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Original Research

# Time-Driven Activity-Based-Costing to Improve Healthcare Resource Use: Patient Pathways and Cost Comparisons for Cardiac Electrophysiology Interventions and Surgical Aortic Valve Replacement in Five Italian Hospitals

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A R T I C L E I N F O

*Key words:*
Time-driven activity-based costing (TDABC)
Benchmarking
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Pacemaker (PM)
Implantable cardiac defibrillators (ICD)
Cardiac resynchronization therapy (CRT)
Care pathways

A B S T R A C T

*Purpose:* Rising healthcare expenditures demand more efficient resource allocation to maximize the return on health for the entire population of a healthcare system while minimizing opportunity costs. Accurate cost measurement is crucial for value-based healthcare, but often neglected in favor of outcomes measurement to guide resource allocation in policy making. Among methods that have been applied in industrial sectors to estimate productions costs, time-driven activity-based costing (TDABC) has made inroads in health care as an effective means to identify and reduce inefficiencies through better resource management and use. This study applied TDABC to estimate and compare full hospital pathway costs for 5 high-cost cardiac interventions—surgical aortic valve replacement (SAVR) and 4 electrophysiological procedures (pacemakers [PM], cardiac resynchronization therapy [CRT] PM [CRT-P], implantable cardiac defibrillators [ICD], and CRT ICD [CRT-D])—across 5 hospitals in Northern Italy.
*Methods:* Using standardized clinical vignettes and structured interviews with multidisciplinary teams, the study quantified time and resource use across pre-, peri-, and postoperative phases. Unit costs were derived from hospital accounting data. TDABC was applied to compute full benchmark costs (minimum, average, maximum) and identify major cost drivers.
*Findings:* Labor costs emerged as the predominant cost driver, accounting for 37–61% of full benchmark costs. Inter-hospital variability was most pronounced in length of stay (especially for SAVR), time in the operating room, and nursing workloads. Benchmark costs for electrophysiology procedures ranged from €1387–1967 (USD: 1540–1967) for PM and ICD and €2057–2921 (USD: 2283–3242) for CRT-P and CRT-D, and for SAVR €7278–8537 (USD: 8079–9476). The benchmarking approach enabled meaningful comparisons despite differences in hospital type and clinical and organizational practices.
*Implications:* TDABC offers granular insights into cost variability, enabling benchmarking and more efficient resource use. Findings here from 5 different hospitals showed that with similar labor and unit prices for supplies and services, labor and the intensity and length of hospital care had the greatest impact on costs, an important finding for policy interventions to contain costs and identify best practices from different hospitals. Providing a detailed picture of cost drivers of inter-hospital variability in full costs and a structured, practical methodology, this study supports hospital managers and policymakers in improving cost transparency, pathway design, quality improvement across hospitals, tariff-setting, and value-based care implementation.

## Introduction

For decades health expenditure has consistently risen faster than economic growth among OECD countries.[1] Prior to the Covid-19 outbreak, an average annual growth rate of 2.7% (0.6% higher than the GDP growth) for health expenditure per capita across OECD countries was predicted, rising from 8.8% of GDP in 2018, to 10.2% by 2030.[1] With the onset of Covid-19, overall health spending sharply increased in 2020

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and 2021, but contracted in 2022 and showed only modest growth in 2023.[2] Though the pandemic has waned, it highlighted health as a key driver of economic growth, even if healthcare spending increase trends return to prepandemic levels.[3]

In OECD countries healthcare expenditure is mainly financed through tax income and social insurance contributions paid by employees, employers, and other contributors.[1] Therefore, efficient budget allocation is crucial to maximize the return on health for the entire population of a healthcare system while minimizing opportunity costs. One way of doing so is to focus on value, as defined by health outcomes achieved per dollar spent, and to favor those services and procedures that deliver more than their cost.[4] This requires that health care providers and policy makers have a clear understanding of the outcomes and costs of production associated with health care interventions. While outcomes measurement has emerged as a guiding principle for resource allocation in policy making,[5] costs measurement is often reduced to consideration of tariffs and charges that, however, may not address the objective of measuring the consumption of resources necessary to deliver adequate healthcare services and procedures.[4,6,7]

Several methods have been applied in industrial sectors to estimate productions costs. Among them, time-driven activity-based costing (TDABC)[8] has made inroads in health care as an effective means to identify and reduce inefficiencies through better resource management and use, comparing not only professional practice or alternative pathways for implementing a surgical procedure or treatment, but also the same procedure across different hospitals. [6,9–17] A recent review of 32 studies using TDABC in health economic analysis,[18] found that it informs both decision making and efficiency, and, building on the pioneering contributions from Kaplan and Anderson (2004),[8] Kaplan and Porter (2011),[4] and Kaplan et al (2014),[6] represents an integral step in moving toward value-based healthcare. With specific reference to different kinds of hospital costs of care, various authors have proposed specific calculation methods,[19–21] with several groups advancing the methodology to compare costs across hospitals and nations.[14–16] Though some variation in TDABC application can be expected, the development of standardized principles to define, estimate, and report costs is seen as an important research objective to improve the intelligibility of TDABC studies.[12,18] Though studies have proposed cost comparisons between different hospitals,[14,16,17,22] in addition to narrative approaches, there is still a lack of usable tools to support managers and policymakers in data interpretation.

We sought here to apply TDABC to estimate the hospital pathway costs for selected surgical interventions to treat patients with common, high-cost cardiovascular diseases (CVDs). CVDs were chosen for their importance as the leading cause of death globally, estimated at 17.9 million premature deaths worldwide in 2019.[23] Within CVDs, we focused on 5 hospital pathways that, to date, lack detailed cost analyses, including surgical aortic valve replacement (SAVR) and 4 surgical therapies for cardiac arrhythmias: implant of pacemakers (PM), cardiac resynchronization therapy (CRT) PM (CRT-P), implantable cardiac defibrillators (ICD), and CRT ICD (CRT-D). These 5 surgical therapies have been steadily rising in Italy (and elsewhere) since 2001, and can be estimated to have collectively accounted for over 110,000 hospital discharges per year nationwide by 2017.[24–26] The study has 4 main goals: first, identify variability in cost drivers in terms of resource consumption and unit costs among a sample of hospitals; second, determine the most relevant full cost components; and third, estimate benchmarks for the minimum, average and maximum full costs of the selected patient pathways. Fourth, the benchmarking methodology is *per se* a research goal, given the scarcity of contributions providing practical tools to make cost data more intelligible in multicenter studies, enabling interpretation and further utilization of the results.

## Participants and Methods

We applied a composite methodology based on several phases summarized in Figure 1. Study data was collected between March 2015 and March 2017 in Lombardy, as the most populous Italian region (16.5% of the roughly 60 million residents in Italy), which also accounts for the majority of implants of the investigated technologies. Analysis of the Italian Ministry of Health National Hospital Discharge Records (HDR) database shows that from 2009 to 2019, between 19 and 24% of all SAVR and heart rhythm devices were implanted in Lombardy hospitals. All costs were estimated in 2015 Euros (€), the start of the observation period. For reporting purposes, values have been converted to US dollars (US$) using the average 2015 exchange rate reported by the European Central Bank (1 Euro = 1.11 US$).

In the first phase, hospitals were invited to participate based on 3 inclusion criteria: selected procedure volumes higher than the regional median; total bed capacity greater than 200 beds (ie, medium- and large-sized hospitals); and availability of detailed information on resource unit costs. Hospitals that met these requirements were clustered according to type: (1) tertiary (ie, highly technical and specialized hospitals, often affiliated with universities) versus secondary (ie, hospitals providing specialty care to patients usually referred from primary care, not affiliated with universities); (2) public versus private ownership; (3) presence versus absence of teaching and research activities; and (4) metropolitan versus urban location. Five hospitals reflecting the diversity of these types were included in the study (Table 1).

In the second phase, for each of the 5 procedures, we designed a clinical vignette presenting a fictitious patient based on a realistic clinical situation, with several open questions for physicians regarding the care to provide and the level of complexity of their patients. As Veloski et al (2005)[27] observe, this phase represents a key step allowing clinicians to describe their patients' complexity profiles and the risks inherent in the pathway. Each vignette was developed by first determining the average characteristics (age, sex (ie, biological and physiological characteristics), and comorbidities) of all patients who underwent the selected procedures in Italy between 2009 and 2012 using the HDR; this analysis allowed us to reflect comorbidities and related complexity in treating patients. These profiles thus correspond to typical elective patients undergoing the procedures in routine Italian practice and exclude extreme high-risk or emergency cases, thereby enhancing comparability across hospitals. The vignettes (Supplementary materials, Table S1) were then

**Table 1**
Main features of the hospitals participating in the research.

| Hospitals | Location and main catchment area* | Ownership# | Teaching# | Type of care# | Size (beds)# |
|---|---|---|---|---|---|
| Niguarda | Metropolitan area of Milan (4,398,000 inhabitants) | Public | No | Tertiary | 1066 |
| Humanitas | Metropolitan area of Milan (4,398,000 inhab.) | Private, for profit | Yes | Tertiary | 702 |
| Manzoni | Urban area of Lecco (118,109 inhab.) | Public | No | Secondary | 526 |
| Papa Giovanni XXIII | Urban area of Bergamo (486,958 inhab.) | Public | No | Tertiary | 1024 |
| Fondazione Poliambulanza | Urban area of Brescia (672,822 inhab.) | Private, not for profit | No | Secondary | 509 |

* A. Spinosa, "Urbanismi, Cluster urbani e aree metropolitane—volume primo, Italia," Roma, 2011.
# dati.salute.gov.it, and hospital websites (accessed 31st May 2020).

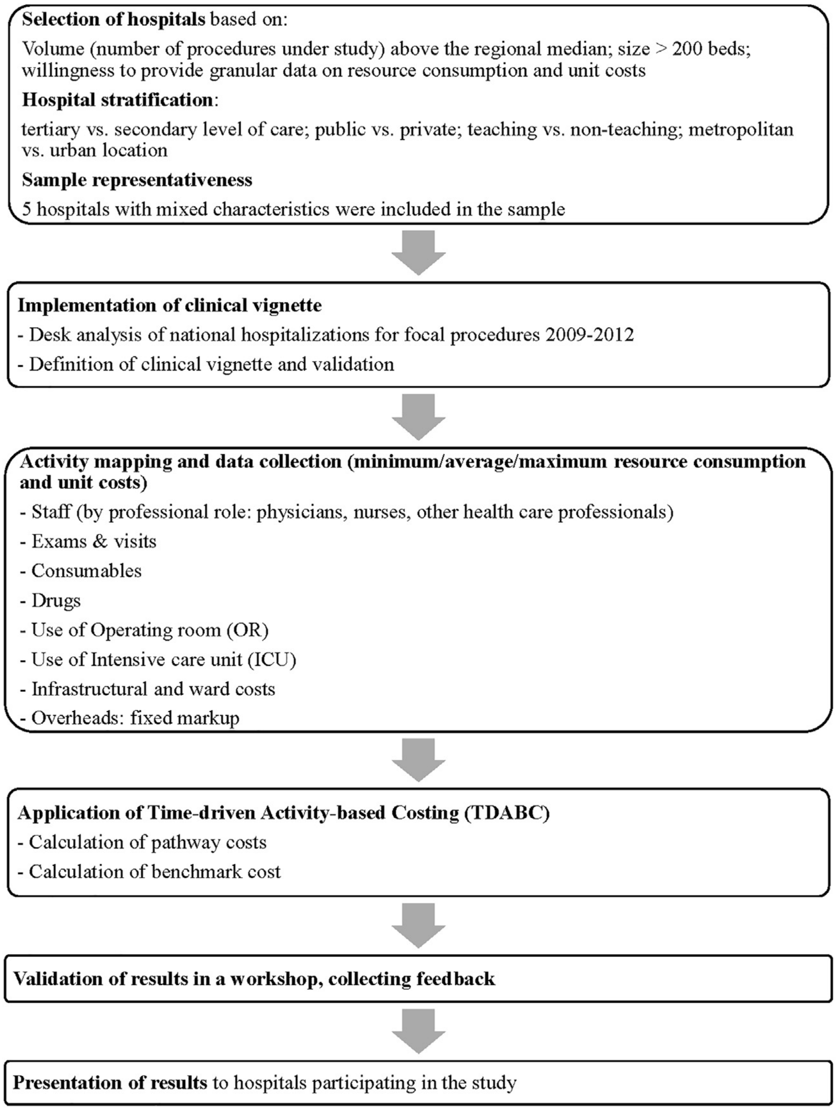


**Figure 1.** Study phases

validated by clinicians from participating study hospitals through pilot interviews. Since our goal was to collect information on the types and quantities of resources consumed to treat the vignette, clinicians were provided with a description of each fictitious patient representing a "standard case" in terms of age, sex, comorbidities, and patient admission mode, mirroring their complexity. The use of clinical vignettes is helpful when surveying hospitals characterized by clinical practice variability and differing levels of patient case-mix, technological innovation, and resource consumption,[28] additionally circumventing privacy issues related to accessing individual patient data.[27]

Subsequently, resource consumption to treat the clinical vignettes was measured in monetary terms using TDABC following a bottom-up approach. We followed the 7-steps indicated by Kaplan and Porter:[4] (1) selection of the medical condition (ie by designing the vignette, as indicated above); (2) definition of the main activities in the patient care episode; (3) identification of the process; (4) estimation of process time; (5–6) calculation of the capacity cost rate (CCR), that is, the actual cost per time unit of each resource, by considering also the burden of unused capacity (7) calculation of the total cost of patient care. More specifically, for activities mainly performed by staff, the time required to perform them was determined and multiplied by the cost per time unit.[8,19] Please note that, for the purposes of this study, the term *cost driver* is used synonymously with *duration/time driver*[21]; it basically expresses the *type of resource used in the care process*.[12]

In order to account for relevant nonstaff costs (eg, machinery, drugs, operating room (OR) sanitation), time data for OR use and inpatient length of stay (LOS) were collected and multiplied by the associated unitary costs, following studies showing inpatient LOS to be a relevant cost driver.[21]

Data was collected through structured interviews with health care professionals using each vignette with the head physician or a delegate (a senior electrophysiologist for heart rhythm devices and a senior cardiac surgeon for SAVR), a ward nurse coordinator, an OR nurse coordinator, and, limited to SAVR, perfusionists and radiologists. Supplementary Table S2 shows the information regarding quantity and unit costs of resources used in the different phases of the procedures (ie, preoperative, peri-operative, postoperative) collected through interviews with clinical staff and comptrollers. The tables used to collect data are also included in the supplementary materials (Tables S3 and S4). To capture variability in the cost functions across the sample, for each cost factor we collected information regarding minimum and maximum levels of consumption, allowing for the calculation of average values. For both minimum and maximum level of consumption of cost factors, we reported the average value (mean), standard deviation (SD), and coef-

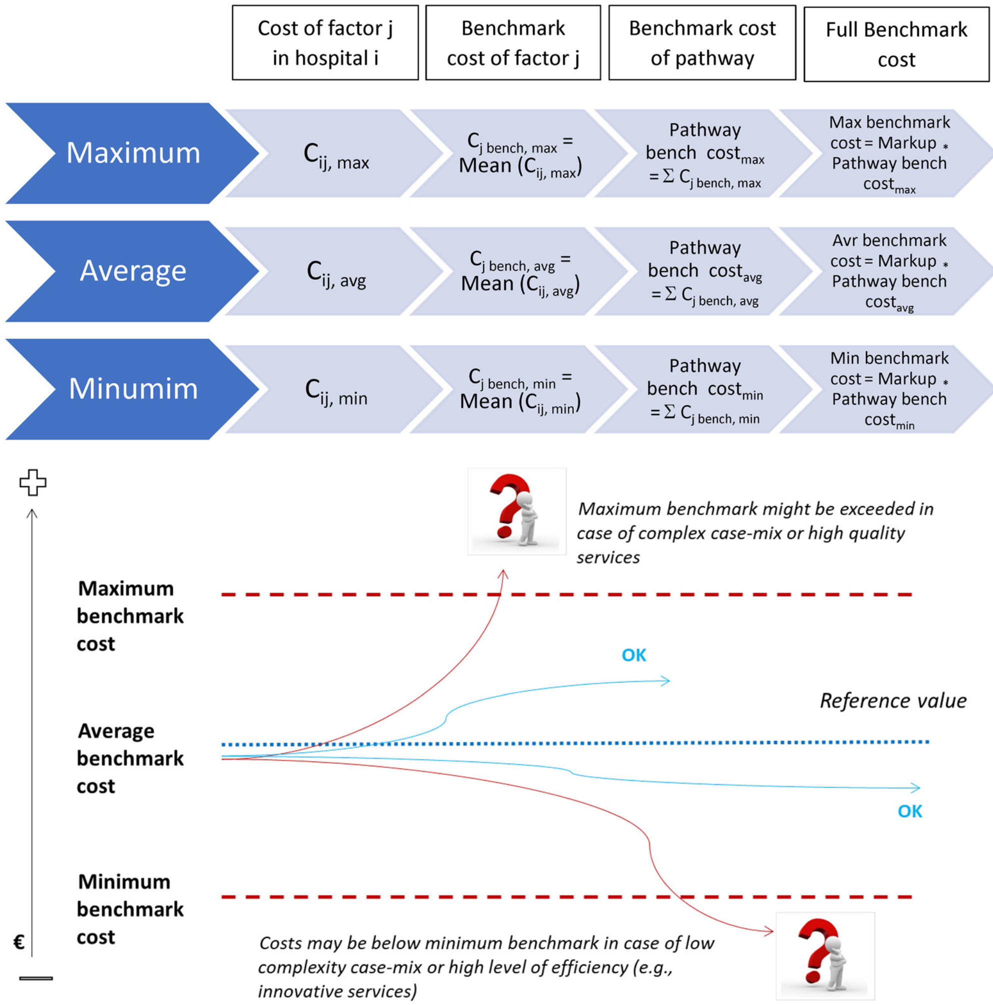


**Figure 2.** Method of calculation for the benchmark costs and interpretation of the results

ficient of variation (CV), a relative measure of dispersion calculated as the ratio of the SD to the mean. We did not collect information regarding the costs of implanted devices because the Lombardy regional contracting authority purchases them through regional tenders, and therefore the unit price is the same among all public providers.

Finally, to provide feedback to the hospitals and compare the range of services and costs across hospitals, we devised a calculation method for estimating benchmarks for full costs and their interpretation (Figure 2). The minimum benchmark cost can be interpreted as a baseline threshold, under which increased efficiency would likely lead to resource shortages. Conversely, overstepping the maximum benchmark could lead to resource-wasting. The average value, based on an average quantity of cost drivers, is instead a value that can be taken as a point of reference to avoid both inefficiencies and shortages (Figure 2).

To calculate the benchmark costs, we multiplied the minimum, average, and maximum resource consumption for cost factor *j* in each hospital *i* by its unit cost, thus obtaining 3 different time-driven, activity-based, costs (ie, $C_{ij\ min}$, $C_{ij\ avg}$, $C_{ij\ max}$). For each level of consumption (ie, minimum, average, maximum) we computed the benchmark cost of factor *j* by calculating the mean across the 5 hospitals. By summing up cost factor benchmark costs we obtained the minimum, average and maximum benchmark cost pathway. By multiplying the latter by the average general cost markups collected from the comptroller, we obtained the minimum, average and maximum full benchmark costs (henceforth benchmark costs) that can be allocated to the care process.

Once collected through the interviews, data were sent to the hospitals for validation. A meeting with the clinical and administrative staff of all the hospitals participating in the study was subsequently organized to discuss and interpret the results.

## Results

### *Activity Mapping*

Table 2 provides a summary of key time-related cost drivers for each of the 5 procedures, while Supplementary Table S5 reports the descriptive statistics (mean, SD and CV for minimum and maximum standard values) for the full range of time-related cost drivers assessed.

Hospitalizations in electrophysiology (EPH) show relatively standard patient journeys, with the maximum SD and CV in LOS reaching 0.8 and 22%, respectively. Conversely, the LOS for SAVR varies considerably across hospitals (ranging from 2 to 9 days in raw data, 5.6 to 6.2 mean days, with SD from 2 to 2.2 days and CV between 33% and 40%). During hospitalization, for all selected procedures the patient is assisted by a nurse and a healthcare assistant (or auxiliary nurse). Where the patient is in good or stable condition, the main physician activity is the daily visit, while admission and discharge days require more intense educational and administrative activity.

### *Operating Room Occupancy and Composition of the Surgical Team*

PMs and ICDs show similar OR occupancy, as does CRT-P compared with CRT-D. Across hospitals, the SD is quite remarkable for CRTs (up to 38–53 minutes) while CV reaches a peak of 37% for PM. OR occupancy

**Table 2**
Summary of key time-related cost drivers by procedure type, minimum and maximum standard values, by mean.

| Procedure | Pacemaker | ICD | CRT pacemaker | CRT ICD | SAVR |
|---|---|---|---|---|---|
| Ward length of stay (mean n. days) | 3.0–3.4 | 3.0–3.4 | 3.2–3.6 | 3.2–3.6 | 5.6–6.2 |
| Operating Room (OR) occupancy (mean n. minutes) | 85–139 | 94–140 | 142–221 | 148–227 | 300–364 |
| Total workload (mean n. minutes) | 600–930 | 632–941 | 854–1296 | 874–1317 | 3717–4458 |
| Physician time (mean n. minutes) | 159–276 | 171–283 | 295–469 | 301–476 | 913–1139 |
| Ward nurse time (mean n. minutes) | 190–263 | 192–265 | 194–272 | 196–274 | 1376–1537 |
| OR nurse time (mean n. minutes) | 170–278 | 188–280 | 284–442 | 296–454 | 748–865 |

ICD = implantable cardiac defibrillators, CRT = cardiac resynchronization therapy, SAVR = surgical aortic valve replacement.

for SAVR is heterogeneous among hospitals, with relevant SD in absolute terms (66–82 minutes) but limited in relative terms (CV = 18%–27%).

The composition of the surgical team varies accordingly with procedure complexity. In EPH procedures, the standard team is composed of 2 electrophysiologists, 2 nurses and 1 healthcare assistant. For SAVR, the team can include 3 or 4 physicians (1 anesthesiologist and 2–3 cardiac surgeons), 1 perfusionist, and 3 nurses, or, alternatively, 2 nurses and 1 healthcare assistant.

*Minutes of Healthcare Assistance*

PM and ICD show comparable workloads, with a 50% increase when switching from minimum to maximum workloads, depending on the variability of clinical practice. The same is observed for CRT-P and CRT-D. Supplementary Figure S1 shows the labor cost breakdown by professional profile. Physicians account for between 25% (SAVR) and 36% (CRT-P and CRT-D). Nurses absorb 55% to 60% of the total assistance, with substantial equilibrium between ward and OR activities for PM and ICD, prevalence of OR for CRT, and ward for SAVR. Healthcare assistants range from 9% to 14%. Interhospital variability is moderate, as indicated by SD and CV (25%–38%), but becomes more relevant for ward nurses (CV = 56%–71%) and electrophysiologists (25%–38%).

*Exams and Visits*

In general, all hospitals perform a common set of diagnostic exams and specialty visits (ie, medical consultation by noncardiologists). EPH procedures entail blood exams (mean range 2.6 to 3, SD range 1.0 to 1.7), electrocardiogram (mean: 1.6, SD: 1.0), chest radiograph (mean: 1–1.2, SD: 0.4–0.6), and, often, echocardiogram (mean: 0.6–0.8, SD: 0.7–0.8). SAVR requires a higher number of these exams, but also coronary angiography (mean: 0.8, SD 0.4), blood transfusion (mean: 0.2–1; SD: 0.0–0.4) and internist consultations (mean: 0.8, SD: 0.7). Heterogeneity in resource consumption is mainly due to inpatient LOS and clinical and organizational elements related to physician choice or hospital clinical guidelines on preoperational activities.

*Activity and Process Costs*

*Unit Costs*

Table 3 reports the average unit costs (per hour or per day) provided by the hospital comptrollers. One center was not able to provide OR unit hourly costs, so the mean and SD have been calculated according to the other centers. Staff costs show limited variance across centers (CV ranging between 10% and 13%) as salaries in public and private hospitals are regulated by collective bargaining. As expected, the most relevant gap is between physicians and HC assistants (the ratio between their hourly costs is 3.0). Daily costs of hospitalizations by wards show moderate variability (CV: 26%–34%); similar for ICUs (18%) and general costs (34%).

*Benchmark Costs*

Table 4 shows the full benchmark costs and components. PM and ICD full benchmark costs are quite aligned, ranging from a minimum of about €1400 (US$ 1544) to a maximum of €2000 (US$ 2220) per hospitalization. The same is observed for CRT-P and CRT- D, with the minimum about €2100 (US$ 2330) to maximum €2900 (US$ 3220). In terms of breakdown by cost driver for EPH procedures, staff costs represent 37% to 45% of full costs. Labor costs rise both in absolute and relative terms when switching from minimum to average to maximum benchmark, and moving towards more complex technologies (ie, from PM and ICD to CTRs). De facto, staff appears to be the key cost driver in determining the increase of full costs and costs per day of stay. The next most important cost driver, exams and visits, accounts for 14% to 21% of the full benchmark cost. The percentage of other relevant cost drivers, eg, use of the operating room (9%–12%), drugs and consumables (10%), and ward costs (6%–10%) show less variation among procedures and type of benchmark, in absolute and relative terms.

Regarding SAVR, full benchmark costs range from nearly €7300 (US$ 8103) to more than €8500 (US$ 9435). Staff costs range from 51% (benchmark minimum) to 61% (benchmark maximum) of the total costs. Labor drives the increase in full costs and costs per day of stay.

## Discussion

In this study we applied TDABC to patient pathways for 4 heart rhythm therapies (ie, PM, ICD, CRT-P, CRT-D) and SAVR in 5 large public and private hospitals in Northern Italy, to identify cost drivers showing the greatest interhospital variability in quantity and unit costs, determine the most relevant full cost components, and estimate benchmarks for full costs of selected patient pathways. We employed clinical vignettes for their ability to survey variability in clinical practice,[29,30] embedding the procedural risks and considering complexity drivers,[27] investigate adherence to clinical pathways and guidelines,[31] and address issues related to cross analyses involving different types of providers located in the same or in different countries, or for different categories of professionals.[32,33] The vignettes were designed to represent “standard” elective cases reflecting average age, sex, and comorbidity profiles derived from national HDR data, and were validated by clinicians across participating centers. By anchoring each pathway to a common, moderate-risk clinical scenario, we aimed to minimize variability attributable to case-mix differences and instead capture differences in organizational and clinical workflow choices. Nevertheless, though standardization in vignette studies inevitably reduces idiosyncratic real-world variability, literature shows vignettes can also deliberately embed multiple dimensions of risk and complexity (comorbidities, physiological scores, dynamic evolution of the case), and that clinician responses to such vignettes mirror their behavior with real, complex patients.[34]

We used TDABC as a means to measure resource consumption for the vignettes using established methods,[20] provide valid data and establish benchmarks for clinicians and administrators to examine variation among hospitals, evaluate processes, reduce costs, and drive change and improvement.[6] Activity mapping here showed little discrepancy among care pathways observed in the hospitals, allowing for consistent comparisons.

**Table 3**
Unit costs (€ 2015, converted into US dollars) by cost factor, for electrophysiology procedures and surgical aortic valve replacement.*

| Staff profile | N obs | Cost per hour | | | | |
|---|---|---|---|---|---|---|
| | | Mean (€) | SD (€) | Mean (USD)* | SD (USD)* | CV |
| Physicians | 5 | 58.5 € | 5.8 € | US$ 64.9 | US$ 6.4 | 10% |
| Nurses—OR | 5 | 27.3 € | 3.6 € | US$ 30.3 | US$ 4.0 | 13% |
| Nurses—Ward | 5 | 25.5 € | 2.8 € | US$ 28.3 | US$ 3.1 | 11% |
| Healthcare assistants | 5 | 19.4 € | 2.1 € | US$ 21.5 | US$ 2.3 | 11% |
| Healthcare technicians | 5 | 26.7 € | 2.9 € | US$ 29.6 | US$ 3.2 | 11% |
| **Setting** | **N obs** | **Cost per day (ward, ICU)** | | | | |
| | | **Mean (€)** | **SD (€)** | **Mean (USD)*** | **SD (USD)*** | **CV** |
| OR—EPH | *4* | *228 €* | *194 €* | US$ 253 | US$ 215 | *85%* |
| *Consumables* | *4* | *105 €* | *125 €* | US$ 117 | US$ 139 | *119%* |
| *Drugs* | *4* | *42 €* | *41 €* | US$ 47 | US$ 46 | *100%* |
| *Other costs* | *4* | *82 €* | *71 €* | US$ 91 | US$ 79 | *87%* |
| OR—SAVR | *4* | *228 €* | *175 €* | US$ 253 | US$ 194 | *76%* |
| *Consumables* | *4* | *86 €* | *63 €* | US$ 95 | US$ 70 | *73%* |
| *Drugs* | *4* | *32 €* | *30 €* | US$ 36 | US$ 33 | *93%* |
| *Other costs* | *4* | *110 €* | *88 €* | US$ 122 | US$ 98 | *80%* |
| Ward—EPH | *5* | *65 €* | *17 €* | US$ 72 | US$ 19 | *26%* |
| *Consumables* | *5* | *8 €* | *9 €* | US$ 9 | US$ 10 | *114%* |
| *Drugs* | *5* | *9 €* | *5 €* | US$ 10 | US$ 6 | *57%* |
| *Other costs* | *5* | *48 €* | *20 €* | US$ 53 | US$ 22 | *42%* |
| Ward—SAVR | *5* | *87 €* | *30 €* | US$ 97 | US$ 33 | *34%* |
| *Consumables* | *5* | *16 €* | *10 €* | US$ 18 | US$ 11 | *63%* |
| *Drugs* | *5* | *13 €* | *6 €* | US$ 14 | US$ 7 | *48%* |
| *Other costs* | *5* | *57 €* | *26 €* | US$ 63 | US$ 29 | *45%* |
| ICU | *5* | *369 €* | *65 €* | US$ 410 | US$ 72 | *18%* |
| *Consumables* | *5* | *143 €* | *60 €* | US$ 159 | US$ 67 | *42%* |
| *Drugs* | *5* | *124 €* | *30 €* | US$ 138 | US$ 33 | *24%* |
| *Other costs* | *5* | *102 €* | *23 €* | US$ 113 | US$ 26 | *23%* |
| General costs - markup | 5 | 15% | 5% | | | 34% |

EPH = electrophysiology; SAVR = surgical aortic valve replacement; ICU = intensive care unit; OR = operating room.
* All costs were estimated in 2015 Euros (€), the start of the observation period. For reporting purposes, values have been converted to US dollars (US$) using the average 2015 exchange rate reported by the European Central Bank (1 Euro = 1.11 USD).

*Clinical Versus Organizational Sources of Variability*

Interhospital variability observed in this study should not be interpreted uniformly as inefficiency. Differences in resource use may arise from clinically justified variation—such as patient monitoring intensity, anesthesia choice, discharge timing, or rehabilitation referral practices—or from organizational factors including staffing models, task allocation, operating room logistics, and local protocols. Because the clinical vignettes were designed to represent comparable moderate-risk patients, major case-mix differences are unlikely to explain the magnitude of variability observed. Therefore, distinguishing between clinically appropriate adaptation and modifiable organizational processes is essential for interpreting benchmark results and identifying meaningful opportunities for improvement.

Analysis revealed 4 areas of marked differences in drivers of costs across hospitals: LOS for SAVR, electrophysiologist and ward nurse workloads, type and number of diagnostic exams, and OR utilization. LOS in cardiac surgeries for SAVR showed the most evident differences among hospitals, ranging from 2 to 9 days in raw data, with a SD of 2.2 (Supplementary Table S5). When presented with findings, physicians explained that variations depend upon heterogeneous levels of care intensity and different patient pathways. Specifically, the hospital with the shortest LOS declared a particularly high intensity of inpatient care, *de facto* a subintensive care unit, for roughly 2 days, followed by discharge and transfer to a rehabilitation facility. Conversely, the hospital characterized by the highest LOS keeps patients longer in a traditional cardiac surgery ward, with no specific intervention by physical therapists. Of note, hospital rehabilitation after SAVR at the time of the interviews was considered “always appropriate” but not compulsory in official regional clinical guidelines (DGR 5118/16, annex 1, p. 21); therefore, both clinical management options were legitimate, at least at the time of data collection. However, subsequent European recommendations, including a 2020 position paper on cardiovascular rehabilitation, clearly support referral to comprehensive cardiac rehabilitation after SAVR and emphasize individualized risk stratification and clinical judgment when determining the appropriate setting.[35]

While rehabilitation should be offered systematically, the choice between inpatient, outpatient, or home-based programs should depend on patient-specific factors such as postoperative complications, ventricular function, comorbidities, frailty, and functional status. Therefore, the setting should not be rigidly determined by organizational practice patterns alone, but tailored to the patient’s clinical profile, safety needs, and rehabilitation goals to ensure appropriateness, efficiency, and equity of care. In this light, the variability observed in length of stay following SAVR warrants careful evaluation to determine whether it reflects appropriate patient-centered adaptation or differences in organizational processes. The benchmarking framework presented here is intended to support such evaluation, rather than to label variation as intrinsically inappropriate.

Though total interhospital variability in workload was limited or moderate, labor (minutes) of ward nurses (CV = 56%–71%) and electrophysiologists (25%–38%) showed considerable variability. In the former, the difference is due to the heterogeneous intensity of care, with LOS always between 3 and 4 days. In the latter, the variability in physicians’ workloads is linked to differences in OR occupancy for CRT implants, with a SD among hospitals of 38 to 53 minutes. This variability may likewise be attributed primarily to organizational factors rather than to inherent clinical variability, given that patients share a comparable profile consistent with the clinical vignette and all procedures are performed under local anesthesia. Diagnostic exams tended to in-

**Table 4**
Minimum, average and maximum benchmark (B) costs, with breakdown by cost driver and cost per day of stay (€ 2015 converted to US dollars).*

| Benchmark costs, minimum (min), average (ave), maximum (max) (€ / US$) | Pacemaker | | | Implantable cardiac defibrillator (ICD) | | |
|---|---|---|---|---|---|---|
| | MIN (€ / US$) | AVG (€ / US$) | MAX (€ / US$) | MIN (€ / US$) | AVG (€ / US$) | MAX (€ / US$) |
| Staff | 515 / 572 | 660 / 733 | 856 / 950 | 545 / 605 | 682 / 757 | 868 / 963 |
| Exams and visits | 285 / 316 | 290 / 322 | 296 / 329 | 239 / 265 | 245 / 272 | 250 / 278 |
| Consumables | 78 / 87 | 99 / 110 | 120 / 133 | 88 / 98 | 108 / 120 | 128 / 142 |
| Drugs | 52 / 58 | 58 / 64 | 69 / 77 | 54 / 60 | 60 / 67 | 71 / 79 |
| Use of OR | 127 / 141 | 164 / 182 | 202 / 224 | 137 / 152 | 174 / 193 | 210 / 233 |
| Use of ICU | - | - | - | - | - | - |
| Infrastructural and ward costs | 145 / 161 | 154 / 171 | 162 / 180 | 145 / 161 | 154 / 171 | 162 / 180 |
| Overheads | 185 / 205 | 220 / 244 | 263 / 292 | 186 / 206 | 219 / 243 | 260 / 289 |
| **Full benchmark cost** | **1387 / 1540** | **1645 / 1826** | **1967 / 2183** | **1395 / 1548** | **1640 / 1820** | **1950 / 2165** |
| *Cost per day of stay* | *462 / 513* | *514 / 571* | *579 / 643* | *465 / 516* | *513 / 569* | *573 / 636* |
| **Benchmark costs, min, ave, max (€ / US$)** | **Cardiac resynchronization therapy (CRT) Pacemaker** | | | **CRT ICD** | | |
| Staff | 796 / 884 | 1004 / 1114 | 1290 / 1432 | 814 / 904 | 1022 / 1134 | 1310 / 1454 |
| Exams and visits | 401 / 445 | 406 / 451 | 412 / 457 | 401 / 445 | 406 / 451 | 412 / 457 |
| Consumables | 127 / 141 | 157 / 174 | 186 / 206 | 129 / 143 | 158 / 175 | 187 / 208 |
| Drugs | 73 / 81 | 83 / 92 | 99 / 110 | 74 / 82 | 83 / 92 | 100 / 111 |
| Use of OR | 231 / 256 | 290 / 322 | 349 / 387 | 233 / 259 | 292 / 324 | 351 / 390 |
| Use of ICU | - | - | - | - | - | - |
| Infrastructural and ward costs | 153 / 170 | 162 / 180 | 170 / 189 | 153 / 170 | 162 / 180 | 170 / 189 |
| Overheads | 275 / 305 | 324 / 360 | 386 / 428 | 278 / 309 | 327 / 363 | 390 / 433 |
| **Full benchmark cost** | **2057 / 2283** | **2425 / 2692** | **2893 / 3211** | **2082 / 2311** | **2451 / 2721** | **2921 / 3242** |
| *Cost per day of stay* | *643 / 714* | *713 / 791* | *803 / 891* | *651 / 723* | *721 / 800* | *811 / 900* |
| **Benchmark costs, min, ave, max (€ / US$)** | **Surgical aortic valve replacement (SAVR)** | | | | | |
| Staff | 3681 / 4086 | 4009 / 4450 | 4508 / 4998 | | | |
| Exams and visits | 622 / 690 | 662 / 735 | 702 / 779 | | | |
| Consumables | 818 / 901 | 845 / 938 | 868 / 963 | | | |
| Drugs | 414 / 460 | 426 / 473 | 439 / 487 | | | |
| Use of OR | 402 / 446 | 445 / 494 | 478 / 531 | | | |
| Use of ICU | 102 / 113 | 102 / 113 | 102 / 113 | | | |
| Infrastructural and ward costs | 268 / 297 | 287 / 319 | 306 / 340 | | | |
| General costs | 972 / 1079 | 1043 / 1158 | 1139 / 1264 | | | |
| **Full benchmark cost** | **7278 / 8079** | **7819 / 8679** | **8537 / 9476** | | | |
| *Cost per day of stay* | 1103 / 1224 | 1103 / 1258 | 1186 / 1316 | | | |

* All costs were estimated in 2015 Euros (€), the start of the observation period. For reporting purposes, values have been converted to US dollars (US$) using the average 2015 exchange rate reported by the European Central Bank (1 Euro = 1.11 US$).

crease with LOS. Indeed, as long as the patient is hospitalized, constant monitoring continues, eg, standard tests like blood exams and electrocardiograms. Therefore, differentiation in care pathways can partially explain the variability in the number of diagnostic exams among hospitals, especially concerning SAVR (cfr. *supra*). However, data collection also showed considerable variability in the type of diagnostic testing and patient monitoring, suggesting a deeply-rooted heterogeneity in clinical approaches, the appropriateness of which would deserve further scrutiny.

Heterogeneity in the quantity of labor and diagnostic exams influences cost levels directly, since unit costs are substantially aligned as they depend, respectively, on collective bargaining and regional tariffs in Italy.[36] However, some cost drivers also register high differences in unit costs. For instance, OR utilization has a CV of 76% for EPH and 85% for cardiac surgery. Comptrollers explained such variations through a number of factors: degree of infrastructural and technological renewal, impact of depreciation; different clinical choices regarding drugs, consumables, and technological endowment; working principles of management accounting systems.

Regarding the second study aim (ie, to identify the most important cost components), labor emerged as the major cost driver for full costs and cost per day of stay for all EPH procedures (37%–45% of full costs) and SAVR (51%–61%), followed by exams, drugs and consumables. This is consistent with broader hospital accounting evidence from OECD countries indicating that personnel expenditure constitutes the largest share of hospital operating costs.[1,37] Labor costs were found to account for as much as 80% of full costs in a study employing TDABC in computed tomography,[38] and an international comparison using TDABC aiming to determine the drivers of higher costs in the United States, noted that the intensity and number of health professionals engaged in ICU care had a greater impact on overall costs than the price of individual workers.[22] In fact, our findings showed that, with similar labor and exams/visit unit prices, the intensity and length of hospital care had the greatest impact on costs, an important finding for policy interventions to contain costs and compare care pathways and identify best practices in different hospitals.

### *TDABC as a Lever for Workflow Redesign and Task Reallocation*

A central premise of TDABC is not only to measure costs, but to identify modifiable levers through which care delivery can be redesigned and improvement can be modeled over time.[4,6,14,16] In this perspective, the observed variability in staff time and the predominance of labor costs suggest opportunities for more rational workflow organization, including reassessment of task allocation across professional roles. Differences in physician and nursing minutes across hospitals indicate that selected activities—such as peri-procedural counseling, documentation, routine monitoring, and discharge preparation—may be distributed differently across centers. TDABC provides a framework to evaluate whether such tasks can be performed by the least resource-intensive appropriate professional category without compromising safety or quality.[6] By modeling alternative staffing configurations and workflow sequencing, hospitals can use TDABC prospectively to assess the impact of reducing unnecessary labor intensity while maintaining patient-centered outcomes.[6,13]

*Integration With Clinical Quality Metrics and Patient-Centered Outcomes*

While the present analysis focused on cost measurement and benchmarking, the structured pathway-level framework developed here can be conceptually aligned with established clinical quality metrics without requiring additional data collection in this study. For example, variability in length of stay, monitoring intensity, and rehabilitation referral practices could be interpreted alongside routinely collected indicators such as complication rates, readmissions, discharge disposition, and adherence to enhanced recovery protocols. Embedding TDABC-derived cost benchmarks within a broader quality assessment framework would allow stakeholders to distinguish lower-cost pathways reflecting genuine efficiency from those potentially associated with underprovision of care. In this sense, the benchmarking methodology is not intended as a purely financial tool, but as a platform for integrating cost transparency with patient-centered outcomes in a value-based healthcare perspective.

*Positioning With Prior TDABC Comparative Work*

Prior applications of TDABC in cardiac surgery and other procedural domains have demonstrated the feasibility of cross-institutional and cross-national comparisons to identify improvement opportunities, including work examining coronary artery bypass grafting and other high-complexity pathways across different health systems.[14–16] These studies have emphasized the role of labor intensity, staffing configuration, and workflow design as key drivers of cost variation. Our study builds on this comparative tradition by extending the analysis to multiple electrophysiology procedures and SAVR within a universal healthcare system, and by introducing a structured minimum–average–maximum benchmark interval designed to facilitate interpretability and practical application at the managerial and policy level. While prior studies have primarily focused on absolute cost comparison or international transferability, our approach emphasizes pathway-level benchmarking as a dialogue tool to support internal process redesign and tariff evaluation within and across hospitals.

The third research goal was to estimate an economic value interval including the appropriate full costs of the service to calculate minimum and maximum benchmarks for average costs for the 5 hospitals. By using TDABC here, we were able to address common problems in benchmarking related to care cycles, inaccurate allocation of costs to patients, and differences related to input prices.[6] We found PM and ICD implants as well as CRT-P and CRT- D to be quite aligned, even considering interhospital variability in care organization reported above. PM and ICD are well-established procedures, with the lowest care complexity and the lowest variability in cost driver utilization. CRTs show limited variability, mainly related to the surgical phase. SAVR is characterized by the highest complexity, intensity of care and variability in core aspects of the care process, even though patient profiles are substantially aligned. These considerations suggest the reliability of the EPH cost values for use in policymaking and evaluation within and between hospitals. While SAVR numbers require a more cautious approach, the results here can still provide reliable information to support efforts to improve care and efficiency in these and other hospitals nationally, as well as providing a comparison for other countries.

The fourth research goal was to propose a practical tool to support managers and policymakers in data interpretation and use. Some TDABC studies have already focused on cost deciles to identify, for instance, high-complexity patients.[39] However, prior to our research, structured but easy-to-use methods to compare cost values in multicenter TDABC studies were lacking. We do believe the benchmarking method we developed and applied throughout the research can facilitate, for example, internal reorganization and process redesign at the hospital level, as well as regulatory interventions (eg, hospital tariff updates) at regional or national levels.

A main limitation of the study is reduced comparability in terms of unitary costs of factors. For example, the allocation method of drugs between OR and other wards may differ among hospitals. Additionally, unit costs, technologies, and surgical techniques may have changed since the time these data were originally collected. Though unit costs may have changed, the analysis can still be replicated and updated and remains relevant. From a resource consumption perspective, technological innovation may have enabled more efficient use of resources, but again, the analysis is largely replicable and updatable. Additionally, technological innovation can be presumed to be adopted with similar timeframes in Italy's universal healthcare system. However, ad hoc surveys might be needed if the approaches have changed completely (eg, minimally invasive surgery for SAVR). Though they can be an important driver of variability,[40] physician preferences for devices and individual skill levels could also not be accounted for here. Other methodological elements of the study point to a need for additional analysis. First, it would be interesting to integrate the analysis by collecting the cost of the postacute care pathway, both in rehabilitation hospitals and in outpatient facilities, but also considering home healthcare approaches. Second, given the increasing burden of chronic diseases, especially among developed nations, full benchmark costs comparing patients with and without relevant comorbidities can be used to determine the effects on pathway costs of comorbidities such as diabetes, chronic obstructive pulmonary disease, etc. Third, full benchmark costs of the inpatient pathway can be easily increased by adding the cost of devices.

Finally, given the small number of hospitals (n = 5), formal multivariable adjusted analyses were not statistically feasible. Future research involving larger multicenter samples could model associations between specific workflow characteristics (eg, OR time, nurse workload, LOS) and cost variability.

## Conclusions

With reference to 4 heart rhythm therapies (ie, PM, ICD, CRT-P, CRT-D) and 1 cardio surgery treatment (SAVR), this paper provides a detailed picture of the most important cost drivers of interhospital variability of full costs. From a theoretical viewpoint and given the increasing importance of value-based healthcare, the study confirms the validity of the activity-based and time-driven methodologies of cost calculation and points to a need for applications of this methodology in healthcare to support decision-making. The work also provides relevant practical implications.

First, it offers insights for hospital managers and professionals aiming to reduce unnecessary variability in input use (eg, type of ward, number of diagnostic exams, hours of labor). As such, results and methods presented here represent a valuable dialogue tool connecting healthcare professional and managerial profiles, particularly the benchmarking method we developed and applied throughout the research.

Second, the paper proposes an economic value interval including the appropriate full costs of the service. Such a value is useful for national policymakers in charge of determining fee-for service tariffs that, in the Italian system, are fundamental to fairly remunerate private and public hospitals. It also offers insight to reflect upon nation-wide standards of care, like appropriate hours of assistance and adequate length of stay.

Third, in view of the full implementation of the Italian National Programme of Health Technology Assessment for Medical Devices (2023-25), our study contributes to improving the measurement of costs of healthcare services and procedures when innovative technologies are introduced into routine practice.

## Author Contributions

**AR, MC:** conceptualization, investigation, literature search, methodology, project administration, data curation, analysis, and validation, writing—original draft, writing—review and editing. **GC:** conceptualization, investigation, methodology, project administration, data review, writing—original draft, writing—revision, review and editing, **HB:** literature search, data analysis, writing—revision, review and editing. **RT:** conceptualization, funding acquisition, project administration, methodology, writing—revision, review.

## Data Availability Statement

The data used in this study were collected as part of a Time-Driven Activity-Based Costing analysis of cardiac interventions. All data have been fully anonymized and are stored securely in accordance with institutional and ethical guidelines. Due to the nature of the data and agreements with participating institutions, they are not publicly available. However, data sharing may be considered on reasonable request to the corresponding author, subject to review and approval by the relevant data governance bodies.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Co-authors Alberto Ricci, Marianna Cavazza, Rosanna Tarricone, and corresponding author Giuditta Callea report financial support was provided by Medtronic Italia in the form of an unconditional grant, with no role in the drafting and preparation or approval of this manuscript. Given her role as a topic editor for Clinical Therapeutics, Giuditta Callea had no involvement in the peer review of this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.clinthera.2026.04.024.

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