several conditions into a single process is a loss of granularity in the cost analysis. However, granularity can be achieved in other ways. One article grouped processes into two categories, technical and non-technical activities performed in five outpatient clinics. A national tariff reimbursed a fixed amount for these individual visits. By grouping similar processes, they were able to develop a cost estimate that was more granular than the one in the reimbursement model. This allowed for an informative profitability analysis [13] without developing processes for every medical condition.

All articles conducted their analysis within the confines of a department or clinic, which limited the scope of the care cycle. This could reflect the departmental silo-thinking of health care [49] that is contradictory to the patient orientation of process costing. The delimitations of processes also varied between articles that addressed the same condition [29, 30, 44]. Both deviations make it impossible to cost the full CDVC and could lead to sub-optimization [49].

In some applications of TDABC, it may be clear from the aim of the cost analysis that specifying a medical condition is not necessary. However, applications should consider defining the start and end of the process outside immediate organizational boundaries so that it better mirrors the patient experience in health care rather than a caregiver silo perspective. This is especially important in the context of efforts to improve care experience and value in health care [1, 50].

Step 2. Define the care delivery value chain.

This step involves charting the activities that occur and their locations over the entire cycle of care, and helps identify required measures and ways to inform and engage patients [5].

Only two articles [30, 44] charted the activities and segments that occurred over the entire cycle of care, and no article included information about location, measurement, and patient information and engagement. The only article that explicitly referred to the CDVC appeared to have misunderstood the concept and saw it as an individual process [39], instead of a set of activities each with its own process.

Only those articles that specified a medical condition could chart the CDVC. Of these, all but two [30, 44] focused on single processes and not processes for all activities in the CDVC. No explanations were provided for skipping this step.

This step is required to either inform reimbursement policy or conduct profitability analyses within bundled payment reimbursement systems. While three articles advocated for bundled payment systems [30, 33, 44], only one [30] successfully estimated the costs of care bundles (for total hip or knee replacement surgeries). No article attempted a profitability analysis against bundled payments, but some were performed against national tariffs for DRGs [13, 25, 29, 35]. In such cases, while the analyses were sufficiently accurate for comparison with national tariffs, the scope of the DRG defined the scope of the cost analysis at the outset.

Theoretically, skipping this step limits providers' ability to eliminate redundancies, capitalize on synergies, and better integrate care delivery over the entire cycle of care. One article [30], found that an analysis across the care continuum broke down silos allowing for cost reductions while maintaining quality of clinical and experiential outcomes for patients.

The rare empirical application of this step raises questions about its purpose and utility, but may also be a consequence of the narrow and intradepartmental focus of the medical condition defined in step 1. In such cases, the CDVC becomes a simple mapping of the care process in the interested department or clinic. For those clinics or departments interested in crossing organizational boundaries or measuring outcomes that matter for patients as described in the VBHC value agenda [1], the CDVC may prove useful.

If the intention is to compare costs across or between organizations and departments, or against a reimbursement model, the cost-accounting methods need to be comprehensive, performed according to standards, and transparent [51]. The long-term opportunity for TDABC to inform reimbursement policy [52] will require coordinated efforts to develop cost-accounting principles aligned with reimbursement systems [51]. A TDABC analysis performed around the entire CDVC is suitable in cases where providers intend to align cost accounting with bundled payment reimbursement systems [30, 36, 38], or to re-organize processes to align clinical, financial, and operational systems around the entire care continuum.

Step 3. Develop process maps for each activity in patient care delivery.

Process maps should be developed for each activity in the CDVC, and should include all relevant resources required for each process step [5].

All articles but one [34] developed process maps or more simply chronologically listed the process steps. The most common data collection method for mapping processes was contextual observations [13, 26, 29, 30, 32, 33, 35, 37-46]. Interviews were often used in conjunction with observations [13, 26, 32, 37, 38, 40-43, 45, 46]. Team meetings or workshops with doctors, nurses, management personnel, consultants, and business analysts were occasionally used to develop process maps [31, 36-38, 40, 41]. In four cases, these meetings/workshops complemented [31, 38, 41] or validated [44] maps developed through observations and interviews. One article [25] did not mention how the process map was developed.

In one case [28], process maps were created from electronic medical records for surgeries and medical assistance activities within the hospital. Quality manuals were used to map activities surrounding surgeries and medical assistance. This article directly linked the ease and speed of process mapping to the quality of the information system. Therefore, process mining methods [53] applied to electronic medical records may provide new and more efficient approaches to mapping care processes.

One article did not perform process mapping [34], but calculated the cost of unused capacity in operating rooms. Annual-unused capacity was multiplied by CCRs to estimate the cost of unused capacity. This article did not correctly interpret TDABC methods. Process mapping is fundamental to TDABC and an analysis cannot be attempted in its absence.

The involvement of care givers in process mapping provided transparency with respect to how resources were costed in care delivery [41, 44], fostered ownership of the change process among providers [41], and improved collaboration among providers [13, 31, 40].

Preliminary process maps should first be developed with staff, and then confirmed through additional methods, e.g. contextual observations. Observations minimized recall bias and the need to engage high-cost personnel, and improved accuracy [30, 39]. Others who conducted contextual observations found the method to be resource intensive [26, 29, 30, 42-44]. Therefore, it would make sense to develop preliminary process maps through interviews or workshops with staff, and then complement and confirm these with observational data. By better integrating different information sources, we could more accurately identify areas with high process variation, which we may otherwise have missed.

Step 4. Obtain time estimates for each process.

The time each resource spends with patients at each step in the process should be estimated. Standard times estimated by experts could be used for common, short, and inexpensive activities. Actual times should be measured for complex, lengthy, and expensive activities, where observations would be the preferred approach [5].

All articles but one, discussed above [34], timed activities within processes. This step involved the same methods for process mapping, and was often performed simultaneously.

Two articles [28, 32] identified complex, long, or expensive activities in the care process to guide data collection methods. One used hospital information systems to capture actual times, but staff estimates for less common and brief activities [28]. The other article [32] conducted both contextual observations and brief staff interviews, and the former was prioritized for more complex and longer activities. During interviews, staff validated observational data. Another article [41] used uniform methods for all activities, but validated observational and interview data using round-table discussions. Time estimates, in one case [37], obtained through observations were replaced by expert-panel estimates because of high variation within a small number of observations [37]. Actual values for all activities, in another article, were obtained from a retrospective review of patient charts because the data was available in detailed medical records [25]. Other articles also used a combination of observations and interviews for time estimation, but they did not describe when or why they used each method [13, 26, 38, 40, 43, 45, 46].

Data collection for both process mapping and time estimates were reported as resource intensive steps in TDABC [26, 29, 30, 39, 42-44]. Interestingly, of the seven articles that highlighted the resource intensive nature of TDABC, four [29, 30, 39, 44] conducted only contextual observations, and did not perform less resource intensive methods for simpler and shorter activities. One [42] stated that they occasionally supplemented observations with self-reported values strictly because observational data collection for all steps in the process was too work intensive. The remaining two articles [26, 43] used interviews and observations only, both of which can be resource intensive and time consuming.

Risks of inaccuracy were described and associated with possible errors in the methods used to collect time estimates through observations, surveys, and interviews [33, 36, 39, 45, 46]. Further, two articles acknowledged a risk of the Hawthorne effect during observations [35, 39]. One article also reported that time estimates were difficult to capture for activities that were seldom performed [42]. Interestingly, none of these articles used a combination of methods in order to validate their results.

It is crucial that data collection methods are selected wisely and employ crude low-cost methods for simple activities, or allow for more liberal spending to cost expensive and complex activities. A mixed approach to data collection should be adopted for purposes of validation. Encouragingly, one article suggested that methods become less resource intensive with time [30].

Automation of data collection through the use of electronic hand-held devices or radio frequency identification devices (RFID) could address some challenges related to step 4, including resource demands and human error [5]. Automated time stamps tied to electronic medical records and RFIDs would be the easiest, least intrusive, and most accurate approach. However, questions of data integrity and cost of systems should be considered.

Step 5. Estimate the cost of supplying patient care resources.

The cost of all primary resources (direct care costs [17]) i.e. those directly involved with care delivery in the process should be estimated. Then estimate the cost of resources required to supply (indirect care costs [17]), and the cost of departments and activities required to support (overhead and support center costs [17]), these primary resources. CCRs should be calculated for support center resources and used to assign these costs to primary resources [5].

Direct Costs

All articles but one [46] costed resources, and a range of methods were used. The most common direct costs were personnel costs. Most staff were costed based on annual salaries or hourly wages, but physicians were costed via physician fees [25]; negotiated additional compensation, incentive compensation, administrative stipends, and outside income [40]; malpractice insurance [31]; or average base salary derived from multiple salary contracts [28, 38]. Estimating physician cost was a common challenge [13, 25, 28, 31, 38, 40]. When accounted for, the cost of physicians was often calculated through complicated approaches [31, 38, 40]. One article, set in an outpatient clinic where the majority of care was provided by nurses, excluded the cost of physicians, citing complications with the physician reimbursement system [13].

Some articles chose to focus on personnel or equipment costs. For example, only personnel costs were included because they accounted for 60% of operating costs [26], or because of resource constraints [28]. Others also excluded personnel cost, but provided no explanation [33, 35, 39]. Two articles focused on equipment because they aimed to specifically understand how these resources could be allocated to care processes [45, 46].

The article [46] that did not cost resources did not complete a full TDABC analysis. The article did not measure cost, but calculated resource use measured in various units depending on the resource, i.e. hours of machine use or kilowatt-hours of electricity used.

Exclusion of any cost limits the scope of inferences that can be made from an analysis. For example, one article [26] that included only personnel costs was limited to improving efficiency in staffing clinical procedures. Another article [28] acknowledged that because they included only equipment and personnel costs, they could not estimate the total cost of DRGs, and thus could not inform the setting of reimbursement tariffs. In cases where major costs are excluded, it is not correct to use the results to inform reimbursement policy.

This step is perhaps the biggest challenge because it is limited by the trade-off between the cost and accuracy of costing, as well as impacted by decisions about this trade-off made in steps 3 and 4. The costs included in the TDABC analysis should be well aligned with the study objective, and analyses aiming to inform reimbursement or budgeting should be as comprehensive and transparent as possible.

Indirect costs

Several articles left out indirect costs altogether [25, 26, 28, 32, 33, 39, 47]. While no article said so explicitly, analyses with an internal focus may not be interested in overhead and support resource costs because they are seen as fixed costs outside the department's sphere of influence [17]. Many articles allocated a select set of indirect costs to primary resources but excluded allocation of supporting departments or activities [13, 30, 35, 37, 38, 41, 54].

No article assigned indirect costs of support departments to primary resources. Of those that included the cost of support departments, we found many variations in how this was done, which were sometimes motivated. One approach was to allocate support department resources to processes on the basis of bed days [29]. A similar approach was to assign building rent costs to operating room space on the basis of square-footage [38]. The costs of support departments and activities were in three cases allocated to care processes as a flat percentage of direct costs varying between 43.8-56.6% [29, 37, 42], reminiscent of traditional cost accounting [17]. This choice was motivated by a lack of resources to map processes and cost personnel within the support departments [37]. No article calculated CCRs for resources within support centers.

The variation in support cost allocation could be explained by the belief that the direct allocation of support center costs is not only impractical but there is no consensus or evidence supporting how this should be done [29]. However, this belief was explicitly described as a myth [5] in the publication that presented the seven-step approach, where crude approaches like using a percentage of direct costs were labeled as "peanut butter approaches". However, no clear detailed examples or explanations of appropriate assignment were provided in the publication.

Variation in the allocation of support resources could significantly impact the estimated cost of care [44], and exclusion of these costs could lead to gross underestimates [39] as they can account for upwards of 30-50% of total operating cost [29, 30, 37, 42]. However, applying a micro-costing approach to assign support center resources to primary resources has been described as impractical [29]. Further, large variation is expected between contexts simply because the support center costs can vary significantly with organizational structure [29].

Support center costs should be included and reported both together with and separately from direct costs, and the impact of organizational structure should be discussed for purposes of comparison. The cost of major support departments accounts for a large and growing [17] proportion of the cost of medical conditions, and thus must be accounted for in analyses making inferences outside immediate organizational boundaries. Most service-line costing approaches advocate assigning support department costs to activities on an appropriate basis [17]. However, single flat rate allocations continue to be used, indicating that innovative approaches to accurately assign indirect costs are still needed.

Step 6. Estimate the capacity of each resource and calculate the capacity cost rate.

Obtain the practical capacity for all primary resources – the annual or monthly time available for patient-related work. Calculate the CCR as the cost of a resource divided by its practical capacity over a given time period [5].

Capacity

All articles, often through interviews with administrative personnel or an attendance register, obtained theoretical capacity, i.e. the total number of days each resource or employee was available for work each year excluding holidays and sick leave.

Most articles that estimated practical capacity used a flat rate adjustment of theoretical capacity to account for breaks, education, teaching, and research [13, 28, 33, 34, 37, 39, 41, 43-45]. This approach reflected suggestions for simple capacity adjustments described in the original TDABC literature published for other industries [6, 8]. Four applied an 80% adjustment [13, 34, 39, 44, 45].

One article adopted a thorough analytic approach to estimate the practical capacity of physicians [40] and exposed extensive variation in physician capacity across specialties involved in a single care process.

Some articles used unadjusted capacity instead of practical capacity [26, 29, 31, 35, 46, 47, 54], and did not discuss or explain why these adjustments were not performed.

However, practical capacity adjustments may not always be necessary. For example, one article that conducted an analysis of total knee replacement [29] estimated the total cost to be 5421.95€, and human resources accounted for 658.37€. A rough practical capacity adjustment of 80% applied to human resources would increase total cost by 164.79€, or 3% of the total cost. In this article, corporate overheads were crudely estimated as 43.8% of total direct patient costs and thus heavily impacted the precision of result, rendering a 3% effect from practical capacity adjustments immaterial.

Another article [26] investigated the cost of *unused capacity* of operating-room physicians performing adenotonsilectomy. While they did not specify what unused capacity entails, it can be assumed to include all non-surgery time, including breaks. Therefore, practical capacity adjustments were of course not necessary.

Occasionally, practical capacity estimates were reported, but not described [25, 27, 30, 32, 38]. In two cases, estimates were adjusted for training, travel [36], and support activities [42], but breaks and education were not mentioned.

The unadjusted annual capacity for human resources will include a significant amount of time not devoted to care delivery. An exaggerated capacity increases the amount of time in a year over which resources are distributed, thus underestimating the cost per minute, the CCR, of resources. Practical capacity adjustments are performed to ensure that the cost of resources are distributed only to time that generates value in care delivery. Ignoring annual practical capacity adjustments could lead to an underestimation of the CCR, and thus the cost of care processes.

One article [35] performed a TDABC analysis of only human resources, without adjusting for practical capacity. They compared the profitability before a process improvement initiative, phase 1, to after the initiative, phase 2. The profit margins in phase 2 were higher because of an increase in throughput, and staff costs were substantially higher in phase 2 as more staff were required to accommodate throughput. Their cost estimates, particularly for phase 2, are likely underestimated because they did not include any practical capacity adjustments, which calls into question their conclusion that Phase 2 was more profitable.

Practical capacity adjustments are not always necessary in a TDABC analysis. They should only be included when resources expected to drive total cost are subject to high levels of unused annual capacity, i.e. staff, equipment, etc. These adjustments are not necessary when investigating the cost of unused capacity alone. In cases where practical capacity adjustments are needed, a flat-rate adjustment of around 80% is recommended only for initial rough practical capacity estimates because as the system becomes established, managers will likely be interested in a more accurate approach [6, 8].

Organizations intent on applying TDABC need to carefully consider how to approach variations in practical capacity, particularly for physicians given the high cost and high variation in estimating cost and capacity for these resources. Physician capacity and cost are not only linked to specialties but also to experience and competency levels and engagement in research and teaching.

CCRs

All articles but one [46], which did not include costs in their analysis, calculated CCRs. Of these, all but two calculated CCRs at the individual resource level. One developed a single CCR for each process [28], and the other grouped resources into resource pools and developed CCRs for each pool [13]. In one peculiar case, an article calculated a single CCR for all support departments and activities, as cost per hours of operation of the setting [27]. These costs were applied on the basis of activity minutes. However, this method is crude and time is not always the most appropriate basis for allocating certain support department costs, and thus could lead to incorrect cost estimates [17].

Most articles calculated CCRs for individual resources as described in the seven-step approach. With respect to the two articles [13, 28] that calculated CCRs for entire processes or resource pools, these applications likely had less granularity in their cost estimates. However, these two articles were also able to conduct much larger scale TDABC analyses spanning over departments and hospitals. One [28] developed a single CCR per process, and was thus able to cost the processes of multiple departments within 16 hospitals in Tuscany. The other article [13] developed CCRs for pools of resources, and was able to estimate the cost of all processes within five separate outpatient clinics while distinguishing between technical and non-technical consultations.

Calculation of resource-level CCRs involves a more thorough analysis and produces estimates that are more accurate. However, calculating resource-pool CCRs or even process-level CCRs allows for larger scale TDABC initiatives. When planning a TDABC analysis, the project scale and availability of funding should be considered when selecting the level of the CCR. A possibly interesting approach, that was not adopted in this review, could be to begin with a low-cost, crude process-level CCR at the outset with the intention of subsequently refining the analysis to resource pools, and then to individual resources. This could be particularly useful in initiatives operating under high resources constraints.

Step 7. Calculate the total cost of patient care.

Multiply the CCR of each resource by its duration of use in each activity, and sum the cost of each activity to obtain the cost of a process. The cost of each process is summed to generate the cost of a complete cycle of care for patients with the medical condition.

This last step simply involved performing the required calculations based on the design of the TDABC analysis. All but two [34, 46] articles estimated the cost of processes. One [34] focused on estimating the cost of unused capacity of a set of operating rooms, and the other [46] on measuring quantities of resources consumed. In both cases, their classification as TDABC analyses is questionable because calculating the total cost of processes is the purpose of TDABC.

Conclusions

TDABC is applicable in health care and can help to efficiently cost processes, and thereby overcome a key challenge associated with current cost-accounting methods. Applications were often constrained by organizational boundaries rather than spanning the full cycle of care for a medical condition. Process maps, resource inclusion, and time estimates were developed using different methods, each demanding different amounts of resources and providing different levels of accuracy. Support resources were not allocated according to the model. The CCRs were calculated often at the resource level and occasionally for processes. All of these deviations had implications for the resulting cost of patient care.

Cost assignment through CCRs was described as more simple than ABC allocation methods, and CCRs together with contextual observations generated more accurate cost estimates, which suggests that TDABC is more able to address complexity in health care. The variation in application suggests that more can be done to address the challenges practitioners are facing. In order to improve the value of TDABC applications in health care, we offer the following suggestions.

With the exception of defining the medical condition and the CDVC, all steps are mandatory for any TDABC analysis. Applications that hope to inform bundled payment reimbursement systems, or inform operational improvement and cost reduction across the care continuum need to cost care over the full CDVC. Articles aiming to compare against or inform reimbursement tariffs should select a process aligned with the target tariff. To avoid unnecessary expenditure of resources when mapping processes and obtaining time estimates, staff or expert estimates should be used for short and low-cost activities. For longer and more expensive activities, actual times should be obtained using observations or medical record data, and an additional method of data collection (actual or estimate) should be performed for validation purposes. Initiatives that involve staff are more successful because they allow for unimpeded customized implementation and foster staff ownership and cooperation. If the purpose of the analysis is operational improvement, only resources around which the initiative is focused need be included, e.g. an initiative to reduce the cost of staff in a department or ward only need to include human resource costs. However, for initiatives intending to compare results outside their context, including against reimbursement tariffs, comprehensive resource inclusion is required, including indirect costs. Indirect costs should be reported separately from direct costs, and how these costs are influenced by the organizational structure should be discussed. CCRs should be calculated at the resource level for analyses aiming for a high level of accuracy, but at the resource-pool or process level for large scale or low budget analyses. Future applications aiming for publication should explicitly report and provide justification if steps in the TDABC process are skipped or modified, otherwise the validity of the analysis is difficult to assess.

Some aspects of TDABC may be simpler to understand and apply than those of ABC. However, the method's ability to inform bundled payment reimbursement systems and to coordinate delivery across the care continuum remains to be demonstrated, and the role of TDABC in this cost-accounting landscape is still developing. Therefore, we should be careful not to suggest that TDABC replace existing systems because novel systems are historically expensive and sometimes no more effective than those they replace [17]. Rather, TDABC should be gradually incorporated into functional systems, while following and building upon the recommendations outlined in this review, to progressively bring stable and reliable process-level cost-accounting practices to health care organizations. In this way, evidence generated around applications can avoid TDABC being labeled as expensive and impractical, and better position the method to estimate the cost of care delivery for conditions and control cost in the effort to create value in health care.

Conflict of interest:

The authors declare that they have no competing interests

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Authors' contributions:

GK, MR, PM and CS designed the study, GK and MR collected the data, conducted the analyses, and drafted the manuscript which was then revised iteratively together with PM and CS. All authors read, contributed to, and approved the final manuscript. PM and CS were PI.

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Appendix A: Search strategies for each database

Database	Search strategy
PubMed\Medline	"time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TDABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time driven ABC*" OR "time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time-driven ABC" OR "time-driven activity"
WebOfScience	"time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TDABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time driven ABC*" OR "time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time-driven ABC" OR "time-driven activity"
EmBase	("time driven activity based cost" OR "time-driven activity-based cost" OR "TD-ABC" OR "TDABC" OR "time-driven activity based cost" OR "time driven activity-based cost" OR "time driven ABC" OR "time driven activity based cost" OR "time-driven activity-based cost" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based cost" OR "time driven activity-based cost" OR "time-driven ABC" OR "time-driven activity") AND ("time driven activity based costing" OR "time-driven activity-based costing" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based costing" OR "time driven activity-based costing" OR "time

Database	Search strategy
	driven ABC" OR "time driven activity based costing" OR "time-driven activity-based costing" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based costing" OR "time driven activity-based costing" OR "time-driven ABC" OR "time-driven activity")
OvidSP	"time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TDABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time driven ABC*" OR "time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time-driven ABC" OR "time-driven activity"
Scopus	"time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TDABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time driven ABC*" OR "time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time-driven ABC" OR "time-driven activity"
CINAHL	"time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TDABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time driven ABC*" OR "time driven activity based cost*" OR "time-driven activity-based cost*" OR "TD-ABC" OR "TD ABC" OR "time-driven activity based cost*" OR "time driven activity-based cost*" OR "time-driven ABC" OR "time-driven activity"
Science Direct	(ALL("time driven activity based cost") OR ALL("time-driven activity-based cost") OR ALL("TD-ABC") OR ALL("TDABC") OR ALL("time driven activity-based cost") OR ALL("time-driven activity based cost") OR ALL("time driven ABC") OR ALL("time driven activity based cost") OR ALL("time-driven activity-based cost") OR ALL("time driven activity based costing") OR ALL("time-driven activity-based costing") OR ALL("TD-ABC") OR ALL("TD ABC") OR ALL("time driven activity-based costing") OR ALL("time-driven activity based costing") OR ALL("time driven ABC") OR ALL("time driven activity based costing") OR ALL("time-driven activity-based costing"))
Google Scholar	("time driven activity based cost*" OR TDABC OR "time driven ABC*" OR "TD ABC") AND (hospital OR hospitals OR health* OR Medicine OR Medical OR *Care OR clinic OR "Primary Care" OR "Practitioner" OR "patient*" OR "doctor" OR "physician")

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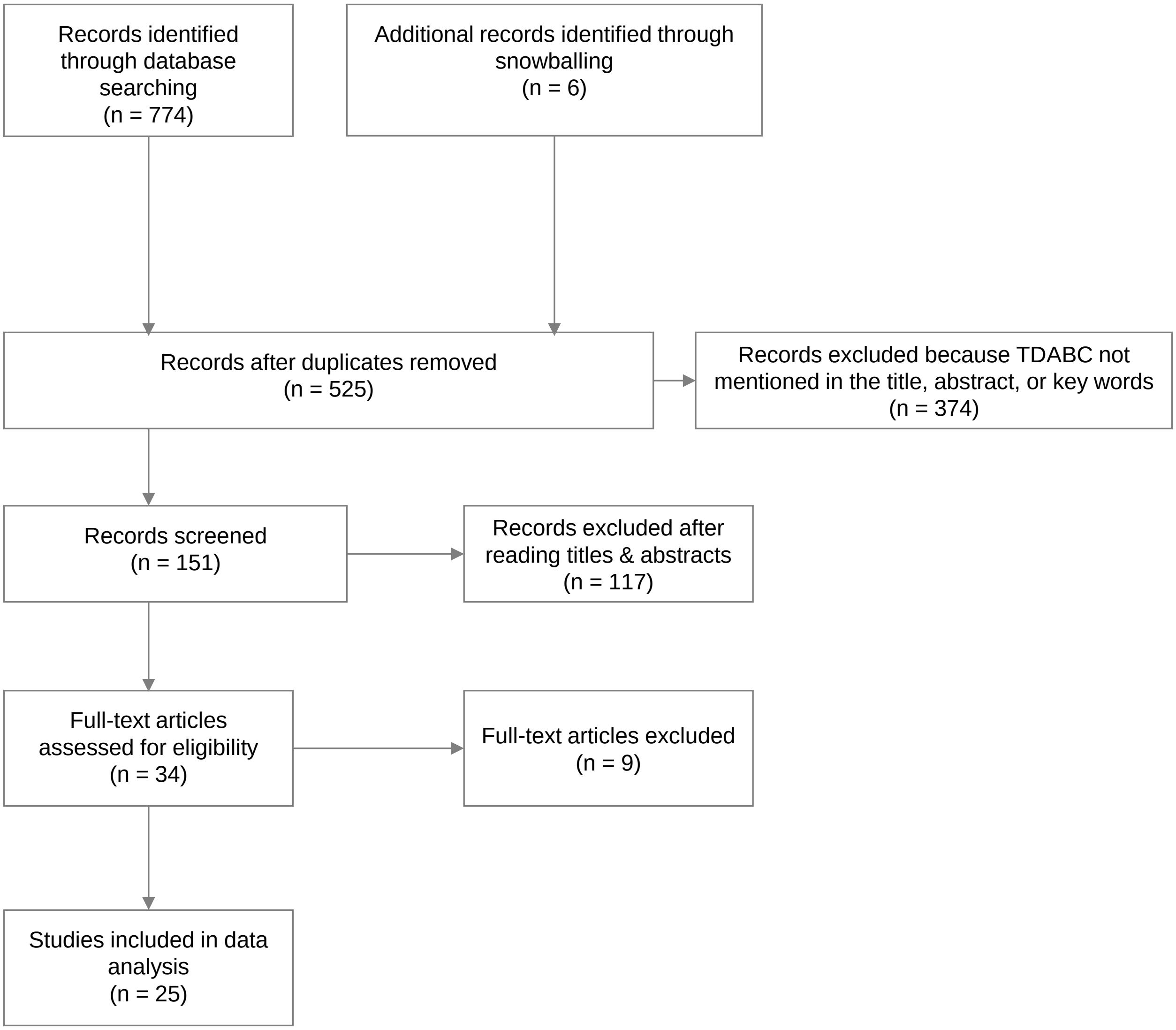
Figures

Figure 1. PRISMA flow diagram



Tables

Table 1. The seven steps of TDABC for health care organizations

Step 1	Select the medical condition
Step 2	Define the care delivery value chain, i.e. chart all key activities performed within the entire care cycle
Step 3	Develop process maps that include each activity in patient care delivery, and incorporate all direct and indirect capacity-supplying resources
Step 4	Obtain time estimates for each process, i.e. obtain time estimates for activities and resources used
Step 5	Estimate the cost of supplying patient care resources, i.e. the cost of all direct and indirect resources involved in care delivery
Step 6	Estimate the capacity of each resource and calculate the capacity cost rate
Step 7	Calculate the total cost of patient care

Table 2. Health care settings in which TDABC has been applied

Health care fields		**Articles**
Hospital Services Inpatient Surgery		
	Hip arthroplasty	[44]*
	Head and neck surgery	[25]*
	Pediatric adeonotonsillectomy	[26]*
	General surgery	[28, 34, 43]
	Total knee replacement	[29]*
	Heart-valve surgery	[31]*
	Hip Arthroplasty & Total knee replacement	[30]*
	Coronary artery bypass grafting	[32]
	Urology, benign prostatic hyperplasia	[36]*
	Neurosurgery	[40]*
	Abdominal surgery	[45]*[46]*
Outpatient surgery		
	Pediatric plastic and oral surgery	[35]*[37]*
	Orthopedic surgery	[47]*
Other outpatient services		
	Psychiatry	[41]
	Hospital (Urology, gastroenterology, Nose, throat, and Ear, Plastic surgery and Dermatology departments)	[13]
	Pre surgery anesthesia	[33]*
Other hospital settings		

	Hospital radiotherapy centers	[42]*
	Academic referral center, prostate cancer	[38]*
Non-hospital services		
Primary care		[39, 54]
Cytometry		[27]

*University hospitals