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ESTIMATION OF THE COST IN A PAEDIATRIC RADIOLOGY SERVICE USING TIME-DRIVEN ACTIVITY-BASED COSTING (TDABC)

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Abstract: Cost estimation is crucial for health accounts analyses in both developed and developing countries. This study aimed to determine a methodology on the issue of costing systems and costing methods applicable to all health services carried out on a large scale that by their nature have a limited variability of resources (time, materials, human resources, etc.). The authors used time-driven activity-based costing (TDABC). The average time of healthcare activities was estimated within the direct observation of the activities and interviews in a paediatric radiology service unit. Direct and indirect costs were calculated regarding the price per minute for each health service category. TDABC allows calculating the actual costs of radiology services. This method reveals a higher expenditure than that reimbursed by the national health service. The empirical study shows high costs for CT and Thoracic spine radiology under sedation, which the national health system does not take into consideration. TDABC can be used by healthcare managers to evaluate the level of costs and to compare the internal results with the reimbursement tariffs from the national health service.

Keywords: radiology, costs, drivers, TDABC, healthcare management.

1. Introduction

The use of diagnostic imaging services has increased due to its essential role in identifying diseases in patients (Jayawardhana & Welton, 2015). Moreover, Smith-Bindman, Miglioretti, and Larson (2008) stated that the speed and resolution for detecting diseases increase the number of computed tomography (CT). However, this is also related to the increase in patient demand and the need for medical surveillance for specific groups of patients with cancer.

For these reasons, the analysis of costs and healthcare accounting are essential factors to consider for healthcare goods and services to increase their acknowledgement between health providers (Kaplan & Porter, 2011; Organisation for Economic Co-operation and Development..., 2011). At the same time, cost estimations require standardised methodologies that allow for comparative analysis between different levels (*from the government level to the individual hospital department)* (Organisation for Economic Co-operation and Development, 2010). However, there is a limited awareness of the costs and information potential in the various healthcare sectors (Biancone, Secinaro, Brescia, & Calandra, 2019; Okike et al., 2014; Vijayasarathi, Duszak, Gelbard, & Mullins, 2016).

The introduction of the Diagnosis-Related Group (DRGs) as a tool to describe hospital productivity, requires accurate information on the costs of treatments (Fetter & Freeman, 1986). Therefore, the DRG is a system that classifies patients and is introduced as a more efficient cost management system. In particular, all groups of physicians are responsible for determining the number of resources needed to treat and perform all the clinical care of patients (Messori Trippoli, & Marinai, 2020). This information is functional for reimbursements that governments at the central level provide to healthcare facilities for the care they provided. Furthermore, each health service is linked with predetermined rates (divided by homogeneous diagnostic grouping) that are allocated for healthcare, and each hospital will have to assess whether its expenditure is higher or lower than the rate recognised by their health systems (Bellavia et al., 2012; Cinquini, Vitali, Pitzalis, & Campanale, 2009).

Different activities are carried out within a healthcare facility in its management (inpatients, outpatient), specialisation, actual times and complexity, thus generating difficulty in determining the cost of specific tasks (Sturmberg & Martin, 2013).

According to the literature, different categories of costs are considered crucial to building a precise analysis of any product or service (Finkler, 1994; Lo Martire, 2017; Suyer, Neumann, & Boles, 1992). For example, direct and indirect costs in hospitals are varied and correspond to the healthcare activities carried out to treat patients.

However, despite the theoretical premise, calculating costs in healthcare is still a critical issue, creating disagreements and problems between doctors and the healthcare personnel in charge of management control (Chapko et al., 2009; Ryan, Watson, & Amaya-Amaya, 2003). Although several researchers have defined specific

methodologies over time, such as Activity-Based Costing (ABC) and Time-Driven Activity-Based Costing (TDABC), the opportunities for strict empirical application have proved very difficult over time (Oklu et al., 2015). The problems are even more prevalent in specialisations such as radiology that require constant investment in new equipment, as well as the obsolescence and the number of examinations carried out over time (Jakovljević et al., 2013). Additionally, as Parikh et al. (2021) suggested, staff dealing with radiology should be included in financial education programmes as an extra-clinical competence essential for the management of radiology departments.

Therefore, drawing on the need to spread more expertise in terms of costs, this study will have three primary objectives:

(1) to map the most commonly used methods for calculating costs in radiology healthcare departments;

(2) to propose the use of the time-driven activity-based costing (TDABC) method through empirical analysis and an interventional case study at the Department of Radiology of the Bambino Gesù Children's Hospital (OPBG) in Rome (Italy);

(3) to compare the reimbursement rates (Campra, Orlandini, Amelio, & Brescia, 2021; Demeere, Stouthuysen, & Roodhooft, 2009; Keel, Savage, Rafiq, & Mazzocato, 2017) of the Ministry of Health with the costs incurred by the hospital.

This research aimed to contribute empirically to the current debate on costing methodologies in radiology departments. Finally, the results demonstrated the inadequate reimbursement by the National Health Service of those added-value services that are also performed to safeguard patients.

The remainder of the paper is structured as follows. Section 2 describes the current literature on cost methodologies such as ABC and TDABC. Section 3 defines the standard workflow and tools used. Section 4 presents the results obtained from the interventionist case study. Moreover, Section 5 provides an in-depth data interpretation, comments, and critique on the main findings, and Section 6 concludes with a summary of the main results obtained.

2. Literature review

2.1. Healthcare cost-accounting methods

The last few years have seen a gradual increase in the population's average age. Economic expansion and access to better healthcare have gradually improved health conditions in different areas of the world (OECD, 2004). This has also been the case in these extraordinary times; for example, during the COVID-19 pandemic, healthcare systems increased the average public spending on emergency health services by adopting hybrid management approaches (Haldane et al., 2021; Secinaro, Calandra, & Biancone, 2020). Therefore, the new reality required new procedures and increased health care costs (Cobianchi, Pugliese, Peloso, Dal Mas, & Angelos, 2020).

In general, costs can be fixed or variable. The former do not vary with the production level, and the latter change linearly with the production level (Finkler, 1994). Both fixed and variable costs can be classified as *direct* or *indirect*. In the first case, these values are directly attributable to the execution of an activity. At the same time, indirect costs do not relate to the event but to the structure where it is carried out and to the support functions that make it possible to carry out the activity in terms of administration, safety, quality, etc. (Lo Martire, 2017; Suyer, Neumann, & Boles, 1992).

Accurately quantifying fixed and variable costs is not easy, and there are several methods to be adopted. According to Chapko et al. (2009), two approaches can be used in cost estimation: top-down and bottom-up. These two classifications differ in the units adopted. For example, while top-down approaches use variables such as the number of days patients spend in a hospital, bottom-up approaches generally break down costs by individual health and administrative services used in patient care (Bellavia et al., 2012; Goldberg & Kosinski, 2011). This calculation method goes under the generic name of Activity-Based Costing (ABC), related to efficiency and adopted in laboratories (Niñerola, Hernández-Lara, & Sánchez-Rebull, 2021a).

However, researchers have studied and validated different methodologies over time. For example, ABC has been modified into a time-driven version by monitoring the costs of healthcare services throughout the period of care (Keel et al., 2017). Other statistical methodologies have been spread by allocating costs from top to bottom according to drivers and key performance indicators decided by healthcare managers.

Despite the spread of countless generic methods, as stated by Parikh et al. (2021), cost management in the radiology sector is more complex and relies solely on reporting. Therefore, radiology healthcare managers should consider strategic methodologies to validate the national health service or insurance revenue streams with departmental costs. The remainder of this section aims to describe specific methods applied in radiology departments.

2.2. Healthcare cost-accounting methods: a radiology perspective

The results of costing studies in radiology are various and related to different approaches. Cost-effectiveness studies (CEA) and cost-benefit analyses of radiology treatment are the most performed (Blackmore & Magid, 1997; Brown, Bryan, & Warren, 1996; Darlington et al., 2015). This method allows for comparing the costs of two treatments or examinations and has clinical implications. In other cases, the authors explained why radiologists should know and understand costs in their direct field (Rubin, 2017) or ways to increase transparency in cost methodology (Durand et al., 2015). The value of these studies is related to the calculation methodologies implemented. For this reason, top-down costing and bottom-up approaches are also implemented in radiology (Darlington et al., 2015; Hollingworth, 2005).

Firstly, the top-down approach demonstrates total expenditure by department (Finkler, 1994), however it could be challenging to calculate the cost of a procedure. Two methods are used: the expenses to charges (RCC) or relative value units (RVUs). RCC is strictly connected with charges – the total costs are considered at departmental level and divided by the total expenses for the observation period.

RVUs consider costs usually deriving from national databases, and the rates are created on average values, thus losing precision in the calculation (Rubin, 2017).

As demonstrated by Rubin (2017), in a simulation for two radiology departments, the results of the two methods are very different, because RCC is related to the real costs at departmental level, whilst RVU derives from the national benchmark. Thus, the two methods are not considered reliable if available individually.

Secondly, the bottom-up approach estimates resource utilisation costs involving many healthcare personnel and managers (Rubin, 2017). The method used is Activity-Based Costing, also called micro-costing, which identifies the cost driver and single-driver rate for each activity and considers the volume of units consumed or used (Frick, 2009; Goldberg & Kosinski, 2011; Hollingworth, 2005; Lanen, Anderson, Maher, & Dearman, 2010). An in-depth analysis of the intervention's cost is essential at departmental level for maximising the effectiveness of care and cost, but this method does not consider multiple costs within a single operation (Demeere et al., 2009; Rubin, 2017). Additionally, other authors stated that this method is deemed time-consuming and resource-intensive (Demeere et al., 2009; Kaplan & Anderson, 2003).

For these reasons, some costing studies used time-driven ABC (TDABC), which estimates the costs of each resource used for treatments when considering the activities over time. This method is also accurate because it focuses on the real-time activities carried out by healthcare personnel (Kaplan & Anderson, 2003; Keel et al., 2017; McLaughlin et al., 2014; Rubin, 2017). Moreover, the method allows building a process map under the patient care cycle (Kaplan & Porter, 2011) or single or multiple departments to describe costs and practical capacity (Chen, 2016; Demeere et al., 2009; Laviana et al., 2016) within hospital departments (Kaplan, 2014; Shankar, Hayatghaibi, & Anzai, 2020). As suggested by the results of Niñerola et al. (2021), the difference in the use of the two methods stems from the simplicity of application and the number of publications in recent years. Furthermore, TDABC as a cost-accounting method, could provide a clearer idea of costs, help healthcare managers to allocate resources and reduce waste of resources (Kaplan et al., 2014). In addition, the approach is more practical, valid, and scalable than ABC. Finally, academic indices regarding the number of publications and journals also indicate an increased interest in TDABC.

Despite the widespread interest in this methodology (Keel et al., 2017), few approaches and calculation methodologies consider the time and effectiveness of the activities performed in specific radiology departments, especially in Italy (Keel et al., 2017; Terje Geitung, 2016). Therefore, this study presents the application of the

TDABC method in a specific radiological department of the Bambino Gesù Hospital in Rome. The following section illustrates in six steps the technique used to study and analyse the information.

3. Methodology

This section describes the six working steps that allowed the research team to collect and subsequently analyse costs according to the TDABC method. Figure 1 summarises the followed process.

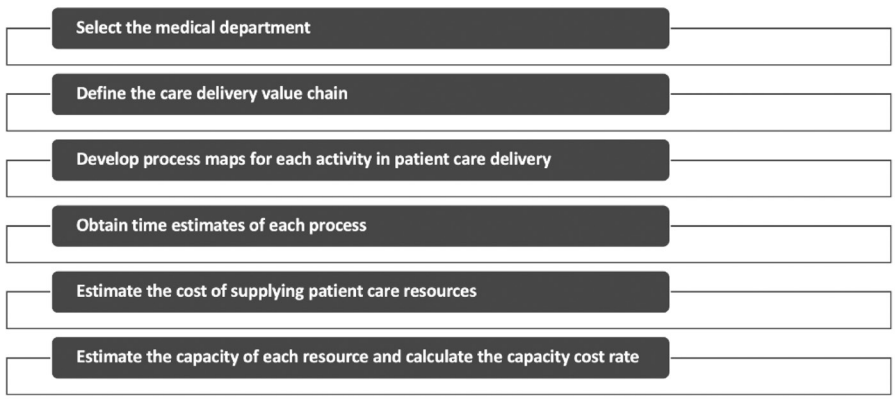

Fig. 1. TDABC steps

Source: authors' elaboration based on (Kaplan & Porter, 2011).

3.1. Selecting the hospital department

The clinical activities regarding patients in Italy are presented based on the tertiary care academic hospital OPBG, which, with its 607 beds, is the largest children's hospital in Italy. Since 1985 it has been known as an Institute for Scientific Hospitalisation and Care (IRCCS) and, additionally, in 2006 it was accredited by the Joint Commission International (JCI), the international body that certifies excellence in reception and quality of care offered (Biancone, Tradori, De Bernardi, & Brescia, 2018; Ciofi degli Atti et al., 2011). For this study, the department was chosen for multiple criteria.

First, the Imaging Department is considered an area characterised by large-scale and repeated healthcare activities.

Second, the performed activities have a limited variability of resources such as time, materials, and human resources. Consequently, the time associated with each health examination is easily standardised, which allows greater rigor and precision.

3.2. Defining the care delivery value chain

The care delivery value chain of the Imaging Department is implemented according to the typical path of patient care (Dal Mas, Piccolo, Edvinsson, Skrap, & D'Auria, 2020; Kaplan & Porter, 2011). Essential elements are the activities of monitoring and prevention. Moreover, diagnosis, preparation and intervention help in the recovery of patients by the medical and technical personnel (doctors, nurses, radiologists) attending to the patient. These tasks include administering the contrast medium, using the medical equipment and carrying out the follow-up visits of the patients. In particular, the healthcare activities carried out are Diagnostic Radiology, Conventional X-ray Fluoroscopy, Ultrasound, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Nuclear Medicine.

Additionally, other essential activities are performed by administrative staff who manage patient reservations and delivery of medical examinations.

3.3. Developing process maps for each activity in delivery of patient care

Patients accessing the Imaging Department may be outpatients or inpatients (in agreement with the public health service). In the first case, this means the patients admitted to the departments of the teaching hospital. In addition, patients not yet treated can also access healthcare services.

The activities can be divided into two groups (Maffioli, Mazzuca, Rota, Salvo, & Silvestri, 2004):

1) diagnostics;

2) therapy.

For diagnostics, outpatients approach the hospital by booking a medical examination (which is associated with the daily schedule and the specific order of the radiopharmaceutical or radioisotope), there is the subsequent administrative acceptance with the assessment of appropriateness and justification of the request (Jarritt, Perkins, Woods, 2004). The hospital administrative activities continue informing the patient prescribing the type of radiopharmaceutical. All these activities are ex-ante administrative activities.

Furthermore, after the quality control of the radiopharmaceutical and the administration, it is possible to carry out the prescribed examination. After this, ex-post administrative activities are carried out by processing the data acquired by the laboratory technicians and the preparation of the iconography end in the report. Finally, the delivery of the report regarding the patient is followed by the administrative filing of the document (Figure 2).

The second group, therapy, starts with the 'therapeutic proposal' to the patient that takes place with the collection of informed consent and the prescription of preliminary examinations (Monge, Perez, & Rein, 2013). Next, ex-ante administrative activities are carried on with the treatment planning, and the administrative order

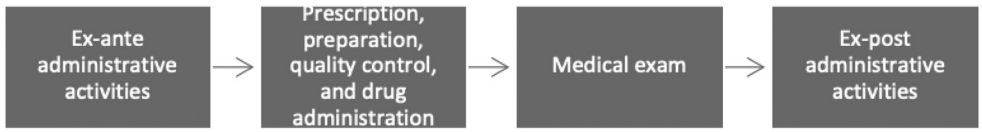

Fig. 2. The main activities for in vitro diagnostics

Source: authors' elaboration.

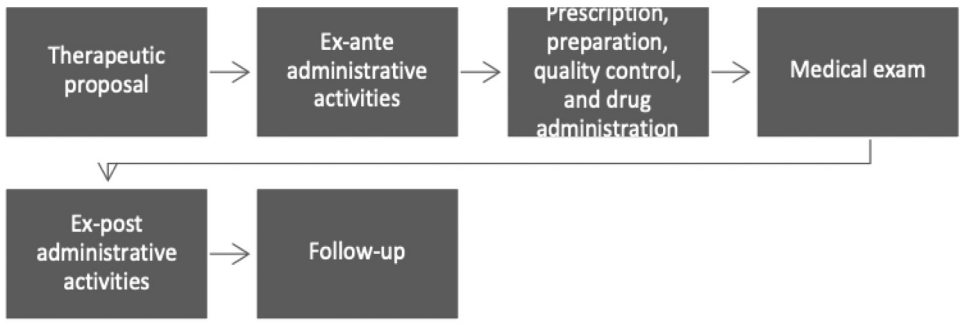

Fig. 3. The main activities for therapy

Source: authors' elaboration.

of the radiopharmaceutical takes place. After the acceptance, the medication and the radiopharmaceutical preparation, it is possible to administer to the patient. During the examination, the recording of diagnostic images is possible. With ex-post administrative activities, the delivery of the findings to the patient, the report is archived with the consequent discharge of the patient and the therapeutic prescriptions. Finally, follow-up is provided for those who have to repeat their exam or come back for another visit (Figure 3).

3.4. Obtaining time estimates of each process

This part concerns the estimation method of time spent with patients. Researchers implemented interviews and direct observations to determine the average time of health activities (Demeere et al., 2009; Keel et al., 2017; Secinaro, Calandra, Cappa, & Bignamini, 2020). In particular, interviews were conducted repeatedly while asking doctors and nurses to account for minutes spent on radiological examinations (DiCicco-Bloom & Crabtree, 2006). Special treatment was used for extraordinary examinations, which made it possible to keep track of even non-routine inspections that substantially impact the activities of the health personnel.

The following are the steps for determining the cost per minute:

1) survey of the services performed in one year by a single technique (conventional radiology, ultrasound, etc.);

2) survey of the average times of the different professional figures involved (radiologists, nurses, radiographers, administrative staff) for each type of examination;

3) calculation of the overall annual minutes for each performance obtained as a product between time per activity and the number of yearly events[1];

4) evaluation of the total worked time of the structure (Department of Diagnostic Imaging) that carries out the performances in question as to the sum of the annual minutes of each activity, see pt. 3;

5) assessment of the cost/minute (chosen as a unit of time) for each cost category as the ratio between the total cost of that category (depreciation, overheads, labour costs, etc.) and the whole minutes of activity of the structure that carries out the services in question. An exception is the direct material costs, which are punctually evaluated and not based on the time taken to perform the examination.

3.5. Estimating the cost of supplying patient care resources

The next step identifies the cost of a single service by determining the rate of a unit of time in a given operational structure which is then multiplied by the average time necessary to perform the whole service itself (Frasquilho et al., 2016; Kaplan & Anderson, 2003).

The direct costs, directly attributable to the performance of the examinations, were calculated as follows: the rate per minute of personnel (for each level) and the depreciation of the equipment used to perform the examinations was multiplied by the minutes of the examination. The material cost was recorded on a case-by-case basis for analysis.

Indirect costs were attributed to the structure using the percentage ratio between the cost of staff of the Department of Imaging Diagnostics and the total cost of personnel of the hospital. The cost shares thus obtained were divided by the whole minutes worked, thus obtaining the price per minute for each indirect cost category allocated to each service.

For a detailed calculation of direct and indirect costs, see Table 1 and Figure 4 below.

[1] The approach used takes one year as the reference period. However, considering the length of the time span, in some cases it was necessary to perform calculations over shorter time horizons, considering corrections or other factors that may affect fluctuations in the variables used in the calculation.

Table 1. Type and method of calculation of direct and indirect costs

Direct costs (Costs directly attributable to the performance of examinations)	Personnel costs Cost of work/minute of the Department of Imaging for the minutes of the execution of the single examinations (*not including supplementing and requires counting labour time*)
	Consumables the sum of the costs of the material used per single examination
	Depreciation of equipment in the Department of Imaging Diagnostics Administration / minute of the equipment of the Imaging Department for the processing minutes of the single examination
	Costs of Health Physics activities Value of Health Physics activities/minute of the Diagnostic Imaging Department for the minutes of processing of the individual examination. Cost of the Physicians/minute per performance of Nuclear Medicine
Indirect costs (all costs related to the structure)	Other materials, Diagnostic Imaging Dept. Cost/minute of material consumption for the processing minutes of the individual examination
	General expenses Cost per minute of General Expenses charged through drivers to the Imaging Diagnostics Department for the processing minutes of the single exam.
	Infrastructure depreciation Cost per minute of infrastructure administration for processing minutes of a single examination
	Personnel costs Cost per minute of non-health personnel for the minutes of processing of the single examinations
	Quality Certification Costs Cost per minute of quality certification procedures for the processing minutes of the individual examination

Source: authors' elaboration.

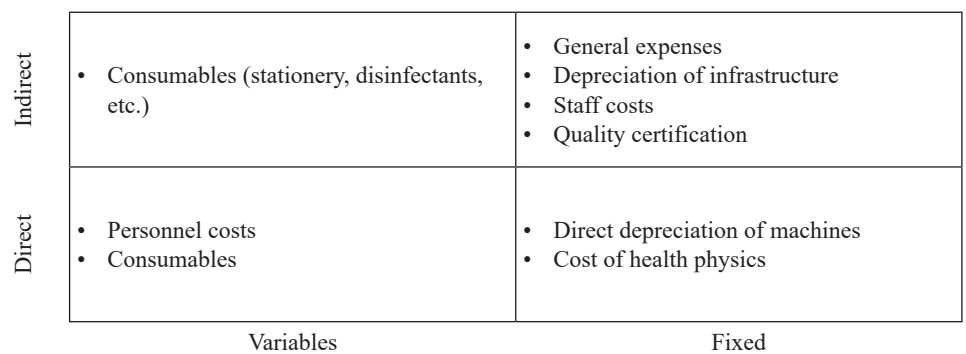

Fig. 4. Costs' matrix

Source: authors' elaboration.

3.6. Estimating the capacity of each resource and calculating the capacity cost rate

The activities of the Department of Diagnostic Imaging were evaluated based on data provided by the Department itself, by the Health Physics Service and by the Department of Anesthesiology, in terms of:

- average time of execution per examination per category of staff involved;
- average additional time for bedside examinations;
- number and type of studies performed with sedation;
- average time of activity of the anesthesiologists;
- average time of action of the Health Physicist for the Department;
- Average time of the Health Physicist for Nuclear Medicine;
- Average time of the Health Physicist for mandatory activities for the Department.

According to the proposed method, the first step was recording the time spent for examination. A survey of the services performed in one year was carried out. For each type of examination, the average time spent by the various professional figures involved was recorded, which, added together, gave the total time worked by the Department (Demeere et al., 2009; Keel et al., 2017; Rubin, 2017). In particular, the average time of services was measured by conducting face-to-face interviews with doctors and nurses after a radiological service had been provided (Brescia et al., 2019; Secinaro, et al., 2020). In addition, a dedicated register was created to track the time and number of extraordinary examinations given to patients.

Concerning the radiographers, the following calculation did not includ the *dead times* in which the radiographers are present 'at the disposal', such as those in the operating theatre or engaged in other activities.

After analysing the survey and recording the time of each operation, it was possible to determine the cost of each process by multiplying the time per cost rate (Rubin, 2017).

Given that:

- C_i = Cost per minute of a given cost category (personnel, depreciation, overheads, etc.)
- T_p = Average performance time
- M_d = Direct material

the Cost of Service (C_p) is:

$$C_p = \left(\sum_{i=1}^{n} C_i \times T_p\right) + Md$$

4. Results

4.1. Obtaining time estimates for each process

The observation of the activities carried out in the Department of Diagnostic Imaging allowed to obtain the number of staff and hence the time required for each process. The staff consists of 144 persons:

- 40 radiologists (of which seven freelancers);
- 12 administrative staff;
- 42 nurses (including six freelancers);
- 47 radiographers;
- 2 auxiliary staff.

The anesthesiologists of the Department of Anesthesiology, Critical Care and Pain Medicine support the activity of Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Nuclear Medicine (NM) for non-cooperative patients.

In this part, it is necessary to identify how much time is required for each exam. This is an essential functional step to calculate in the second part the cost per minute.

The number of examinations carried out in the Department in 2016 was equal to 155,738 for 9,494,912 minutes. The highest number related to "Standard chest X-Ray" with 23,971 examinations linked to a commitment of 841,596 minutes. Next, an MRI of the brain and brainstem amounted to 2,343 examinations for 390,838 minutes and an US of the lower abdomen with 4,332 examinations for 21,449 minutes, followed by CT of the thorax with 1,618 times for a total of 158,258 minutes. In addition, live dosimetry was performed 40 times for 35,672 minutes. Musculoskeletal ultrasound examinations were performed 539 times for a total of 28,532 minutes. Finally, for a segmented scintigraphy, followed by a total body scintigraphy, was completed 244 times for 22,402 minutes, radiography of the thoracic spine was performed 569 times for 20,945 minutes. Lastly, an Abdomen CT was carried out 49 times for 4,131 minutes and physical dosimetric study 25 times for 2,725 minutes. For more details see Table 2.

Table 2. The timescale for each examination and category of health operator

Examinations	Number per year	Number of radio-logists	Number of admini-strative staff	Number of nurses	Number of radio-graphers	Total	Total minutes per year
1	2	3	4	5	6	7	8
Abdomen CT	49	33	9	21	22	84	4,131
Thorax CT	1,618	36	9	31	22	98	158,258
Thoracic spine radiography	569	10	6	4	17	37	20,945
Standard chest X-RAY	23.971	7	6	4	18	35	841,596
Skeletal Survey	118	30	6	4	32	72	8,474

Table 2, cont.

1	2	3	4	5	6	7	8
US of the lower abdomen	4,332	20	9	18	2	49	211,449
Musculoskeletal Ultrasound	539	21	9	21	2	53	28,532
MRI of the srain and brainstem	2,343	75	9	36	47	167	390,838
Segmentary scintigraphy after total body scintigraphy	244	30	30	15	17	92	22,402
Physical-dosimetric study	25	90	30	0	2	122	2,725
Live dosimetry	40	90	30	140	632	892	35,672

Source: authors' elaboration.

4.2. Estimating the cost of supplying patient care resources: direct costs

In the second part of the TDABC method, the study estimated the cost per minute for both direct and indirect costs.

Firstly, direct costs include labour costs per minute which include the total annual cost per each year and the total minutes of activities per year; this is repeated for the four categories of health operators: radiologists, administrative staff, nurses, and radiographers. For radiologists, the annual labour cost was €3,398,974, the capacity in terms of minutes was 3,303,237; the radiologists' cost was 1.03 €/min. The annual labour cost of administrative staff amounted to €331,910, the capacity in terms of minutes of activities – €1,205,548; the administrative cost was 0.28 €/min. For nurses, the value of annual labour was €1,410,255, the capacity in terms of minutes of activities was €3,003,122; the nurses' cost was 0.47 €/min. Finally, the radiographers' annual cost was €2,123,556, the capacity for minutes of activities – €2,395,650; the radiographers' cost was 0.89 €/min. See Table 7 in Appendix 1 for a holistic view of the direct costs per examination.

Secondly, direct costs also include all healthcare consumption used by the Department to execute examinations, excluding drugs, contrast media and radiopharmaceuticals. The total amount of consumables was €186,667, while the capacity for minutes of activities – €10,092,218; the cost of consumables was 0.02 €/min.

Thirdly, the authors also considered also contrast media and radiopharmaceuticals, which are essential for computerised axial tomography (n = 4,835 examinations in 2016), magnetic resonance (n = 7,145), radiography (n = 1,930), and scintigraphy and nuclear medicine (n = 2,381). For computerised axial tomography, total costs are

€62,407, the full capacity per year was 614,393 minutes, the cost per minute – 0.10 €/min. The total costs for magnetic resonance were €50,212, the capacity in terms of minutes was 1,092,301; the cost per minute was 0.05 €/min. For radiography, the total costs were €49,358. The minute capacity was 69,343, while the cost per minute 0.71 €/min. Finally, the whole scintigraphy and nuclear medicine costs were €93,757, the capacity per minute was 710,024, and the cost per minute 0.13 €/min.

Additionally, the annual depreciation of the machines was considered. Annual amortisation of the equipment was €1,232,028, the total minutes per year was 10,092,218; the machine depreciation was 0.12 €/min.

Moreover, annual costs of service for machinery contracts and interventions were considered. The total fees for equipment maintenance were €919,778, the total minutes per year was 10,092,218; the equipment maintenance was 0.09 €/min.

Furthermore, the labour costs of the health physicist were calculated separately due to external contracts. The price for health physics was €127,416, and the total number of minutes per year of activities was 10,092,218; health physics cost was 0.01 €/min.

To conclude, additional costs for examinations under sedation, or not included in the price list, were considered. The total cost for the consumption of materials for anaesthesia which allows the execution of MRIs and CT scans on non-cooperative patients, was €145,146, total minutes per year of activities was 142,738; the additional costs were 0.74 €/min (Table 3).

Table 3. Direct costs

Direct costs	Specifications	€/min
Labour costs	Radiologists	1.03
	Administrative	0.28
	Nurses	0.47
	Radiographers	0.89
Cost of consumables	–	0.02
Contrast media/Radiopharmaceutical	Computerised axial tomography	0.10
	Magnetic resonance	0.05
	Radiography	0.71
	Scintigraphy and nuclear medicine	0.13
Machines depreciation	–	0.12
Equipment maintenance	–	0.09
Health Physics	External service	0.01
Additional costs	Sedation for non-cooperative patients	0.74

Source: authors' elaboration.

4.3. Estimating the cost of supplying patient care resources: indirect costs

Indirect costs were attributed to the unit using as a driver the percentage ratio between the cost of personnel of the Department of Diagnostic Imaging and the total cost of personnel of the hospital. The cost per minute was obtained by dividing the shares by the total number of minutes worked to be charged to each service. The department's consumables, not directly used for the execution of the examinations, were attributed to each examination by their cost per minute.

The percentage ratio was calculated as follows: the personnel costs were €7,329,356, annual personnel costs on the entire hospital amounted to €157,082,655. The share of expenses for the Department of Diagnostic Imaging was 4.7%.

Indirect costs include the cost of utilities (electricity, telephony, gas, water, heating), contracts (linen hire, cleaning, waste disposal, medical records management, secretarial services, sterilisation, security), accommodation for accompanying persons and fuel. Total general expenses for OPBG were €15,224,406 × 4.7% equal €710,359. The total minutes per year of expenses was 10,092,218, hence the cost per minute was 0.07.

Moreover, infrastructure depreciation includes the depreciation of buildings and plants, office machinery, equipment not assigned to the Clinic. Total amortisation of the hospital was €13,565,377 × 4,7% equal €632,950. The total minutes per year was 10,092,218, therefore the cost per minute – €0.06.

Furthermore, staff costs are not assigned to Clinical Departments, but to those who carry out their activities in support of their management, i.e. the staff not working in the health services were considered. The total staff costs of the hospital were €30,695,037 × 4.7% equal €1,432,207 for the Diagnostic Imaging Department. The total minutes per year was 10,092,218, thus the cost per minute was €0.14.

To conclude, costs for quality certification (ISO9000) were considered. The total cost was €15,333 × 4.7% equals €715. The total minutes per year was 10,092,218, thus the cost per minute was €0.0001 (Table 4).

Table 4. Indirect costs

Indirect costs	€/min
Cost of utilities	0.07
Infrastructure depreciation	0.06
External staff	0.14
Quality certification	0.001

Source: authors' elaboration.

4.4. Calculating the total cost of patient care

After estimating the cost per minute for direct and indirect costs, it was possible to calculate the total costs for each examination performed in the Department of Diagnostic Imaging of OPBG. Total costs were calculated in two steps.

First, all direct costs (personnel, external personnel, contrast or radio drugs, depreciation of machines, maintenance of machines, Health Physics, and additional costs in case of sedation) were considered. These costs derived from the methodology formulation, which includes cost per minute of a given cost category × average performance time. Additionally, the authors included the direct material costs to calculate the service cost.

Second, all indirect costs (consumption of other materials, general expenditure, structure's amortisation, external staff, and certification costs were considered. See Tables 5.1 and 5.2 for a detailed picture of total costs.

Table 5.1 Total direct costs

Examinations	Direct costs in euro							Total direct costs
	Personnel	External personnel	Contrast/ radio drugs	Depreciation	Maintenance	Health Physics	Additional costs	
Abdomen CT	65	2	0	10	8	1	0	86
Abdomen CT under sedation	65	2	0	10	8	1	20	106
Thorax CT	0	73	2	10	12	9	0	106
Thorax CT under sedation	0	73	2	10	12	9	20	126
Thoracic spine radiography	0	29	1	0	4	3	0	37
Standard chest X-RAY	0	27	1	0	4	3	0	35
Skeletal survey	0	63	1	0	9	7	0	79
US of the lower abdomen	0	33	1	0	6	4	0	44
Bedside Ultrasound	0	33	1	0	6	4	0	44
Musculoskeletal Ultrasound	0	36	1	0	6	5	0	48
Bedside Musculoskeletal Ultrasound	0	36	1	0	6	5	0	48
MRI of the brain and brainstem	0	138	3	8	20	15	0	184
MRI of the brain and brainstem under sedation	0	138	3	8	20	15	43	228

Segmentary scintigraphy after total body scintigraphy	0	61	2	12	11	8	0	94
Physical-dosimetric study	2,624	2,726	2	16	15	11	0	5,394
Live dosimetry	605	1,332	16	118	109	81	0	2,261

Source: authors' elaboration.

Table 5.2 Total indirect costs in euro

Examinations	Consumption other materials	General expenditure	Structure's amortisation	Staff	Certification costs	Total indirect costs	Total costs
Abdomen CT	0	6	5	12	0.01	23	109
Abdomen CT under sedation	0	6	5	12	0.01	23	129
Thorax CT	1	0	7	6	13.88	28	134
Thorax CT under sedation	1	0	7	6	13.88	28	155
Thoracic spine radiography	0	0	3	2	5.22	11	48
Standard chest X-RAY	0	0	2	2	4.98	10	45
Skeletal survey	1	0	5	5	10.19	21	100
US of the lower abdomen	1	0	3	3	6.93	14	59
Bedside Ultrasound	1	0	3	3	6.93	14	59
Musculoskeletal ultrasound	1	0	4	3	7.51	15	63
Bedside Musculoskeletal ultrasound	1	0	4	3	7.51	15	63
MRI of the brain and brainstem	2	0	12	10	23.67	48	233
MRI of the brain and brainstem under sedation	2	0	12	10	23.67	48	276
Segmentary scintigraphy after total body scintigraphy	1	0	6	6	13.03	27	121
Physical-dosimetric study	2	0	9	8	17.29	35	5,429
Live dosimetry	11	2	63	56	126.56	258	2,519

Source: authors' elaboration.

5. Discussion

The presented analysis describes the cost transparency for the Department of Diagnostic Imaging and its services. TDABC offers the possibility to evaluate the healthcare process and assess the value of patient care. As a result of the analysis, healthcare management can better organise the future costs for the department, also in light of the reimbursements of the national health service (Kaplan & Porter, 2011).

According to the rates currently applied for reimbursements provided in the Decree of the Commissioner no. U00313/13 "*Approval of the Regional Tariff Nomenclature for Outpatient Specialist Assistance Services*", the current tariff has a lower level than the real expenditure of the Department (see Table 6).

Table 6. Total costs vs national health reimbursements in euro

Exams	Total costs	Reimbursements	Δ
Abdomen CT	109	104	(5)
Abdomen CT under sedation	129	104	(25)
Thorax CT	134	124	(10)
Thorax CT under sedation	155	124	(31)
Thoracic spine radiography	48	17	(31)
Standard chest X-RAY	45	15	(30)
Skeletal survey	100	90	(10)
US of the lower abdomen	59	32	(27)
Bedside ultrasound	59	32	(27)
Musculoskeletal ultrasound	63	28	(35)
Bedside Musculoskeletal ultrasound	63	28	(35)
MRI of the brain and brainstem	233	248	15
MRI of the brain and brainstem under sedation	276	248	(28)
Segmentary scintigraphy after total body scintigraphy	121	25	(96)
Physical-dosimetric study	5429	30	(5399)
Live dosimetry	2519	112	(2407)

Source: authors' elaboration.

The analysis found that the cost of each process is higher than the level of reimbursements provided by the national health system. The main problem is related to the physical-dosimetry study, and live dosimetry is less considered by the health service due to the high cost.

More generally, the analysis addressed a problem regarding examinations under sedation. The healthcare system applies the same reimbursement without sedation

for abdomen CT and Thoracic spine radiology. This contributes to the higher cost of these two examinations.

This paper focuses on a precise methodology reporting the entire cycle of care in the department, contributing to the knowledge of healthcare managers and policymakers. At the same time, the authors compared the results with the reimbursement tariffs, which required the calculation of indirect costs (Keel et al., 2017).

Healthcare departments should consider this methodology as a standard tool for evaluating the cost of care and improving the standardised process. Additionally, national health systems should employ new and more innovative cost methodologies, such as TDABC, as an accurate measuring technique.

This paper, as every research, has its limitations, however they provide opportunities for pursuing interesting new avenues of future research. Firstly, this method required a multi-professional team to evaluate all the care cycles, so many researchers needed to implement an analysis. Secondly, the study was conducted in a single Italian hospital dealing with the care of children. Future studies could extend the sample of hospitals studied long-term to Italy and other countries in this setting. Thirdly, the study applied the TDABC method to a radiology department, one of the less complex medical services. Future studies could enlarge the sample and extend the analysis to ordinary and extraordinary wards to validate the results.

6. Conclusion

This analysis provides a detailed view of direct and indirect costs in the Imaging field. The authors applied the TDABC methodology in the Department of Diagnostic Imaging to value costs (Chen, 2016; Demeere et al., 2009; Laviana et al., 2016). According to Rubin (2017), Kaplan and Porter (2011) and Keel et al. (2017), this method also considers the cost of the effective time of procedures, and in this case the total minutes for activities include training, meetings and other support activities.

The main innovation of the study was to apply the methodology in a departmental context while considering the whole map of processes to enhance the value of patient care. As stated by Kaplan and Porter (2011), their first pilot study with a departmental cost-control system, TDABC made it possible to increase processes and restructure care delivery. These results and the reimbursement rates suggest that this kind of analysis should be repeated periodically to evaluate staff and management processes changes. In this sense, the article showed an underestimation of costs. However, these derive from a precise accounting of TDBAC, and should reflect the healthcare system including all the expense elements in the reimbursements.

Moreover, the public health service treats reimbursement on examinations involving patient sedation as standard as they are not recognised.

Thus this analysis also provides several theoretical and practical implications.

In terms of theory, the study contributes to the growing literature of TDABC as a cost-accounting method that considers costs according to the actual time frame of the healthcare professional. In addition, the authors show how the theoretical premise of the method can also be applied to a real case study of a paediatric radiology department.

The article revealed a gap between direct and indirect costs concerning national reimbursements in terms of the practical implications. Furthermore, it demonstrates that excellent healthcare departments that deliver high-quality services often do so on an internal accounting basis, thus adding to their internal budget.

This method is a real challenge for healthcare managers, policymakers, and personnel to manage healthcare expenditure and assess real healthcare activities and patient treatment (Shankar et al., 2020). Finally, these findings could be applied to inform all the stakeholders, especially in the case of future expenditure management.

Abbreviations

TDABC – Time-Driven Activity-Based Costing; CT – Computed Tomography; DRG – Diagnostic Related Group; CEA – Cost-effectiveness studies; RCC – Ratio of cost to charges; RVU – Relative Value Units; OPBG – Ospedale Pediatrico Bambino Gesù; IRCCS – Institute for Scientific Hospitalisation and Care; MRI – Magnetic Resonance Imaging; NM – Nuclear Medicine.

Competing interest

The authors declare that they have no competing interests.

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Appendix

Table 7. Direct costs per exam in euro

Examinations	Radiologists cost per exam (Cost per minute × Average performance time)	Cost depreciation per exam (Cost per minute × Average performance time)	Nurse cost per exam (Cost per minute × Average performance time)	Radiographer cost per exam (Cost per minute × Average performance time)	Personnel costs per exams
Abdomen CT	33 (1.03 × 33)	2 (0.28 × 9)	10 (0.47 × 21)	19 (0.89 × 22)	65
Thorax CT	37	2	15	19	73
Thoracic spine radiography	10	2	2	15	29
Standard chest X-RAY	7	2	2	16	27
Skeletal survey	31	2	2	28	63
US of the lower abdomen	21	2	9	2	33
Muscoloskeletal ultrasound	22	2	10	2	36
MRI of the brain and brainstem	77	2	17	41	138
Segmentary scintigraphy after total body scintigraphy	31	8	7	15	61
Physical-dosimetric study	93	8	-	2	102
Live dosimetry	93	8	66	560	727

Source: authors' elaboration.

SZACOWANIE KOSZTÓW USŁUG RADIOLOGII DZIECIĘCEJ Z WYKORZYSTANIEM RACHUNKU KOSZTÓW DZIAŁAŃ STEROWANEGO CZASEM (TDABC)

Streszczenie: Szacowanie kosztów jest istotnym elementem analiz rachunków zdrowia w krajach rozwiniętych i rozwijających się. Celem niniejszego opracowania jest określenie metodologii w kwestii systemów i metod rachunku kosztów stosowanych do wszystkich świadczeń zdrowotnych realizowanych na dużą skalę, które charakteryzują się ograniczoną zmiennością zasobów (jak czas, materiały, zasoby ludzkie). Stosujemy rachunek kosztów działań uzależniony od czasu (TDABC). Średni czas działań zdrowotnych oszacowano na podstawie bezpośredniej obserwacji działań i wywiadów w placówce radiologii dziecięcej. Koszty bezpośrednie i pośrednie obliczono z uwzględnieniem ceny za minutę dla każdej kategorii usług zdrowotnych. TDABC pozwala na obliczenie praktycznych wydatków na usługi radiologiczne. Metoda ta ujawnia wyższe wydatki niż te, które są refundowane przez państwową służbę zdrowia. Badanie wykazuje wysoki poziom kosztów w przypadku tomografii komputerowej i radiologii kręgosłupa piersiowego w sedacji, których krajowy system opieki zdrowotnej nie uwzględnia. TDABC może być wykorzystywane przez menedżerów służby zdrowia do oceny poziomu kosztów i porównania wyników wewnętrznych z taryfami refundacyjnymi krajowej służby zdrowia.

Słowa kluczowe: radiologia, koszty, nośniki, TDABC, zarządzanie zdrowiem.