### Study Protocol: Time-driven Activity Based Costing of Multi-Vessel Coronary-Artery Bypass Grafting Across National Boundaries to Identify Improvement Opportunities

<table>
<thead>
<tr>
<th>Journal</th>
<th><strong>BMJ Open</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manuscript ID</td>
<td>bmjopen-2015-008765</td>
</tr>
<tr>
<td>Article Type</td>
<td>Protocol</td>
</tr>
<tr>
<td>Date Submitted by the Author</td>
<td>14-May-2015</td>
</tr>
<tr>
<td>Complete List of Authors</td>
<td>Erhun, Feryal; Stanford University, Clinical Excellence Research Center Mistry, Bipin; Harvard Business School, Platchek, Terry; Stanford University, Clinical Excellence Research Center Milstein, Arnold; Stanford University, Clinical Excellence Research Center Narayanan, V.G.; Harvard Business School, Kaplan, Robert; Harvard Business School,</td>
</tr>
<tr>
<td>&lt;b&gt;Primary Subject Heading&lt;/b&gt;</td>
<td>Health economics</td>
</tr>
<tr>
<td>Secondary Subject Heading</td>
<td>Medical management, Surgery</td>
</tr>
<tr>
<td>Keywords</td>
<td>HEALTH ECONOMICS, Health economics &lt; HEALTH SERVICES ADMINISTRATION &amp; MANAGEMENT, Coronary intervention &lt; CARDIOLOGY, Cardiac surgery &lt; SURGERY</td>
</tr>
</tbody>
</table>
Study Protocol: Time-driven Activity Based Costing of Multi-Vessel Coronary-Artery Bypass Grafting Across National Boundaries to Identify Improvement Opportunities

F. Erhun1*, B. Mistry2, T. Platchek1, A. Milstein1, V.G. Narayanan2, R.S. Kaplan2
1 Clinical Excellence Research Center, Stanford University, Stanford CA
2 Harvard Business School, Boston MA

Introduction: Coronary artery bypass graft (CABG) surgery is a well-established, commonly performed treatment for coronary artery disease — a disease that affects over 10% of U.S. adults and is a major cause of morbidity and mortality. In 2005, the mean cost for a CABG procedure among Medicare beneficiaries in the U.S. was $32,201+/- $23,059. The same operation reportedly costs less than $2,000 to produce in India. The goals of the proposed study are to (1) identify the difference in the costs incurred to perform CABG surgery by three Joint Commission accredited hospitals with reputations for high quality and efficiency and (2) characterize the opportunity to reduce the cost of performing CABG surgery.

Methods and Analysis: We use time-driven activity-based costing (TDABC) to quantify the hospitals’ costs of producing elective, multi-vessel CABG. TDABC estimates the costs of a given clinical service by combining information about the process of patient care delivery (specifically, the time and quantity of labor and non-labor resources utilized to perform each activity) with the unit cost of each resource used to provide the care. Resource utilization was estimated by constructing CABG process maps for each site based on observation of care and staff interviews. Unit costs were calculated as a capacity cost rate, measured as a $/minute, for each resource consumed in CABG production. Multiplying together the unit costs and resource quantities and summing across all resources used will produce the average cost of CABG production at each site. We will conclude by conducting a variance analysis of labor costs to reveal opportunities to bend the cost curve for CABG production in the United States.

Ethics and Dissemination: All our methods were exempted from review by the Stanford Institutional Review Board. Results will be published in peer-reviewed journals and presented at scientific meetings.

* Corresponding Author: Feryal Erhun, PhD. Clinical Excellence Research Center, Stanford University, 75 Alta Road, Palo Alto, CA 94305-6015, phone: 650-724-3988, fax: 650-723-8611
STRENGTHS OF THIS STUDY

• Time-driven activity-based costing is a bottoms-up costing approach based on the actual clinical and administrative processes used at each site. Its detailed process maps and unit costs allow for granular comparison of the cost of producing CABG across multiple sites.

• The multi-site study design enables us to compare the CABG production processes across three hospitals that follow different strategies for their CABG procedures. We will identify how the choices made lead to differences in resource consumption and cost.

• The use of variance analysis across the three sites will allow us to characterize opportunities to improve CABG affordability.

LIMITATIONS OF THIS STUDY

• We cannot independently cross-reference our data with public cost data. Within the context of this study, public cost data is neither readily available (as the healthcare industry has historically not invested in accurately measuring the actual costs of delivering patient-level care) nor is it informative when it is available (as the costs reported in the literature use arbitrary and inaccurate ratios of costs-to-charges to allocate overall hospital costs down to specific clinical procedures).

• Although the scope of the TDABC analysis is the same across the sites, structural and regulatory differences between the health systems in India and the U.S. may not permit some of the low cost practices in the Indian hospital to be replicated in U.S. hospitals.

• This study is unable to evaluate the extent to which each site uses different resources such as personnel, space, and equipment relative to their capacity. While, in principle, TDABC does enable unused resource capacity to be estimated directly, we studied only one of the many cardiovascular surgical procedures done at the three sites and therefore could not independently calculate or compare the quantities of unused resource capacity at each site.
1. INTRODUCTION

Healthcare spending accounts for about 18% of gross domestic product in the United States.\(^1,2\) Some have estimated that up to 30% of that spending is wasted due to inefficiency.\(^3,4\) In response to evidence of suboptimal outcomes against the backdrop of high and rising costs, government and private sector payers are incentivizing healthcare providers to provide better health with less spending.

Coronary artery disease (CAD) affects over 10% in U.S. adults\(^5\) and is a major cause of morbidity and mortality. Coronary artery bypass graft surgery (CABG) is a well-established, commonly performed treatment for CAD, with nearly 400,000 procedures performed annually in the U.S.\(^6\) According to the 2012 Healthcare Cost and Utilization (HCUP) Project Statistics, the mean charges for performing CABG surgery are $149,480\(^6\), well more than an order of magnitude higher than those at international sites with equivalent outcomes.\(^7\)

While charge data like those reported above are readily available, a key challenge in healthcare is accurate cost information.\(^a\) The healthcare industry has historically not invested in accurately measuring the specific costs of delivering patient-level care.\(^8,9\) Recently introduced government and private sector incentives are motivating healthcare providers to better understand the cost of production of various service lines.\(^10-14\) Time-driven activity-based costing (TDABC),\(^15,16\) a costing method widely employed in other sectors, such as retailing, manufacturing, and financial services, has recently begun gaining traction in healthcare.\(^17-22\) In the select healthcare cases where it has been applied, TDABC has been successful at identifying and reducing unused capacity and improving resource allocation for optimal efficiency.\(^18\)

We conducted a TDABC study in conjunction with three Joint Commission accredited hospitals with reputations for high quality and efficiency; two in the U.S. and one in Bangalore.

\(^{a}\) The cost values reported in the abstract, for example, were calculated by multiplying the total charges that were found in the Medicare Provider Analysis and Review file by the appropriate hospital's overall cost-to-charge ratio, obtained from the fiscal year 2005 Medicare Cost Report.
India. The goal of the study was to compare the CABG production processes of these selected hospitals in an attempt to explain the difference in production costs between them and to characterize opportunities to improve CABG affordability in the United States.

2. METHODS AND ANALYSIS

2.1. Background on Sites
We conducted a TDABC study to calculate production costs for isolated, elective, uncomplicated, multi-vessel CABG surgeries performed at two sites in the U.S. (Site 1 and Site 2) and one site in India (Site 3). Site 1 is a multi-specialty hospital and uses an integrated, systems-based approach to deliver high-quality, evidence-based, affordable care. Site 2 is a dedicated heart hospital, known for its high quality (ranking in the top 2% of all heart surgery programs in the U.S.) and patient-centered care. Site 3 is one of the largest heart hospitals in the world and is notable for combining minutely detailed care protocols with an assembly-line approach to care delivery.

2.2. Background on TDABC
TDABC\textsuperscript{8,15,16}, the costing methodology in this study, generates cost of production using estimates of two parameters: (1) the unit cost of resource inputs (labor and non-labor), and (2) the time and the quantity of resources required to perform a transaction or an activity. In the healthcare context, TDABC combines information about the patient care cycle for a given medical condition (e.g., CABG), with the resources consumed during that care cycle. Display 1 details steps of a TDABC analysis\textsuperscript{8}.

TDABC begins with selecting the medical condition and defining the beginning and end of the patient care cycle. The second step is creating detailed process maps that document every administrative and clinical process involved in the treatment of the selected medical condition. Process maps involve observing patients through their care cycle, and conducting
Display 1: Step by step TDABC analysis

1. Select the medical condition and define the care delivery cycle
2. Develop process maps with the following principles:
   a. Each step reflects an activity in patient care delivery
   b. Identify the resources involved for the patient at each step
   c. Identify any supplies used for the patient at each step
3. Obtain time estimates for each process step through interviews and observations
4. Calculate the capacity cost rate (CCR) for each resource:
   \[
   \text{CCR of Resource } A = \frac{\text{Expenses attributable to Resource } A}{\text{Practical capacity of Resource } A}
   \]
5. Calculate the total direct costs (personnel, equipment, space, and supplies) of all the resources used over the cycle of care
6. Identify and allocate the indirect costs attributable to the cycle of care
7. Validate cost estimation with pertinent stakeholders

Source: Kaplan and Porter (2011)

interviews and surveys with personnel involved in the care cycle. The final process map is a detailed document that captures all of the activities performed over the complete care cycle along with the average time, the personnel type, and equipment required to complete each activity. Process mapping also identifies purchased materials, supplies, devices, implants, and grafts consumed during the care cycle.

Obtaining time estimates depends on the predictability of the activity. For simple tasks, subject matter experts may provide accurate estimates. For more complex tasks, such as the procedural steps of surgery, time duration can be obtained by direct observations and extant systematic measures of time to deliver care.

Process maps also capture the resources (i.e., space and equipment) used at each care activity, as well as probabilistic decision nodes to capture alternative pathways caused by individual patient characteristic variability and process variations. The estimation of the probabilities can be challenging, and frequently requires interviews with a number of different clinicians and staff to validate.

The fourth step of TDABC is to determine the capacity cost rate (CCR) for each resource consumed, i.e., the cost per minute for the clinical and administrative resources – licensed and
unlicensed personnel, physical space, equipment, and supplies involved in the care cycle. The simplified equation is

\[
CCR \text{ of Resource } A = \frac{\text{Expenses attributable to Resource } A}{\text{Practical capacity of Resource } A}.
\]

The expenses attributable to a resource require the calculation of the total cost incurred to make the resource available for patient care. For personnel, this includes salary, fringe benefits, administrative support, information technology, and office expenses. For physical space, this includes annual depreciation, maintenance, operating and housekeeping costs, real estate costs, and the cost value of all equipment in that space. The practical capacity of a resource is the number of clinical minutes that resource is available per year. For personnel, available time only includes direct time available for patient care (such as during clinical shifts) and on-call time, but does not include off-duty, vacation and holiday time, nor does it include time devoted to research, administration, and medical education.

The total direct costs are then calculated in step 5 by multiplying the CCR for each resource (personnel and space) by the average minutes that resource is being used for each activity step, plus the cost of supplies and equipment consumed at that step. For the purposes of defining the calculation, let \( r_j^i \) be the CCR for resource \( i \) at site \( j \) and \( q_j^i \) be quantity of resource \( i \) consumed during the care cycle at site \( j \). Furthermore, we define \( N_L \) as the total resource classes of labor and \( N_S \) as the total resource classes of space. To calculate labor and space (including equipment) costs, for each resource, we multiply the total utilization of that resource obtained from the process maps with the CCR for that resource. The sum of the individual resources gives us the total cost of the labor and space resources that the site uses to perform a CABG surgery:

\[
\text{Total labor cost at site } j = \sum_{i=1}^{N_L} q_j^i \times r_j^i,
\]

\[
\text{Total space (including equipment) cost at site } j = \sum_{i=1}^{N_S} q_j^i \times r_j^i.
\]
The TDABC direct cost estimate is the sum of the total labor cost, the total space (including equipment) cost, as well as costs of purchased supplies (i.e., acquisition costs for material and medications).

Step 6 includes identification and allocation of the indirect costs attributable to the cycle of care. Indirect costs are those costs which cannot be traced to any particular resource used in the direct care of the patient but are none-the-less essential to be able to provide care. Examples of indirect costs include management salaries, insurance fees, and taxes.

The final step of TDABC analysis is the validation of cost estimates with financial and clinical teams from sites, and follow-up refinements to update the costs accordingly.

2.3. Data Collection

2.3.1. Process and Costs: We conducted the TDABC study at three sites and defined CABG surgery as the target medical condition. Process observations and detailed data collection were limited to cardiovascular care departments at each site. Care processes in ancillary departments such as radiology, laboratory and transfusion services, or housekeeping were not observed; instead, we requested each site estimate a cost per patient for those services.

We defined the start of the care delivery cycle as hospital admission and ended the care cycle with hospital discharge. Costs associated with any readmission (even if related to the initial CABG admission) were not included in our TDABC; however, we did capture the CABG readmission and complication rates at each site.

We restricted our study to an “average” (based on relative co-morbidities) patient at each site undergoing elective (not emergent), first (no previous CABG or valve surgery), isolated (no other procedures), multi-vessel CABG. Table 1 displays the criteria for excluding patients from the study. We studied uncomplicated CABG procedures to allow for valid comparisons across the three sites without the confounding effects of different risk stratification and patient mix variation among the sites.
Table 1: Exclusion criteria

- Concomitant valve surgery or aneurysm removal
- Ventricular Assist Device (VAD) implantation or removal
- Other cardiac procedure
- Emergent procedure (including for surgical complication)
- Previous CABG or valve surgery
- Previous Percutaneous Coronary Intervention (PCI) in ≤ 6 hours
- Mitral insufficiency < 21 days
- History of cardiogenic shock or CardioPulmonary Resuscitation (CPR)
- Pre-operative inotrope dependence

Our team visited each hospital to directly observe the CABG procedures and conduct interviews with care providers. During these site visits, the team recorded the following data which was subsequently used to create process maps: 1) all the activities performed over the complete care cycle of CABG, 2) the personnel who performed each activity, 3) the resources consumed in the activity (i.e., equipment, space, and materials), 4) the length of time each activity required, and 5) the probability of occurrence of each activity.

The CABG care cycle can be divided into four phases: pre-operative, intraoperative, post-operative (further segmented by post-operative day), and discharge. For each of these phases, a healthcare provider gave us a brief overview of the main steps, which we then observed to document activities in detail, timed either directly and/or using time estimates from interview notes. We attempted to interview at least 3 persons in each personnel category, via a pair of interviewers to minimize interviewer bias. For each activity, we interviewed personnel types performing the activity as well as types who would have knowledge of, but not responsibility for, the activity to confirm the accuracy of the original estimates. A copy of the data collection sheet is included in Table 2.

During the interview process, the interviewer introduced himself and briefly explained the purpose of the interview. He stated that he was interested in the interviewee’s experience with “uncomplicated CABG”. The interviewer asked about the interviewee’s best estimates of the
Table 2: Fields of the data collection sheet

1. Interviewee: Personnel type and initials
2. For each activity:
   a. Process (pre-operative, intraoperative, etc.)
   b. Detailed description of the activity
   c. Space
   d. Personnel types needed for activity
   e. Probability activity takes place (%)
   f. Activity time:
      i. Per interviewee (minutes)
      ii. Per observation (minutes)
   g. Discrepancy in activity time between observation and interviews (yes/no)
      i. If yes, frequency of discrepancy
      ii. If yes, causes of discrepancy

The time required to perform each activity for an “average” patient and the probabilities of all activities taking place, as some activities occur for 100% of the patients and others less frequently. The interviewer documented the resources consumed during the activity. The interviewer also asked the provider to estimate “during your whole shift, how much time do you spend with one patient,” and the provider to patient ratio. If the interviewer recognized a discrepancy with prior observations or interviews, he questioned the causes of this discrepancy. Also, the interviewer asked the interviewee how long each activity would take for a less/more experienced provider.

The information from the observations and interviews was then translated into a process map, providing a step-by-step outline of the CABG care pathway. Discrepancies between interviewees, or between observations and interviews, were resolved by further observations and additional interviews with more experienced personnel. Once the process maps were completed (see Figure 1 for a sample process map), we validated them with a different set of providers individually or in groups. After returning from the site visits, the team coordinated with each of the sites to collect and verify financial and human resources data.
CUB: Cardiovascular Universal Bed; PODx: Post-operative Day x; RN: Registered Nurse

Figure 1: Process maps document each activity during the care cycle. For each activity (rectangles), the personnel type assigned to the activity (color codes), the average time to complete the activity (circles), the probability that the activity takes place (diamonds), and the space where the activity takes place (column) are also documented.

Table 3 details the data requested from sites. Although the sites were generally willing and able to share detailed cost data, where data elements were unavailable, we assigned numbers based on reasonable assumptions or external sources, and we verified them with the sites. All cost data received from the site in India were in rupees, so we used the conversion rate as of November 11, 2013 (the start date of our site visit to the site in India), which was 63.34 rupees to 1 U.S. Dollar (USD), to convert these costs to USD.

Once the data became available, the CCR for each labor and space resource was calculated (as described earlier) and process map steps were then inserted into the financial model template in conjunction with the financial and human resources data collected by the respective site managers at the sites.

Next, we will validate the cost estimates with financial and clinical teams from sites, and will perform follow-up refinements to update the costs if necessary.
Table 3: Requested data

<table>
<thead>
<tr>
<th>PERSONNEL</th>
<th>SPACE</th>
<th>EQUIPMENT</th>
<th>MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Salary and bonus</td>
<td>● Space name</td>
<td>● Space name</td>
<td>● Activity</td>
</tr>
<tr>
<td>● Fringe benefits</td>
<td>● Area (sq. ft.)</td>
<td>● Equipment</td>
<td>● Material or consumable name</td>
</tr>
<tr>
<td>● Supervision</td>
<td>● New construction costs per sq. ft. ($)</td>
<td>● Replacement cost</td>
<td>● Number used in space</td>
</tr>
<tr>
<td>● Administrative support</td>
<td>● Useful life (years)</td>
<td>● Useful life (years)</td>
<td>● Cost per item ($)</td>
</tr>
<tr>
<td>● Training and travel</td>
<td>● Annual construction depreciation per sq. ft. ($)</td>
<td>● Yearly depreciation</td>
<td></td>
</tr>
<tr>
<td>● Office space</td>
<td>● Annual maintenance costs per sq. ft. ($)</td>
<td>● Yearly maintenance costs (% of replacement cost)</td>
<td></td>
</tr>
<tr>
<td>● Information Technology (IT) (hardware and support)</td>
<td>● Annual operating costs (incl. utilities) per sq. ft. ($)</td>
<td>● Yearly maintenance costs</td>
<td></td>
</tr>
<tr>
<td>● Office expenses</td>
<td>● Yearly housekeeping costs per sq. ft. ($)</td>
<td>● Yearly maintenance costs</td>
<td></td>
</tr>
<tr>
<td>● Malpractice insurance</td>
<td>● Yearly real estate costs per sq. ft. ($)</td>
<td>● Equipment cost per year ($/year)</td>
<td></td>
</tr>
<tr>
<td>● Time spent on research, education, and administrative time</td>
<td>● Availability (minutes)</td>
<td>● Availability (minutes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Space capacity cost rate ($/min)</td>
<td>● Capacity cost rate ($/min)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Room capacity (number of patients at once)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 Background on Variance Analysis

To quantify differences in consumption and pricing of labor resources between the three sites, we will perform a quantitative investigation using variance analysis on labor costs. Variance analysis helps us understand how much of the cost difference between two sites is due to different prices for inputs (personnel, equipment, space) and how much is due to different productivities of resources at the two sites. For example, we can define the total difference in personnel cost between site 1 and site 2 ($\Delta_{1,2}$) as:

$$\Delta_{1,2} = \sum_{i=1}^{N_L} q_1^i \times r_1^i - \sum_{i=1}^{N_L} q_2^i \times r_2^i,$$

where $q_1^i$ ($q_2^i$) is the quantity of personnel type $i$ at site 1 (site 2) and $r_1^i$ ($r_2^i$) is the price per unit of personnel type $i$ at site 1 (site 2).

If we designate site 2 as the benchmark site, then the cost difference can be thought of as the cost of site 1 relative to the benchmark site. Furthermore, the cost difference can be split into the sum of two effects: a price or rate variance due to different capacity cost rates of...
resource \( i \) and a quantity variance due to differential use of resource \( i \) at the two sites:

\[
\Delta_{1,2} = \sum_{i=1}^{N_L} q_1^i \times r_1^i - \sum_{i=1}^{N_L} q_2^i \times r_2^i
\]

\[
= \text{CCR variance at site 1 relative to site 2} + \text{Quantity variance at site 1 relative to site 2}
\]

where

\[
\text{CCR variance at site 1 relative to site 2} = \sum_{i=1}^{N_L} (r_1^i - r_2^i) \times q_1^i \text{ and}
\]

\[
\text{Quantity variance at site 1 relative to site 2} = \sum_{i=1}^{N_L} (q_1^i - q_2^i) \times r_2^i.
\]

The price (CCR) variance is caused by different CCRs at the two sites; a negative value indicates that site 1 has lower unit resource costs than site 2 and vice versa. The quantity variance (the difference in quantities of inputs) explains cost differences due to different quantities of resources used between the two sites; a negative value indicates that site 1 uses fewer resources than site 2 in performing the CABG surgery, and vice versa. The price variance is due to factors mostly exogenous to health systems, as managers, in the short run, have little ability to modify salaries—which are determined by market conditions—and the capacity of hours worked by personnel, which can be determined by prevailing industry practice and labor union negotiations. Managers, however, can control the quantity variance by improving processes and capacity utilization. The variance analysis, therefore, enables us to focus on cost differences due to differential productivity at the sites, and avoid the confounding effects of different compensation of comparable personnel and different prices paid for equipment and space. CCR variance and quantity variance will help us quantitatively discern differences between processes of selected sites.

We can further decompose the quantity variance into two factors. The first is the mix variance where the two sites use a different mix of resources. For instance, consider the resource of labor. Site 1 may use relatively more physician time while site 2 may use relatively
more nurse time. This mix variance is measured as follows:

\[
Mix\ variance\ at\ site\ 1\ relative\ to\ site\ 2 = \left( \sum_{i=1}^{N_L} \left( \frac{q_1^i}{Q_1} - \frac{q_2^i}{Q_2} \right) \times r_2^i \right) \times Q_1,
\]

where \(Q_1\) and \(Q_2\) measure the total quantity of labor time used at sites 1 and 2, respectively.

The second is the efficiency variance. This variance measures the cost differences that arise between the two sites because one site uses more of resource, say labor, than the other. Note, here we are only concerned with differences in total quantity of the resource used rather than the break-up into the different categories of labor such as physician hours or nurse hours.

\[
Efficiency\ variance\ at\ site\ 1\ relative\ to\ site\ 2 = \left( \sum_{i=1}^{N_L} r_2^i \times \frac{q_2^i}{Q_2} \right) \times (Q_1 - Q_2).
\]

Mix variance and efficiency variance allow us to separate out cost differences due to a different mix of personnel skill used in the care delivery from those due to the quantities of total personnel time used, respectively.

A site can reduce an unfavorable mix variance by shifting more of the work to lower paid personnel. It can reduce an unfavorable efficiency variance by adopting methods used at the more productive site to reduce the total quantity of employee minutes required to achieve a successful CABG surgery.

For example, let us assume that site 1 uses 10 minutes of surgeon time and 30 minutes of nurse time to complete a task. Site 2, on the other hand, uses 15 minutes of surgeon time and 15 minutes of nurse time for the same task. Let the capacity cost rate at site 2 be $2/min for a surgeon and $1/min for a nurse. The quantity variance at site 1 relative to site 2 is $5; that is, it costs $5 more to produce the same task at site 1 ignoring differences in rates. The mix variance is -$10. That is, the cost difference between sites attributable solely to site 1’s labor mix that favors more expensive resources is $10 in favor of site 1. However, site 1 uses a lot of labor relative to site 2. This efficiency variance is $15 and it is in favor of site 2. That is, site 1 uses 10 more hours of labor time than site 2 (without regard to the mix of labor used at either
site) and this costs site 1 an extra $15. The net effect of these two variances is $5 extra cost at site 1. Recall that this difference is purely on account of quantity variance and ignores any differences in rates per hour across the two sites (which is captured in the rate variance calculations).

3. ETHICS AND DISSEMINATION

All our methods were exempted from review by the Stanford Institutional Review Board. Results will be published in peer-reviewed journals, and presented at national and international scientific meetings.

4. DISCUSSION

Time-driven activity-based costing, using capacity cost rates for resource inputs (labor and non-labor) combined with detailed process maps, will allow for granular comparison of the cost of producing CABG across multiple sites. The use of variance analysis across the three sites will enable us to understand inter-site differences. We will identify the differences, if any, in care delivery between the selected sites. We hypothesize that understanding the sources of cost variation across the three sites may reveal opportunities for cost reduction which does not jeopardize patient outcomes. Such an analysis can also identify best practices in efficient CABG production.

AUTHORS’ CONTRIBUTIONS: AM initially proposed the study. RK and VGN specified the methodology. All authors contributed to the protocol design and planning the analysis. FE wrote the initial manuscript, and all authors contributed to improving the manuscript. All authors approved the final manuscript.

ACKNOWLEDGEMENTS: We thank Maziyar Kalani, MD; Christine Nguyen, MD, MS; Kimberly Brayton, MD, JD, MS; Mary Carol Mazza, PhD; and Rajinder Mann for their help with interviews.
FUNDING STATEMENT: The study was supported by the Sue and Dick Levy Fund, an advised fund of the Silicon Valley Community Foundation.

Disclosures: None; Disclaimers: None

BIBLIOGRAPHY


<table>
<thead>
<tr>
<th>Journal</th>
<th>BMJ Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manuscript ID</td>
<td>bmjopen-2015-008765.R1</td>
</tr>
<tr>
<td>Article Type</td>
<td>Protocol</td>
</tr>
<tr>
<td>Date Submitted by the Author</td>
<td>20-Jul-2015</td>
</tr>
<tr>
<td>Complete List of Authors</td>
<td>Erhun, Feryal; Stanford University, Clinical Excellence Research Center Mistry, Bipin; Harvard Business School, Platchek, Terry; Stanford University, Clinical Excellence Research Center Milstein, Arnold; Stanford University, Clinical Excellence Research Center Narayanan, V.G.; Harvard Business School, Kaplan, Robert; Harvard Business School,</td>
</tr>
<tr>
<td>Primary Subject Heading</td>
<td>Health economics</td>
</tr>
<tr>
<td>Secondary Subject Heading</td>
<td>Medical management, Surgery</td>
</tr>
<tr>
<td>Keywords</td>
<td>HEALTH ECONOMICS, Health economics &lt; HEALTH SERVICES ADMINISTRATION &amp; MANAGEMENT, Coronary intervention &lt; CARDIOLOGY, Cardiac surgery &lt; SURGERY</td>
</tr>
</tbody>
</table>
Study Protocol: Time-driven Activity Based Costing of Multi-Vessel Coronary-Artery Bypass Grafting Across National Boundaries to Identify Improvement Opportunities

F. Erhun¹*, B. Mistry², T. Platchek¹, A. Milstein¹, V.G. Narayanan², R.S. Kaplan²

¹Clinical Excellence Research Center, Stanford University, Stanford CA
²Harvard Business School, Boston MA

Introduction: Coronary artery bypass graft (CABG) surgery is a well-established, commonly performed treatment for coronary artery disease — a disease that affects over 10% of U.S. adults and is a major cause of morbidity and mortality. In 2005, the mean cost for a CABG procedure among Medicare beneficiaries in the U.S. was $32,201+/- $23,059. The same operation reportedly costs less than $2,000 to produce in India. The goals of the proposed study are to (1) identify the difference in the costs incurred to perform CABG surgery by three Joint Commission accredited hospitals with reputations for high quality and efficiency and (2) characterize the opportunity to reduce the cost of performing CABG surgery.

Methods and Analysis: We use time-driven activity-based costing (TDABC) to quantify the hospitals’ costs of producing elective, multi-vessel CABG. TDABC estimates the costs of a given clinical service by combining information about the process of patient care delivery (specifically, the time and quantity of labor and non-labor resources utilized to perform each activity) with the unit cost of each resource used to provide the care. Resource utilization was estimated by constructing CABG process maps for each site based on observation of care and staff interviews. Unit costs were calculated as a capacity cost rate, measured as a $/minute, for each resource consumed in CABG production. Multiplying together the unit costs and resource quantities and summing across all resources used will produce the average cost of CABG production at each site. We will conclude by conducting a variance analysis of labor costs to reveal opportunities to bend the cost curve for CABG production in the United States.

Ethics and Dissemination: All our methods were exempted from review by the Stanford Institutional Review Board. Results will be published in peer-reviewed journals and presented at scientific meetings.

*Corresponding Author: Feryal Erhun, PhD. Clinical Excellence Research Center, Stanford University, 75 Alta Road, Palo Alto, CA 94305-6015, phone: 650-724-3988, fax: 650-723-8611
STRENGTHS OF THIS STUDY

- Time-driven activity-based costing is a bottoms-up costing approach based on the actual clinical and administrative processes used at each site. Its detailed process maps and unit costs allow for granular comparison of the cost of producing CABG across multiple sites.

- The multi-site study design enables us to compare the CABG production processes across three hospitals that follow different strategies for their CABG procedures. We will identify how the choices made lead to differences in resource consumption and cost.

- The use of variance analysis across the three sites will allow us to characterize opportunities to improve CABG affordability.

LIMITATIONS OF THIS STUDY

- We cannot independently cross-reference our data with public cost data. Within the context of this study, public cost data is neither readily available (as the healthcare industry has historically not invested in accurately measuring the actual costs of delivering patient-level care) nor is it informative when it is available (as the costs reported in the literature use arbitrary and inaccurate ratios of costs-to-charges to allocate overall hospital costs down to specific clinical procedures).

- Although the scope of the TDABC analysis is the same across the sites, structural and regulatory differences between the health systems in India and the U.S. may not permit some of the low cost practices in the Indian hospital to be replicated in U.S. hospitals.

- This study is unable to evaluate the extent to which each site uses different resources such as personnel, space, and equipment relative to their capacity. While, in principle, TDABC does enable unused resource capacity to be estimated directly, we studied only one of the many cardiovascular surgical procedures done at the three sites and therefore could not independently calculate or compare the quantities of unused resource capacity at each site.
1. INTRODUCTION

Healthcare spending accounts for about 18% of gross domestic product in the United States\(^1,2\). Some have estimated that up to 30% of that spending is wasted due to inefficiency\(^3,4\). In response to evidence of suboptimal outcomes against the backdrop of high and rising costs, government and private sector payers are incentivizing healthcare providers to provide better health with less spending.

Coronary artery disease (CAD) affects over 10% of U.S. adults\(^5\) and is a major cause of morbidity and mortality. Coronary artery bypass graft (CABG) surgery is a well-established, commonly performed treatment for CAD, with nearly 400,000 procedures performed annually in the U.S.\(^6\). According to the 2012 Healthcare Cost and Utilization (HCUP) Project Statistics, the mean charges for performing CABG surgery are $149,480\(^6\), well more than an order of magnitude higher than those at international sites with equivalent outcomes\(^7\).

While charge data like those reported above are readily available, a key challenge in healthcare is accurate cost information. The healthcare industry has historically not invested in accurately measuring the specific costs of delivering patient-level care\(^8,9\). Indeed, the widespread confusion between the dollar amount charged for medical services rendered, the dollar amount reimbursed, and the cost of providing the services is a major barrier to reducing the cost of healthcare\(^8\). A common myth is to use charges as a good surrogate for costs\(^8\), either by multiplying total charges with cost-to-charge ratios\(^10\) or by assigning expenses to procedures and patients with Relative Value Units (RVUs). Such an approach introduces distortions and cross-subsidies among different service lines. Recently introduced government and private sector incentives are motivating healthcare providers to better understand the cost of production of various service lines\(^11-15\). Time-driven activity-based costing (TDABC)\(^16,17\), a costing method widely employed in other sectors, such as retailing, manufacturing, and financial services, has recently begun gaining traction in healthcare\(^18-23\).
been applied, TDABC has been successful at identifying and reducing unused capacity and improving resource allocation for optimal efficiency\textsuperscript{19}.  

We conducted a TDABC study in conjunction with three Joint Commission accredited\textsuperscript{24,25} hospitals with reputations for high quality and efficiency; two in the U.S. and one in Bangalore, India. The goal of the study was to compare the CABG production processes of these selected hospitals in an attempt to explain the difference in production costs between them and to characterize opportunities to improve CABG affordability in the United States.

2. METHODS AND ANALYSIS

2.1. Background on Sites
We conducted a TDABC study to calculate production costs for isolated, elective, uncomplicated, multi-vessel CABG surgeries performed at two sites in the U.S. (Site 1 and Site 2) and one site in India (Site 3). Site 1 is a multi-specialty hospital and uses an integrated, systems-based approach to deliver high-quality, evidence-based, affordable care. Site 2 is a dedicated heart hospital, known for its high quality (ranking in the top 2\% of all heart surgery programs in the U.S.) and patient-centered care. Site 3 is one of the largest heart hospitals in the world and is notable for combining minutely detailed care protocols with an assembly-line approach to care delivery.

2.2. Background on TDABC
TDABC\textsuperscript{8,16,17}, the costing methodology in this study, generates cost of production using estimates of two parameters: (1) the unit cost of resource inputs (labor and non-labor), and (2) the time and the quantity of resources required to perform a transaction or an activity. In the healthcare context, TDABC combines information about the patient care cycle for a given medical condition (e.g., CABG), with the resources consumed during that care cycle. Display 1 details steps of a TDABC analysis\textsuperscript{6}.
**Display 1: Step by step TDABC analysis**

1. Select the medical condition and define the care delivery cycle
2. Develop process maps with the following principles:
   a. Each step reflects an activity in patient care delivery
   b. Identify the resources involved for the patient at each step
   c. Identify any supplies used for the patient at each step
3. Obtain time estimates for each process step through interviews and observations
4. Calculate the capacity cost rate (CCR) for each resource:
   \[
   \text{CCR of Resource } A = \frac{\text{Expenses attributable to Resource } A}{\text{Practical capacity of Resource } A}
   \]
5. Calculate the total direct costs (personnel, equipment, space, and supplies) of all the resources used over the cycle of care
6. Identify and allocate the indirect costs attributable to the cycle of care
7. Validate cost estimation with pertinent stakeholders

**Source:** Kaplan and Porter (2011)

TDABC begins with selecting the medical condition and defining the beginning and end of the patient care cycle. The second step is creating detailed process maps that document every administrative and clinical process involved in the treatment of the selected medical condition. Process maps involve observing patients through their care cycle, and conducting interviews and surveys with personnel involved in the care cycle. The final process map is a detailed document that captures all of the activities performed over the complete care cycle along with the average time, the personnel type, and equipment required to complete each activity. Process mapping also identifies purchased materials, supplies, devices, implants, and grafts consumed during the care cycle.

Obtaining time estimates depends on the predictability of the activity. For simple tasks, subject matter experts may provide accurate estimates. For more complex tasks, such as the procedural steps of surgery, time duration can be obtained by direct observations and extant systematic measures of time to deliver care.

Process maps also capture the resources (i.e., space and equipment) used at each care activity, as well as probabilistic decision nodes to capture alternative pathways caused by individual patient characteristic variability and process variations. The estimation of the
probabilities can be challenging, and frequently requires interviews with a number of different clinicians and staff to validate.

The fourth step of TDABC is to determine the capacity cost rate (CCR) for each resource consumed, i.e., the cost per minute for the clinical and administrative resources – licensed and unlicensed personnel, physical space, equipment, and supplies – involved in the care cycle. The simplified equation is

\[
CCR of Resource A = \frac{\text{Expenses attributable to Resource A}}{\text{Practical capacity of Resource A}}.
\]

The expenses attributable to a resource require the calculation of the total cost incurred to make the resource available for patient care. For personnel, this includes salary, fringe benefits, administrative support, information technology, and office expenses. For physical space, this includes annual depreciation, maintenance, operating and housekeeping costs, real estate costs, and the cost value of all equipment in that space. The practical capacity of a resource is the number of clinical minutes that resource is available per year. For personnel, available time only includes direct time available for patients care (such as during clinical shifts) and on-call time, but does not include off-duty, vacation and holiday time, nor does it include time devoted to research, administration, and medical education.

The total direct costs are then calculated in step 5 by multiplying the CCR for each resource (personnel and space) by the average minutes that resource is being used for each activity step, plus the cost of supplies and equipment consumed at that step. For the purposes of defining the calculation, let \( r^i_j \) be the CCR for resource \( i \) at site \( j \) and \( q^i_j \) be quantity of resource \( i \) consumed during the care cycle at site \( j \). Furthermore, we define \( N_L \) as the total resource classes of labor and \( N_S \) as the total resource classes of space. To calculate labor and space (including equipment) costs, for each resource, we multiply the total utilization of that resource obtained from the process maps with the CCR for that resource. The sum of the individual resources gives us the total cost of the labor and space resources that the site uses to perform a CABG surgery:
\[
\text{Total labor cost at site } j = \sum_{i=1}^{N_L} q_j^i \times r_j^i, \\
\text{Total space (including equipment) cost at site } j = \sum_{i=1}^{N_S} q_j^i \times r_j^i.
\]

The TDABC direct cost estimate is the sum of the total labor cost, the total space (including equipment) cost, as well as costs of purchased supplies (i.e., acquisition costs for material and medications).

Step 6 includes identification and allocation of the indirect costs attributable to the cycle of care. Indirect costs are those costs that cannot be traced to any particular resource used in the direct care of the patient but are none-the-less essential to be able to provide care. Examples of indirect costs include management salaries, insurance fees, and taxes.

The final step of TDABC analysis is the validation of cost estimates with financial and clinical teams from sites, and follow-up refinements to update the costs accordingly.

2.3. Data Collection

2.3.1. Process and Costs: We conducted the TDABC study at three sites and defined CABG surgery as the target medical condition. Process observations and detailed data collection were limited to cardiovascular care departments at each site. Care processes in ancillary departments such as radiology, laboratory and transfusion services, and housekeeping were not observed; instead, we requested each site estimate a cost per patient for those services. Indirect costs were obtained from the sites; however, they were not used to calculate the final cost of CABG in order to standardize our process and to avoid introduction of site-specific assumptions into our comparisons.\(^a\)

We defined the start of the care delivery cycle as hospital admission and ended the care cycle with hospital discharge. Costs associated with any readmission (even if related to the

\(^a\) We chose this approach because assigning these costs accurately would require extending the scope of the TDABC analysis on all these categories of expenses, which would require a great deal of time and effort.
initial CABG admission) were not included in our TDABC; however, we did capture the CABG readmission and complication rates at each site.

We restricted our study to an “average” (based on relative co-morbidities) patient undergoing elective (not emergent), first (no previous CABG or valve surgery), isolated (no other procedures), multi-vessel CABG. Table 1 displays the criteria used to exclude patients from the study. We studied uncomplicated CABG procedures to allow for valid comparisons across the three sites without the confounding effects of different risk stratification and patient mix variation among the sites.

Table 1: Exclusion criteria

1. Concomitant valve surgery or aneurysm removal
2. Ventricular Assist Device (VAD) implantation or removal
3. Other cardiac procedure
4. Emergent procedure (including for surgical complication)
5. Previous CABG or valve surgery
6. Previous Percutaneous Coronary Intervention (PCI) in ≤ 6 hours
7. Mitral insufficiency < 21 days
8. History of cardiogenic shock or CardioPulmonary Resuscitation (CPR)
9. Pre-operative inotrope dependence

Our team visited each hospital to directly observe the CABG procedures and conduct interviews with care providers. During these site visits, the team recorded the following data which was subsequently used to create process maps: 1) all the activities performed over the complete care cycle of CABG, 2) the personnel who performed each activity, 3) the resources consumed in the activity (i.e., equipment, space, and materials), 4) the length of time each activity required, and 5) the probability of occurrence of each activity.

The CABG care cycle can be divided into four phases: pre-operative, intraoperative, post-operative (further segmented by post-operative day), and discharge. For each of these phases, a healthcare provider gave us a brief overview of the main steps, which we then observed to document activities in detail, timed either directly and/or using time estimates from...
interview notes. We attempted to interview at least 3 individuals in each personnel category, via a pair of interviewers to minimize interviewer bias. For each activity, we interviewed personnel types performing the activity as well as types who would have knowledge of, but not responsibility for, the activity to confirm the accuracy of the original estimates. A copy of the data collection sheet is included in Table 2.

Table 2: Fields of the data collection sheet

| 1. Interviewee: Personnel type and initials |
| 2. For each activity: |
| a. Process (pre-operative, intraoperative, etc.) |
| b. Detailed description of the activity |
| c. Space |
| d. Personnel types needed for activity |
| e. Probability activity takes place (%) |
| f. Activity time: |
| i. Per interviewee (minutes) |
| ii. Per observation (minutes) |
| g. Discrepancy in activity time between observation and interviews (yes/no) |
| i. If yes, frequency of discrepancy |
| ii. If yes, causes of discrepancy |

During the interview process, the interviewer introduced himself and briefly explained the purpose of the interview. He stated that he was interested in the interviewee’s experience with “uncomplicated CABG.” The interviewer asked about the interviewee’s best estimates of the time required to perform each activity for an “average” patient and the probabilities of all activities taking place, as some activities occur for 100% of the patients and others less frequently. The interviewer documented the resources consumed during the activity. The interviewer also asked the provider to estimate how much time they spent with one patient during their whole shift and the provider to patient ratio. If the interviewer recognized a discrepancy in activity time between observation and interviews (yes/no) they documented the frequency of discrepancy and causes of discrepancy.

During the interviews, the interviewers returned back to this concept several times and when there was any uncertainty in terms of what this concept was, re-explained it to the interviewees. After the interviews, we compared the process maps to make sure that they did not reflect activity associated with complications or other patient characteristics that differed from the clinical frame of reference that we wanted them to use.
discrepancy with prior observations or interviews, he questioned the causes of this discrepancy. In addition, the interviewer asked the interviewee how long each activity would take for a less/more experienced provider.

The information from the observations and interviews was then translated into a process map, providing a step-by-step outline of the CABG care pathway. Discrepancies between interviewees, or between observations and interviews, were resolved by further observations and additional interviews with more experienced personnel. Once the process maps were completed (see Figure 1 for a sample process map), we validated them with a different set of providers individually or in groups. After returning from the site visits, the team coordinated with each of the sites to collect and verify financial and human resources data.

**** FIGURE 1 TO BE INSERTED ****

Table 3 details the data requested from sites. Although the sites were generally willing and able to share detailed cost data, we assigned numbers based on reasonable assumptions or external sources where data elements were unavailable and verified them with the sites. All cost data received from the site in India were in rupees (INR), so we used the median market exchange rate for the fourth quarter of 2013 (the start date of our site visit to the site in India was November 11th), which was 62 INR (rounded) to 1 U.S. Dollar (USD), to convert these costs to USD26. For the same year, the purchasing power parity (PPP) for India was 17 INR (rounded) to 1 USD27. We checked the robustness of our cost calculations using PPP and results were directionally similar. We plan to report cost calculations with both conversion methods.
Table 3: Requested data. To link this data with the capacity cost rates, we refer the reader to the spreadsheet template presented in the Appendix.

<table>
<thead>
<tr>
<th>PERSONNEL</th>
<th>SPACE</th>
<th>EQUIPMENT</th>
<th>MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel type</td>
<td>Space name</td>
<td>Space name</td>
<td>Material or consumable name</td>
</tr>
<tr>
<td>Salary and bonus</td>
<td>Area (sq. ft.)</td>
<td>Equipment type</td>
<td>Number used in space/activity</td>
</tr>
<tr>
<td>Fringe benefits</td>
<td>New construction costs per sq. ft. ($/sq. ft.)</td>
<td>Replacement cost</td>
<td>Cost per item ($)</td>
</tr>
<tr>
<td>Supervision</td>
<td>Useful life (years)</td>
<td>Useful life (years)</td>
<td></td>
</tr>
<tr>
<td>Administrative support</td>
<td>Annual maintenance costs per sq. ft. ($/sq. ft.)</td>
<td>Yearly maintenance costs</td>
<td></td>
</tr>
<tr>
<td>Training and travel</td>
<td>Annual operating costs (incl. utilities) per sq. ft. ($/sq. ft.)</td>
<td>Yearly housekeeping costs per sq. ft. ($/sq. ft.)</td>
<td></td>
</tr>
<tr>
<td>Office space</td>
<td>Yearly real estate cost per sq. ft. ($/sq. ft.)</td>
<td>Yearly real estate cost</td>
<td></td>
</tr>
<tr>
<td>Information Technology (IT)</td>
<td>Room capacity (number of patients at once)</td>
<td>Room capacity (number of patients at once)</td>
<td></td>
</tr>
<tr>
<td>(hardware and support)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office expenses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malpractice insurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spent on</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>research, education,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and administrative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>time (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capacity</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical availability*</td>
<td>Availability**</td>
<td>Availability**</td>
<td></td>
</tr>
<tr>
<td>(minutes per year)</td>
<td>(minutes per year)</td>
<td>(minutes per year)</td>
<td></td>
</tr>
<tr>
<td>On-call time spent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>working (minutes per year)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Clinical availability includes direct time available for patients care (such as during clinical shifts) and on-call time, but does not include off-duty, vacation and holiday time, nor does it include time devoted to research, administration, and medical education

** Space and equipment availability includes direct time available for patients care but does not include holiday time, nor does it include maintenance and cleaning time

Once the data became available, the CCR for each labor and space resource was calculated (as described earlier) and process map steps were then inserted into the financial model template in conjunction with the financial and human resources data collected by the respective site managers at the sites.

Next, we will validate the cost estimates with financial and clinical teams from sites, and will perform follow-up refinements to update the costs if necessary.

2.3.2 Background on Variance Analysis

To quantify differences in consumption and pricing of labor resources between the three sites, we will perform a quantitative investigation using variance analysis on labor costs. Variance
analysis helps us understand how much of the cost difference between two sites is due to different prices for inputs (personnel, equipment, space) and how much is due to different productivities of resources at the two sites. For example, we can define the total difference in personnel cost between site 1 and site 2 ($\Delta_{1,2}$) as:

$$\Delta_{1,2} = \sum_{i=1}^{N_L} q^i_1 \times r^i_1 - \sum_{i=1}^{N_L} q^i_2 \times r^i_2,$$

where $q^i_1$ ($q^i_2$) is the quantity of personnel type $i$ at site 1 (site 2) and $r^i_1$ ($r^i_2$) is the price per unit of personnel type $i$ at site 1 (site 2).

If we designate site 2 as the benchmark site, then the cost difference can be thought of as the cost of site 1 relative to the benchmark site. Furthermore, the cost difference can be split into the sum of two effects: a price or rate variance due to different capacity cost rates of resource $i$ and a quantity variance due to differential use of resource $i$ at the two sites:

$$\Delta_{1,2} = \sum_{i=1}^{N_L} q^i_1 \times r^i_1 - \sum_{i=1}^{N_L} q^i_2 \times r^i_2$$

$$= \text{CCR variance at site 1 relative to site 2} + \text{Quantity variance at site 1 relative to site 2}$$

where

$$\text{CCR variance at site 1 relative to site 2} = \sum_{i=1}^{N_L} (r^i_1 - r^i_2) \times q^i_1$$

and

$$\text{Quantity variance at site 1 relative to site 2} = \sum_{i=1}^{N_L} (q^i_1 - q^i_2) \times r^i_2.$$ 

The price (CCR) variance is caused by different CCRs at the two sites; a negative value indicates that site 1 has lower unit resource costs than site 2 and vice versa. The quantity variance (the difference in quantities of inputs) explains cost differences due to different quantities of resources used between the two sites; a negative value indicates that site 1 uses fewer resources than site 2 in performing the CABG surgery, and vice versa. The price variance is due to factors mostly exogenous to health systems, as managers, in the short run, have little
ability to modify salaries—which are determined by market conditions—and the capacity of hours worked by personnel, which can be determined by prevailing industry practice and labor union negotiations. Managers, however, can control the quantity variance by improving processes and capacity utilization. The variance analysis, therefore, enables us to focus on cost differences due to differential productivity at the sites, and avoid the confounding effects of different compensation of comparable personnel and different prices paid for equipment and space. CCR variance and quantity variance will help us quantitatively discern differences between processes of selected sites.

We can further decompose the quantity variance into two factors. The first is the mix variance where the two sites use a different mix of resources. For instance, consider the resource of labor. Site 1 may use relatively more physician time while site 2 may use relatively more nurse time. This mix variance is measured as follows:

\[
Mix\ variance\ at\ site\ 1\ relative\ to\ site\ 2 = \left( \sum_{i=1}^{N_L} \left( \frac{q_1^i}{Q_1} - \frac{q_2^i}{Q_2} \right) \times r_2^i \right) \times Q_1,
\]

where \(Q_1\) and \(Q_2\) measure the total quantity of labor time used at sites 1 and 2, respectively.

The second is the efficiency variance. This variance measures the cost differences that arise between the two sites because one site uses more of a resource, say labor, than the other. Note, here we are only concerned with differences in total quantity of the resource used rather than the break-up into the different categories of labor such as physician hours or nurse hours.

\[
Efficiency\ variance\ at\ site\ 1\ relative\ to\ site\ 2 = \left( \sum_{i=1}^{N_L} r_2^i \times \frac{q_2^i}{Q_2} \right) \times (Q_1 - Q_2).
\]

Mix variance and efficiency variance allow us to separate out cost differences due to a different mix of personnel skill used in the care delivery from those due to the quantities of total personnel time used, respectively.

A site can reduce an unfavorable mix variance, for example, by shifting more of the work
to lower paid personnel—when it can be done without adverse impact on quality and outcomes—by ensuring that personnel work near or at the “top of license” or “top of capabilities.” It can reduce an unfavorable efficiency variance, for example, by adopting methods used at the more productive site to eliminate non-value added activities in order to reduce the total quantity of employee minutes required to achieve a successful care delivery without having any adverse impact on quality, safety, and outcomes.

For example, let us assume that site 1 uses 10 minutes of surgeon time and 30 minutes of nurse time to complete a task. Site 2, on the other hand, uses 15 minutes of surgeon time and 15 minutes of nurse time for the same task. Let the capacity cost rate at site 2 be $2/min for a surgeon and $1/min for a nurse. The quantity variance at site 1 relative to site 2 is $5; that is, it costs $5 more to produce the same task at site 1 ignoring differences in rates. The mix variance is -$10. That is, the cost difference between sites attributable solely to site 1’s labor mix that favors more expensive resources is $10 in favor of site 1. However, site 1 uses a lot of labor relative to site 2. This efficiency variance is $15 and it is in favor of site 2. That is, site 1 uses 10 more hours of labor time than site 2 (without regard to the mix of labor used at either site) and this costs site 1 an extra $15. The net effect of these two variances is $5 extra cost at site 1. Recall that this difference is purely on account of quantity variance and ignores any differences in rates per hour across the two sites (which is captured in the rate variance calculations).

3. ETHICS AND DISSEMINATION

All of our methods were exempted from review by the Stanford Institutional Review Board. Results will be published in peer-reviewed journals, and presented at national and international scientific meetings.

4. DISCUSSION
Time-driven activity-based costing, using capacity cost rates for resource inputs (labor and non-labor) combined with detailed process maps, will allow for granular comparison of the cost of producing CABG across multiple sites. The use of variance analysis across the three sites will enable us to understand inter-site differences. We will identify the differences, if any, in care delivery between the selected sites. We hypothesize that understanding the sources of cost variation across the three sites may reveal opportunities for cost reduction which does not jeopardize patient outcomes. Such an analysis can also identify best practices in efficient CABG production.

ACKNOWLEDGEMENTS: We thank Maziyar Kalani, MD; Christine Nguyen, MD, MS; Kimberly Brayton, MD, JD, MS; Mary Carol Mazza, PhD; and Rajbinder Mann for their help with interviews.

AUTHORS’ CONTRIBUTIONS: AM initially proposed the study. RK and VGN specified the methodology. All authors contributed to the protocol design and analysis plan. FE wrote the initial manuscript, and all authors contributed to improving the manuscript. All authors approved the final manuscript.

COMPETING INTERESTS: None

FUNDING STATEMENT: The study was supported by the Sue and Dick Levy Fund, an advised fund of the Silicon Valley Community Foundation.

DATA SHARING AGREEMENT: N/A

BIBLIOGRAPHY


Figure 1: Process maps document each activity during the care cycle. For each activity (rectangles), the personnel type assigned to the activity (color codes), the average time to complete the activity (circles), the probability that the activity takes place (diamonds), and the space where the activity takes place (column) are also documented.

CUB: Cardiovascular Universal Bed; PODx: Post-operative Day x

320x215mm (300 x 300 DPI)
APPENDIX
TDABC Model Template

The spreadsheet template that we use to calculate TDABC costs has 7 tabs:

1. **Cost Allocation** (Figure A.1)
   Allocation of personnel, equipment, space, and materials costs by process step

2. **Personnel Capacity**
   Time available for performing clinical work by personnel type

3. **Personnel Costs**
   Fully loaded cost of each personnel type and calculated capacity cost rate

4. **Equipment Costs**
   Fully loaded cost of each equipment type and calculated capacity cost rate

5. **Space Capacity**
   Time available for clinical use

6. **Space Costs**
   Fully loaded cost of space and calculated capacity cost rate (includes costs of equipment used in room)

7. **Materials Costs**
   Cost of materials consumed during care process

Below, we display “Cost Allocation” tab to give more verisimilitude about how data were collected and organized.
### Figure A.1: Allocation of personnel, equipment, space, and materials costs by process step

For the care process, this tab reports each activity, personnel type associated with the activity, space type the activity takes place, probability that the activity takes place, number of that type of personnel required for the activity, and process time for the activity. With these inputs, we calculate the probability weighted time for each activity. Using personnel capacity cost rates (from "Personnel Costs" tab) and probability weighted time, we allocate personnel costs. Next, we allocate the space and equipment cost (using data from “Space Costs” tab) and materials costs (from “Materials Costs” tab). The total cost for an activity is the sum of personnel, equipment and space, and materials costs.

| Map No | Process | Activity Code | Activity | Personnel type | Space | Probability Activity Takes Place | Number of That Type of Personnel | Process Time (min) | Probability Weighted Time (n=i*j*k) | Personnel CCR ($/min ("Personnel Costs" tab) | Allocated Personnel Cost ($) (i*l*m) | Space and Equipment CCR ($/min ("Space Costs" tab) | Allocated Space and Equipment Cost ($) (i*k*o) | Materials Costs ($) ("Materials Costs" Tab) | Total Costs ($) (n+p+q) |
|--------|---------|---------------|----------|-----------------|-------|-------------------------------|-------------------------------|---------------------|---------------------------------------|-------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| 1      | Office Visit | 1 | Patient check-in | Office Assistant | Reception | 100% | 1 | 7 | 7 | $0.68 | $4.79 | $0.10 | $0.67 | $0.00 | $5.46 |
| 1      | Office Visit | 2 | Initial patient assessment | Physician Assistant | Exam room | 100% | 1 | 6 | 6 | $1.35 | $8.08 | $0.06 | $0.34 | $0.00 | $8.43 |
| 1      | Office Visit | 3 | Take x-rays | X-Ray Tech | X-ray room | 85% | 2 | 7 | 12 | $0.72 | $8.55 | $0.53 | $1.16 | $1.70 | $13.41 |
| 1      | Office Visit | 4 | Scan, process, annotate image | X-Ray Tech | X-ray room | 85% | 1 | 5 | 4 | $0.72 | $3.05 | $0.53 | $2.26 | $0.00 | $5.31 |
| 1      | Office Visit | 5 | Review patient information before appointment | Surgeon | Office | 100% | 1 | 7 | 7 | $6.00 | $41.99 | $0.06 | $0.40 | $0.00 | $42.39 |
| 1      | Office Visit | 6 | Discuss X-rays with patient and develop plan of care | Surgeon | Exam room | 100% | 1 | 10 | 10 | $6.00 | $59.99 | $0.06 | $0.57 | $0.00 | $60.65 |
| 1      | Office Visit | 7 | Dictate notes, and consult with staff as needed | Surgeon | Office | 100% | 1 | 8 | 8 | $6.00 | $47.99 | $0.06 | $0.46 | $0.00 | $48.54 |
| 1      | Office Visit | 8 | Transcribe surgeon’s notes | Scribe | Office | 100% | 1 | 8 | 8 | $0.57 | $4.58 | $0.06 | $0.46 | $0.00 | $5.04 |
| 1      | Office Visit | 9 | Discuss surgery and answer | RN | Education room | 100% | 1 | 2 | 2 | $1.12 | $2.25 | $0.06 | $0.11 | $0.00 | $2.36 |
| 1      | Office Visit | 10 | Bring patient to education room | RN | Education room | 100% | 1 | 15 | 15 | $1.12 | $16.84 | $0.06 | $0.86 | $0.00 | $17.70 |
| 1      | Office Visit | 11 | Patient checks out | Office Assistant | Reception | 100% | 1 | 2 | 2 | $0.68 | $1.37 | $0.10 | $0.19 | $0.00 | $1.56 |

RN: Registered Nurse; CCR: Capacity Cost Rate