

Time-driven activity-based costing and its use in health economic analysis: a systematic literature review

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Supplementary file 4 : Details on the adherence of the studies to the methodological framework and methods applied

	Step 2	Step 3	Step 4	Step 5	Step 6
Studies following seven-step methodological framework					
Study	Define the care delivery value chain (CDVC)	Develop process maps	Obtain time estimates for each process	Estimate the cost of supplying patient care resources	Estimate capacity cost rate (CCR)
[24] Thaker NG et al.	Clinical, administrative, and financial teams created patient-level process maps for the full cycle of care.	A data relationship management software algorithm was created to link each patient-specific clinical activity (based on CPT codes) with a process map.	Activity times for each step were documented by content experts, frontline staff, direct observation of personnel, and the institutional scheduling system	Average hourly rates were calculated for each personnel resource, based on the job code. Compensation data based on job codes were obtained from the institutional PeopleSoft (Oracle Inc, Redwood Shores, California) payroll application.	Practical capacity for equipment was estimated from institutional normal work week and number of hours and procedures per day. The total salary and benefit expense for a particular job group was divided by the annual number of work hours in a year and adjusted for non-productive and indirect work time. The

					adjusted average hourly rate was divided by 60 minutes to calculate the capacity cost rate.
[25] Dziemianowicz M. et al.	CDVC were defined from pre-consultation, consultation, to treatment for each treatment modalities.	Process maps were outlined separately for pre-consultation, consultation, and treatment phases and for different treatment modalities (IMRT, LDR, and HDR brachytherapy) based on the institution's practice.	Estimated the time it takes for each personnel to complete each step by interviewing each member of the team.	Estimated the cost of personnel, equipment, and supplies by accessing salary data, equipment purchasing information, and contacting medical centre administration to estimate facility costs. Salary amounts were based upon institutional published amounts for resident physicians; and median salaries reported by the Association of American Medical Colleges survey for attending radiation oncologist, urologist and anaesthesiologist. Equipment costs were based on the institution's real purchase cost and costs were spread over a 10-year horizon. For both BT and IMRT, we obtained 2016 Medicare reimbursement rates.	calculated the capacity cost rate for each staff member and item of equipment by dividing the annual cost by the capacity. Days off and hours worked per year were based upon institutional policies for vacation time and assumed a 40-hour work week except for 50 hours for physicians.
[26] Gaitonde S. et al.	Detailed each step in RUTI management based on observation, expert knowledge, and institutional practice.	Based on the CDVC the process map was developed , and for long-term RUTI management, index pathways	Provider estimates, CPT billing codes, published literature, and institutional data were used to estimate office-based processes. Observation and informal patient reports were used to approximate time spent for	Medicare Physician Fee Schedule database was queried for cost components corresponding to Current Procedural Terminology (CPT) codes. Medication and	Practical capacity was defined as time actively delivering care. Capacity cost rate (CCR) was calculated by dividing cost of resources by practical capacity. CCR was limited to individual processes, as a surrogate

		were extrapolated[36] .	patient-directed processes, such as time spent taking an oral medication or applying vaginal cream.	supplement costs were averaged from GoodRx, Walmart, CVS Pharmacy, Walgreens, Kroger, and Amazon pricing. Institutional data were used for all other costs. Total costs were tabulated from direct and indirect costs.	measure of cost-efficiency of each resource.
[27] Ning MS et al.	Process maps were developed through a multidisciplinary effort between clinical and administrative teams. It details an episode of adjuvant care for VCB, IMRT, combined modality RT	Personnel, equipment and planning software involved at were accounted for by input from attending physicians, administrative staff, other frontline clinical staff, and direct observation of clinic workflow.	The time required of each personnel member at each step was estimated through separate rounds of multidisciplinary panel interviews with staff members.	For each personnel member, cost data were pulled from the PeopleSoft (Oracle Inc., Redwood Shores, CA) payroll application and included salary, bonuses, fringe benefits, support, training, travel, and insurance expenses specific to our institution.	To calculate the CCR for each resource, the total annual cost for each personnel or equipment was divided by the annual availability of each resource. For personnel, available capacity was estimated by starting with the entire calendar year and subtracting time unavailable due to vacations, breaks, and weekends.
[28] Blumenthal K.G. et al.	It was defined each step along the outpatient penicillin allergy evaluation pathway in a process map by direct observation of patients.	We then identified the personnel, consumables, and space used for 30 unique patients presenting for penicillin allergy evaluation by direct observation of patients process.	Time was estimated by observing all 30 patients.	Personnel cost was determined by using regional and national averages to achieve more generalizable results. Medical consumables used at each stage were costed according to the acquisition cost to MGH. Space costs were calculated using the mean time patients occupied the examination room and	CCR was calculated using regional and national compensation data that included salary, payroll taxes, and fringe benefits. Allergists/Immunologists and other personnel were estimated to work 8.0 hours per day. ²⁷ Within each work day, we assumed 5% idle or break time for physicians and 10% idle or break time for other personnel.

				allergy testing space, Construction and renovation costs were incorporated by using the price per square foot.	
[29] Dutta S.W. et al.	CDVC were defined from pre-consultation, consultation, to treatment for each treatment modalities.	Process maps were outlined separately for pre-consultation, consultation, and treatment phases and for different treatment modalities (IMRT, LDR, and HDR brachytherapy) based on the institution's practice.	Estimated the time it takes for each personnel to complete each step by interviewing each member of the team.	Estimated the cost of personnel, equipment, and supplies by accessing salary data, equipment purchasing information, and contacting medical centre administration to estimate facility costs. Salary amounts were based upon institutional published amounts for resident physicians; and median salaries reported by the Association of American Medical Colleges survey for attending radiation oncologist, urologist and anaesthesiologist. Equipment costs were based on the institution's real purchase cost and costs were spread over a 10-year horizon. For both BT and IMRT, we obtained 2016 Medicare reimbursement rates.	calculated the capacity cost rate for each staff member and item of equipment by dividing the annual cost by the capacity. Days off and hours worked per year were based upon institutional policies for vacation time and assumed a 40-hour work week except for 50 hours for physicians.
[30] Schutzer ME et al.	Outlines were generated listing each process involved in the delivery of adjuvant radiotherapy. Data were obtained from	Process maps were then created for each process and displayed in Visio format. For every activity, the	Given the potential outliers among individual patient care cycles, time estimates were based on staff interviews rather than prospective patient data. Estimates were vali-	The annual cost was estimated for personnel, equipment, and physical space. Data were taken from published median salaries specific to	The capacity for both equipment and space was determined on the basis of their available clinical days per year and average minutes per day. For each resource, annual cost

	interviews with involved personnel and from observing clinic workflow.	involved personnel, facility space, and equipment were recorded, as well as the materials consumed.	dated by comparing them to data obtained from patient tracking.	Richmond, VA. For attending physicians, Medical Group Management Association data were used and residents' published salaries were used.	was then divided by annual capacity to determine the CCR.
[31] Suralik G. et al.	Created for each institution to represent all treatment steps involved in delivering CB-IORT and PB-IORT based on staff members input and observation.	For each step, the specific resources involved were determined based on input from staff members and by observation before and during treatment delivery.	The amount of time spent at each step was estimated through interview of staff members and corroborated with observations. Because treatment time varies among procedures, the personnel time estimates represent an approximate average per case	Annual personnel costs were determined from institutional salary and fringe benefit data from one institution, to allow comparison of dollar amounts without adjusting for interinstitutional salary variations. Equipment and facility costs were determined by the administrative department with 10-year time horizon	Capacity cost rates for each resource were calculated by dividing the annual costs by total annual capacity for the resource.
[32] Su L. et al.	Process maps were created to represent each step from initial consult to completion of therapy	The resources were determined through interviews with the involved staff and by observation of personnel, equipment, and consumable supplies	The amount of time spent at each step was estimated through interview of staff members and corroborated with observations.	Annual personnel costs were determined from institutional salary and fringe benefit data. Equipment and facility costs were determined by the administrative department with a 10-year time horizon for equipment (and annual service contract included)	Capacity cost rates for each resource were calculated by dividing the annual costs by total annual capacity for the resource.
[33] Mericli A F et al.	The process map for breast reconstruction illustrates patient flow through each phase of	It identifies the process along with the roles and responsibilities of	<i>Not clearly mentioned.</i>	The salary and fringe benefits for each employee listed in the process map were	The capacity cost rate of each employee was determined by dividing total compensation by

	care (preoperative, intraoperative, postoperative, and post discharge) in the ERAS process	the multidisciplinary team.		estimated from publicly available data published by the US Bureau of Labor Statistics. Facility costs were determined using DRG codes from the 2018 charge schedule of Akron General Hospital. Procedural costs were estimated using CPT codes for inpatients undergoing unilateral mastectomy and immediate microvascular breast reconstruction. Drug costs were estimated from the wholesale acquisition cost according to the 2018 Red Book	annual number of minutes worked per year.
[34] Bulman J C et al.	Accordance with detailed clinical staff interviews.	Accordance with detailed clinical staff interviews.	Utilization times were captured from electronic health record time stamps and staff interviews using validated techniques.	Clinical Staff interviews.	Capacity cost rates were estimated using institutional data and manufacturer proxy prices
[39] Alaoui S et al	An overall view of the care process was defined, including the following principal activities: diagnosis, care planning, intervention and evaluation of treatment results.	A more detailed process map was developed for each step in the care delivery value chain, mapping processes, activities and measurements throughout the care cycle,	The duration for each activity was estimated through time studies (observations and interviews) for each staff category (i.e. coordinating nurse, medical secretaries, psychologists and medical doctors). Besides, the time estimates were gathered from treatment software logged time that therapist spent	Data were collected from several sources, including administrative and medical staff, the payroll system, local business intelligence systems and the treatment software data-base, using 2013 as a reference year for salaries and overhead costs.	Practical capacity was estimated to be 80% of actual worked hours. Calculation of practical capacity was based on attendance and wages per employee, as indicated by the payroll system. Overhead costs were allocated over each staff category evenly per minute. Software costs for the treatment platform were allocated only to

		including personnel used in each step.	working online with each patient.		therapists. Costs for hospital space were calculated as the square meter price divided by floor space per staff category
[40] Ridderstrale M et al.	By interviews.	<i>No process map (graph) developed.</i> But interview was conducted with each member of the team to create process map.	Time was estimated based on interviews and estimation.	Cost drivers of the care delivery chain at the service were identified by interviews and estimation. Data were validated by the department secretary responsible for follow-up statistics and the nurse primarily in charge.	Cost per time unit was calculated straightforward without adjusting for idleness since researchers did not expect this to be a significant variable, or at least not differ between the alternatives.
[41] Keel G et al.	Meeting with clinical staff, contextual observations, and e-medical records.	Meeting with clinical staff and contextual observations. R software was used to generate process maps. Each process map was presented to staff to minimise reporting biases.	Staff provided their own time estimates for each step, and later they were shown time estimates from contextual observations. Differences were discussed and appropriate modifications were made to produce the final maps.	Hospital accounting sheets, and BI firm accounting sheets.	CCRs were calculated for nurses, doctors and USKs. Breaks were removed from clinical time for all staff, according to the controllers' recommendation, at a rate of 1 hour/day per FTE. Hospital HR sheets data were used.
[42] Dowd WN et al.	From semi-structured interviews with providers and other staff at the participating hospitals and in the surrounding communities.	Process map was developed for four different health states of dementia (Mild, mild-moderate, Moderate-severe, and Severe)	Gathered through field observations and semi-structured interviews	Vignette approach was employed as the basis for cost estimation and transition through the stages of dementia. Obtained estimates of provider salaries from publicly available health and social care system data. Specific and accurate overhead cost data were provided by	Used provider cost and overhead cost information to estimate a monthly cost of care under the standard of care for each of the four disease states of Dementia.

				the finance/costing departments.	
[43] Doyle G A et al.	Vignette based interviews with clinical staff along with the care pathway was conducted to get answers on who/what/how long of the process and validated by senior clinical staff.	Vignette-based data collection helped to develop care pathway and cataloguing of all the resources that feed into the process of care.	A standard survey instrument was administered to key clinical and administrative staff at primary, secondary and tertiary levels via face-to-face semi-structured interviews.	Interviews were conducted with members of finance department to find out the standard costs lists and overhead costs of all activities, resources, and personnel.	This resource total is then divided by the actual practical capacity of the resources in the care pathway. Practical capacity is calculated as 80% of the overall working time where 20% is attributed to breaks, training and annual leave.
[44] Kenny C et al.	Literature review was used to map the care and was verified by the consultant rheumatologist.	Vignette-based estimate for each patient profile and literature helped to draft process map and verified by consultant rheumatologist.	Interview with staff	Interview with staff. Annual salary and stipend paid by the Health Service Executive; Ireland was referenced.	Capacity per day was calculated by assuming an 80% of a standard 37-h work week. Finally, practical capacity per month was calculated using the practical capacity per day and the number of days worked per month.
[45] Marx T et al.	Discussion with local team members within the ED and walk-in-clinic for each respiratory condition.	Developed based on the CDVC and validation from on-field observation of patients and time-measurement. Map was developed from ambulatory arrival to reassessment.	Observing patients and measuring duration of the process using time-motion software.	Discussing with local team, administrative team and from electronic medical records.	Obtained by dividing yearly expenses for a cost element by the total yearly number of minutes worked in the facility. The minutes excluded vacations, meetings and breaks. CCR was calculated for human resources and equipments, consumable supplies, overhead, and medication.
[46] Nabelsi V et al.	Information was obtained during interviews with the oncology team at hospital and then validated with a manager and the radiation oncologist	Based on the CDVC, the detailed process map/process of a care trajectory was developed.	Gathered in interviews with the oncology team and validated according to each group of activities.	Data from the finance department helped to extract data to determine the total cost of the direct resource groups and their practical production capacity. Based on the employees'	Actual worked time by employees, without overtime were extracted from the system, which corresponds to the individuals' practical capacity. From these hours, break time of 30 minutes a day per person was deducted.

				identification numbers, annual salaries, including all benefits and payroll taxes paid were extracted.	
[47] Lievens Y. et al.	Activities in the process of providing EBRT to a specific patient, from first consultation, over treatment preparation, delivery and quality assurance to treatment completion, were included.	<i>Not provided</i>	Time data for treatment-related activities were measured or reported by the personnel concerned. Bottom-up calculations were performed multiplying time by the number of times each activity was performed annually. It was not realistic to perform time measurements for all activities; hence we relied on self-reported time estimates for noncore and out-of-scope activities.	The study followed the guidelines of the Belgian Health Care Knowledge Centre (KCE) “Manual for Cost-Based Pricing for Hospital Interventions”. Average annual wage costs from the KCE manual were applied to each fulltime equivalent. For equipment costs, the actual purchase price was used. For overhead costs the hospital-wide overhead proxy from the KCE manual was used.	<i>Not mentioned.</i>
[48] Nevens D. et al.	Belgian college for Physicians in Radiation Oncology database report and expert estimates.	Only provided in the table but has referenced previous research that has used same model provided with process map..	Obtained from Belgian college for physicians in radiation oncology database and expert opinion obtained through modified Delphi consensus. Time of equipment occupation is assumed to equate the time of involved personnel.	Data were extracted from Belgian college for Physicians in Radiation Oncology database report and expert estimates.	Available time of 80% of the theoretical paid time accounts for unplanned breaks, sick leaves. Data were extracted from Belgian college for Physicians in Radiation Oncology database report and expert estimates.
[49] Bartakova J. et al.	Overall costs, time and resources used to implement INTERCARE were calculated for the preparatory, transitional and intervention periods.	<i>Not provided in the article.</i>	Time estimates were collected by self-developed questionnaire and survey with Nursing home managers.	Using a self-developed questionnaire, we surveyed the managers of the participating NHs via e-mail to determine costs and revenues associated with residents’	The intervention costs were expressed as the average yearly INTERCARE nurse salary per bed during the intervention period; intervention time was expressed as average employment percentage per INTERCARE nurse; and

				hospitalisation. We asked every NH for their price list of services provided to residents for the years 2017–2020 and relevant information about hospitalisations' impact on their revenues.	intervention resources were given as average number of INTERCARE nurses per 100 beds. We assumed that all INTERCARE nurses had a 13th month salary and that employment percentages and pay rates remained constant over the period and year, respectively.
[50]Li B. et al.	An episode of care was defined as initial consultation to completion of the last day of radiation therapy.	Process maps were outlined with the radiation oncology department chair and chief medical physicist and then verified with multiple in-person interviews of different staff across each phase of care.	Calculated by sitting with radiation oncology department chair and chief medical physicist and then verified with multiple in-person interviews. Some process times were reported as ranges depending on the experience of radiation oncologists and medical physicists performing the role.	Salary for personnel and purchase and maintenance were obtained from administration data and weighted average were applied to process maps. The purchase cost per year was calculated based on the purchase cost and expected lifespan of the equipment, and maintenance costs reflected current contractual annual fees.	The annual salary before income tax reductions was divided by the number of minutes worked per year to obtain the personnel CCR. For each equipment, total minutes in use per year was calculated based on number of weeks in use per year. The annual equipment cost was divided by the number of minutes in use per year to obtain the equipment CCR.
[51]Duan K.I et al.	Identified through key informant interviews with medical personnel and direct observation of patients receiving care	Process maps were developed for both Diabetes usual care process and for community-based care program.	Duration of each activity was calculated through key informant interviews with medical personnel and direct observation of patients receiving care.	Staff time was valued at full salary cost, including benefits. Costs were obtained from organizational budget, price lists from actual vendors, publicly available government pricing lists. We adopted a societal perspective and included the opportunity cost of all	<i>Not clearly mentioned how they calculated CCR.</i>

				involved individuals (including patients)	
[52] Rognoni C et al.	Online interview were performed with vascular surgeon and her staff to describe all activities involving staff and patient flows from patient admission to its discharge.	Face-to-face interview was performed with vascular surgeon to validate and finalize the process map. Process map included personnel and clinical resources, and time estimation required in each step of the care cycle.	Online interview, face-to-face interview and in-depth observation of patients were carried out to estimate the time.	The cost data for personnel, goods and services, spaces and technologies were gathered through the help of administrative office at Hesperia Hospital.	The capacity cost rate for each resource and process step was calculated as the euro per minute capacity cost rate for all the clinical resources absorbed by the process steps. For healthcare personnel, costs were computed by multiplying the minutes spent in each phase by the wage per minute for each role.
[53] Goh OQM e al.	These were created in consultation with experienced clinicians, nurses, and allied health professionals.	These were created in consultation with experienced clinicians, nurses, and allied health professionals.	obtained time estimates from interviewing a range of experienced clinicians, residents, nurses, allied health professionals, administrative staff, and ancillary health care staff.	Consulted the hospital's human resource department to determine wage-per-minute estimates based on annualized wages	consulted the hospital's human resource department to determine wage-per-minute estimates based on annualized wages, taking into account individual benefits, bonuses, and the annual wage supplement in 2022.
[54] Keyrilainen J. et al.	Developed based on the direct implementation and observation of the process.	Based on the standard clinical practice at the Department of Oncology and Radiotherapy of Turku Uni Hospital.	Direct observation/practice. The durations of imaging for RTP were determined by timing 10 MRI and 12 CT sessions for RTP, respectively and, the duration of image registrations was determined by timing 10 cases. The durations of structure contouring on CT and MRI images were obtained from our previous studies.	The costs of the selected workflow steps were calculated by multiplying the mean time spent in completing the step by the capacity cost rate of the personnel resource used in the step. The prices of the scanners and their maintenance contracts were average prices	The CCR for each occupational group was obtained by dividing the annual salary costs by the annual working time of the occupational group. For the sake of simplicity, overhead expenses, e.g. electricity and cleaning, were ignored in this study.

				based on seven recent offers from different vendors at various hospitals in Finland.	
Studies following eight step methodological approach					
	Map the process: the care delivery value chain	Identify the main resources used in each activity and department	Estimate the total cost of each resource group and department	Estimate the capacity cost rate	Analyze the time estimates for each resource used in an activity
[35] Vargas D.F et al.	Observation of the steps of the procedure and interviews with professionals involved in the process.	For each activity mapped, the resources involved were identified: professionals, unit structure, ECP kit, exams and supplies using same method in step 2..	The capacity of the hemotherapy unit was determined in hours and the unit's operating time with medical professionals was considered. The mean salary, examination fees, and ECP kit purchase value were considered. Data were obtained from financial department.	Based on monthly cost of hemotherapy unit and monthly capacity, the unit cost rate was obtained by dividing the cost of the hemotherapy unit by the hourly capacity of unit's physicians. The cost of staff training was not considered.	The time required to conduct the sessions was determined by the observation of the procedure and interviewing the responsible physician and nurse.
[36] Da Silva Etges A. et al.	Mapped based on the interviews with coordinators and executors of the "TeleOftalmo Project".	Data on resource consumption and the TelessaúdeRS infrastructure at all points of care were mapped on the basis of the identified flow of activities mapped from interviews.	The median cost per telediagnosis was presented. This information was obtained from the TelessaúdeRS financial department, considering the average cost observed in the preceding 12 months. For human resource costs, data on salaries, fees, and benefits were obtained from TelessaúdeRS. For face-to-face care, and an analysis of the cost of a municipality that has its own government-funded service.	For telemedicine, the hourly costs of human resources were thus calculated considering the contracted workload and an expected idle. For face-to-face, the mean cost per patient encounter was defined as the cost per diagnostic encounter with a specialist ophthalmologist.	Time data were collected from TeleOftalmo databases for the last 2 years. Calculated median times were subsequently confirmed by the TeleOftalmo providers. For face-to-face care, a survey of municipal contracts for specialist ophthalmology services was carried out.

[37] Vargas Alves R J et al.	Patient accounts and electronic medical records were evaluated to identify the departments that the patients most frequently attended. The main activities of each department were mapped.	Based on the step 2, interviews were conducted with physicians and nurses to identify the professionals involved in each activity.	The workload data for each professional involved in the activities were retrieved after consultation with the hospital's personnel department. The resources involved with the structure were extracted from the Tasy© software report. Then the total cost of each resource group was calculated.	The practical capacity of the care workforce was calculated based on the monthly workload information of the employees, department structures was calculated based on the working hours and resources available for clinical appointments, such as clinical offices and hospital beds. A practical capacity adjustment of 80 percent was considered for calculating the actual practical capacity.	Chrono-analysis was performed with the direct observation of patients.
[38] Da Silva Etges APB et al	The care cycle was mapped by a multidisciplinary team that includes health professionals from the participating blood centers and researchers in the field of health technology assessment	Clinical records on the electronic medical records of a sample of patients were studied to identify activities routinely performed during the care cycle.	Financial data were obtained from institution's finance department. Financial data include fixed costs for operating the structure, such as electricity supply, depreciation, taxes, support materials, expenses with health professionals by professional category (wages and taxes), and expenses with the purchase of supplies and medications.	For capacity data, the number of beds and chairs available to serve the population and the operating hours of the patient care unit were used for estimating the capacity of the blood centre structure. For data on professionals' capacity, the mean workload established per professional category was considered, and as recommended on cost management literature an expected 20% inactive time within this workload was discounted.	To collect and analyze the mean length of time spent by patients in each activity, the health professionals involved in the care pathway collected time data during their routines in the blood centres of São Paulo and Ceará. In the blood centre of Rio de Janeiro state, mean times from the other two other centres were used due to data unavailability

[55]Dittrich L.B et.al	The study team mapped the care flow based on the hospital's ischemic stroke care routines and protocols, validated by a vascular neurologist. Process map was developed including five microphases across the care pathway: emergency, general ward, angiography, intensive care unit, and stroke unit.	The resources consumed in these phases were identified based on the ischemic stroke care routines and protocol, and interviews with professionals.	Labour costs were calculated based on the monthly salary of each professional plus their benefits, considering the volume of consultations across the identified phases. Fixed monthly costs of space were used for hospital infrastructure. Data acquisition involved reviewing financial reports from hospital departments.	The capacity of each department's space was estimated based on room and bed availability, while the contracted workload determined labour capacity for one month. To account for inherent process losses, 85% of the installed capacity was considered for both resources.	The average time for each patient consultation was estimated through employee allocation scales, interviews with professionals, and hospital guidelines. Interviews with department managers and hospital productivity reports determined the time spent in each department per patient.
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