Cost Accounting System for an Emergency Department

by

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B.S., Carnegie Mellon University, 2009

Submitted to the Engineering Systems Division and the MIT Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Engineering Systems and Master of Business Administration

In conjunction with the Leaders for Global Operations Program at the Massachusetts Institute of Technology

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Abstract

In 2011, Michael Porter and Robert Kaplan – the godfather of modern managerial accounting and professor at Harvard Business School – said “There is an almost complete lack of understanding of how much it costs to deliver patient care, much less how those costs compare with the outcomes achieved.” They also stated “U.S. healthcare costs exceed 17% of GDP and continue to rise” and “a fundamental source of escalating costs is the system by which those costs are measured” [1]

In 2015, Beth Israel Deaconess Medical Center (BIDMC), a Harvard teaching hospital, and MIT’s Leaders for Global Operations program partnered to address this cost measurement issue for BIDMC’s Emergency Department (ED). The joint team developed a cost accounting model and implemented it as a software system.

Using the resulting system as a ruler for measuring cost of each patient visit, the ED is now able to assess cost of each visit, identify leverage points for cost reduction, and discover best practices from its own data. Most importantly, the ED is now making informed cost improvement decisions and can measure the impact of changes.

This paper documents in detail how we developed the cost accounting model and implemented the cost accounting system at the BIDMC ED, so that other emergency departments may be able to benefit.

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1. Overview

This first chapter sets context for the Beth Israel deaconess Medical Center’s (BIDMC) Emergency Department (ED) for the purpose of our project. This chapter also summarizes the problem, our approach to solving it, and the results and findings.

1.1. Context

For any nation, the management and delivery of healthcare is a critically important issue. Unfortunately, the US trails other developed nations in health and outcome measures despite spending significantly more on care [2] [3]. Furthermore, our healthcare costs have consumed an increasing share of GDP over the past fifteen years [4].

Within the overall healthcare costs, emergency medicine (i.e. the costs of emergency room visits) is an important component due to its scale and role as an entry point and filtering mechanism for the more expensive inpatient care [5] [6].

1.1.1. Emergency Medicine

Emergency medicine (EM) is a medical specialty caring for adult and pediatric patients with illnesses or injuries that require immediate and urgent medical attention [7]. EM physicians (MDs) diagnose a large variety of illnesses and focus on two objectives: If possible, they perform acute interventions to treat the illness and discharge the patient home. Otherwise, they resuscitate and stabilize patients enough to be admitted for more definitive inpatient care which could involve surgery and ICU (intensive care unit).

Historically, emergency care started in the military. Then, until 1960s, interns and residents often staffed emergency rooms at large hospitals. However, given the importance of the emergency care and the unique combination of skills required, EM was recognized as a medical specialty in 1979, making it one of the most modern medical specialties [5]. Today, emergency physicians require a broad field of knowledge and advanced procedural skills including airway management, surgical procedures, heart attack treatment, X-Rays interpretation, and even delivery of babies to name a few.
As a result, now emergency medicine plays an important role in our healthcare system as a 24-hour one-stop shop for urgent medical needs.

1.1.2. Emergency Department within a Hospital Business

As the emergency medicine matured as a specialty, emergency rooms have grown into emergency departments (EDs) and became a critical component of hospital businesses. Today, a hospital in the US may run an ED for three reasons:

1. **Generate revenue as a business unit.**

2. **Drive customer traffic for higher-margin inpatient care business:** In the last decade, inpatient business increased only 4% in number of admissions, but the ED-related inpatient admissions increased 17% [8].

3. **Medicare receiving hospitals are required** by federal law to provide care to anyone needing emergency healthcare treatment regardless of citizenship, legal status or ability to pay [9].

In practice, most EDs are successful at attracting inpatient customers and providing access to emergent care, but lose money as a business unit in the process. Worse yet, due to the lack of research on how to accurately measure the fixed and variable costs of ED visits, most hospitals don’t have a clear idea on just how much money their ED is losing (or making) and where within the ED the losses are happening [6].

1.2. Beth Israel Deaconess Medical Center (BIDMC)

BIDMC is a fully integrated medical center born from the 1996 merger of New England Deaconess and Beth Israel hospitals. Today, BIDMC is ranked each year as a "Best Hospital" by U.S. News & World Report in multiple specialties. Furthermore, BIDMC is the lead hospital of the CareGroup Network, a top 5 healthcare system in the country for quality and safety according to Thomson Reuters.
BIDMC provides adult care, with over 50,000 annual inpatient discharges, 540,000 outpatient visits, 649 licensed beds, and over 1,250 physicians, virtually all of whom are faculty at Harvard Medical School. As a result, BIDMC is focused on training the next generation of physicians and researching revolutionary therapies and healthcare management techniques.

Finally, as a "Most Wired" – and a "Most Wireless" – Hospital, BIDMC leads the way in healthcare information technology (IT) and all BIDMC clinicians use centrally hosted, certified electronic medical records [10]. This culture of modern IT made BIDMC a perfect medical center for studying cost-related data and implementing a software solution.

1.3. Emergency Department at BIDMC

The Emergency Department at BIDMC is a Level I Trauma Center serving the Boston metropolitan area with 59 beds, over 40 Attending physicians, 39 residents, and over 200 nurses and supporting staff. Each year nearly 55,000 patients are treated in the state-of-the-art ED, which includes dedicated CT scanning, bedside monitoring and registration, and enhanced communication systems.

Also, the BIDMC ED’s Division of Emergency Informatics has faculty members with board certifications in Medical Informatics. These MD-informaticians conduct relevant research and host a fellowship program to train the next generation of informaticians. For example, major components of the ED’s cutting edge information systems were developed in-house by these faculty members and fellows. The department director and this project’s supervisor Larry Nathanson, M.D. designed and programmed the "ED Dashboard", the ED information system that is used at BIDMC and a number of other hospitals. This project’s mentor Steven Horng, M.D. developed a Google Glass application for assisting diagnosis and documentation by the ED physicians [11].

Finally, Since the BIDMC leads the CareGroup network (i.e. BID network), the physicians affiliated with BIDMC ED oversee 7 other ambulatory care sites at BID Milton, BID Needham, BID Plymouth, St. Luke’s Hospital, St. Vincent’s Hospital, and 2 urgent cares, treating over 300,000 total annual ambulatory visits annually.
1.3.1. Chief Complaints

As a Level 1 Trauma Center, BIDMC ED receives every type of emergency cases. As these cases arrive “pre-diagnosis”, they are categorized by chief complaints. Chief complaints are very brief statement of the reason for the ED visit entered by the triage nurses. Also, some cases arrive to the ED with multiple chief complaints. In the FY2013, ED saw 9807 unique combinations of chief complaints, demonstrating the complexity of the ED environment similar to “a manufacturing floor dealing with almost ten thousand unique products”.

The following are the eight most typical cases as examples.

<table>
<thead>
<tr>
<th>Chief Complaint</th>
<th>Number of Visits in FY2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABD PAIN</td>
<td>3596</td>
</tr>
<tr>
<td>CHEST PAIN</td>
<td>1952</td>
</tr>
<tr>
<td>S/P FALL</td>
<td>1150</td>
</tr>
<tr>
<td>HEADACHE</td>
<td>806</td>
</tr>
<tr>
<td>SHORTNESS OF BREATH</td>
<td>784</td>
</tr>
<tr>
<td>FEVER</td>
<td>760</td>
</tr>
<tr>
<td>DYSPNEA</td>
<td>756</td>
</tr>
<tr>
<td>BACK PAIN</td>
<td>741</td>
</tr>
</tbody>
</table>

1.3.2. Organizational Structure

Executives: As one of the thirteen medical departments at BIDMC, the ED is headed by three individuals at the top:

1. Chief of Emergency Medicine (Chief): The chief has a “chairman” responsibility over the BIDMC ED and 7 other ambulatory care sites of the BID network. Chief reports directly to the CEO, manages over 150 Attending physicians and allied health providers, and oversees the residency program for 39 residents through the program director. As an Attending physician and faculty himself, the Chief also practices emergency medicine and instructs the residents.

---

2. Chief Administrative Officer (CAO): The CAO dual-reports to the ED Chief as the administrative head of all ambulatory care sites of the BID network. CAO manages all fiscal and administrative operations throughout the BID network.

3. Director of Ambulatory Services: This is a complex role combining management of over 100 nurses, over 30 technicians, and other direct labor as well as logistical and ancillary operations (e.g. supplies, ambulances, etc.) of all ambulatory care sites. This director dual-reports to the ED Chief and BIDMC SVP of Ambulatory and Emergency Services who reports to the CEO.

Operating Divisions: The Chief distributes medical responsibilities across these divisions run by his physicians and nurses. Examples are the residency program, QA, and informatics to name a few.

Harvard Medical Faculty Physicians (HMFP): The Attending physicians are employed by HMFP, a physicians group that is affiliated with BIDMC and Harvard Medical School. HMFP is contracted by the hospital for the physician services. HMFP manages the physicians, pays them directly, and provides them supports such as the malpractice insurance.

Harvard University: Given BIDMC’s teaching hospital designation, the Attending physicians are appointed as faculties at Harvard Medical School with varying ranks from instructors through professors. The 39 residents are therefore enrolled trainees of Harvard Medical School.

1.3.3. Process Flow
An average visit to BIDMC ED lasts around five and half hours and follows the following process:

1. Upon arriving, the patient is welcomed by a greeter who collects basic information. If arriving via ambulance, the patient goes directly to the next step. Otherwise, the patient may wait for the next step in the waiting room.
2. A triage nurse collects pertinent medical information, takes vitals, and listens to the symptoms. Then, the triage nurse registers the patient into the system and assigns chief complaint(s) and acuity level. These two labels determine how quickly the next step happens and in which part of the ED. For example, if the triage nurse is concerned that the patient is having a heart attack, stroke or another imminently life threatening condition they will call a rapid response "trigger" which mobilizes a team of physicians and nurses to immediately evaluate and stabilize the patient.

3. Based on the acuity, patients are assigned to different “zones” of the ED where a registered nurse and resident will “work up” the patient, draw blood for lab testing, and order other tests and scans as necessary. If the patient arrived in critical condition (by ED standard), multiple physicians and nurses will be involved in this process and may attempt immediate resuscitation.

4. The lab and scan results will allow the resident to diagnose the patient and order treatments. Every diagnosis and order is discussed and confirmed by the Attending physician for quality and learning.

5. The nurse will administer the treatments and continue to monitor the patient progress.

6. Once the patient condition is improved or stabilized, the resident will order discharge or admission appropriately with the Attending physician’s approval.

7. The nurse will process the discharge or admission.

8. Sometimes a decision to admit or discharge cannot be made without a longer period of monitoring and tests. These patients can be placed into ED Observation status for up to 23 hours prior to a decision to admit or discharge. This observation has an impact of the total length-of-stay in the ED and cost of the visit.
Once the patient is in one of the ED zones, the nurse is constantly managing the patient’s well-being medically and otherwise. To manage the nurse load, simpler tasks are often performed by the technicians. Depending on the patient condition, other personnel such as other personnel such as technicians or housekeepers may be involved.

1.4. Summary of Problems

As discussed in 1.1.2, many EDs are loss leaders as business units. This was not the case at BIDMC ED, where the annual reimbursements from the payers provided sufficient contribution margin to cover the direct labor and supply costs (not including hospital indirect costs such as utility, space, etc). However, the margin was slim and the reimbursement rates are coming down. The ED had to start reducing cost, without compromising on quality.

Unfortunately, the department was unable to answer the following basic questions necessary to identify opportunities and measure progress:

1. Was a particular patient visit contributing or detracting from the overall margin?
2. Which type of visit drives majority of the annual cost?
3. Which process step drives majority of the annual cost?
4. Which provider is deemed more cost-efficient?
5. Are individual providers or the department improving over time?

In short, they were missing a “ruler” for measuring the cost of each visit to compare against the reimbursements to understand their contributions to the hospital’s financial sustainability. Furthermore, the ruler was necessary to compare across the Attending physicians, chief complaints, or process steps to understand where the improvement opportunities existed.

---

2 The CAO tracked the average reimbursement vs. average cost, calculated as the fiscal year total cost divided by the number of visits.
1.5. Summary of Approach

At a very high level, we designed and implemented the “ruler” for measuring per-visit cost of every single ED patient visit. The project broke down into two phases:

1. **Cost accounting model:** We studied different ways of allocating variable and fixed costs across units produced from literature review and the manufacturing industry. Then, we combined and customized them to represent the actual environment of the ED, which is very different from other hospital services such as surgery which more closely resembles a manufacturing cell. We used regression analysis, time study, and other analytic methods to inform our custom modeling choices.

2. **Cost accounting system:** We implemented our trained model as managerial accounting software that runs daily to calculate standard costs, report on the per-visit cost of each patient visit from the prior day, and report on various cost-related and other aggregated performance metrics about providers, chief complaints, etc.

1.6. Summary of Findings and Next Steps

From this project, we learned various ways to design a cost accounting model for complex yet flexible ED environment and the method and value of implementing the model as a software system.

As a result, BIDMC ED can now assess the financial contribution of each visit, identify opportunity areas to reduce cost, and discover best practices as the direct result of the project works. *Chapter 7* discusses these findings in detail. Furthermore, *Section 5.4* summarizes the learnings specific to the cost accounting modeling and *Chapter 6* highlights learnings about the software implementation.

As the next step, BIDMC ED will continue to improve the accounting model and the software system. Furthermore, the cost performance management analytic tools will be extended to non-cost metrics such as throughput and also be applied to other departments and hospitals. Finally, being able to reliably differentiate expensive visits from the cost-efficient visits (e.g.
Table 5.8) unlocks a plethora of cost-related research topics which lacked the data to study until today.

Therefore, this project team hopes that future research will enrich the knowledge of ED cost management. Furthermore, we hope that other departments and hospitals will use this project as a baseline to implement their own cost accounting systems and begin to systematically and continuously improve cost performance.
2. Problem

In the previous chapter, we developed a case for the BIDMC Emergency Department (and EDs in general) to improve its cost efficiency without compromising on quality.

In fact, BIDMC ED made a few isolated attempts already, such as conducting Lean studies and instituting standardized processes (called clinical pathways) for cases based on a narrow set of symptoms. Unfortunately, each effort either wasn’t focused on big enough of a cost driver or the result couldn’t be quantified, because the ED didn’t have a reliable way to measure the cost of the patient visits it tried the new processes on.

Instead, to continuously improve its cost efficiency, ED needs an accurate costing, as it allows the impact of process improvements to be readily calculated, validated, and compared. With the right costing, ED should follow this systematic approach:

1. **Identify** the current cost of individual (or a set of) visits and assess their margin
2. **Prioritize** a similar set of visits, when their margin is improved, could have the largest impact on the financial sustainability of the ED
3. **Change** the process (or provider behavior) to improve the cost
4. **Measure** the result, then repeat

And to enable the above process, the ED had to first address the cost measurement problem, by building a good “ruler”.

2.1. The Emergency Department Cost Accounting Problem

Therefore, the ED invested in this project to develop a cost measurement (accounting) system for BIDMC ED that would measure cost, help prioritize interventions, and inform types of changes that could improve the cost efficiency.

Prior to this project, the current state of analysis for ED cost was limited in breadth and depth.

2.1.1. “Current” Approach
Basically, the ED Chief Administrative Officer (CAO) had a very difficult job of managing ED’s cost without the necessary data. He had reliable access to only the direct costs of operations.

1. Nurse, technician, and other hourly labor
2. Supplies purchased by the ED supply manager, such as IV bags and sutures
3. Residency program cost (including the resident salary)
4. ED administration labor
5. ED office supply and other office budget

With this data, he could track if the ED’s expenditure increased in aggregate and for per-visit basis. He could also tell which of the above five categories drove the increase or decrease.

2.1.2. Limited Depth of Analysis

In the current approach above, the CAO took the sum of the five categories of costs he knew (i.e. ED expenditure) then divided it by the number of patient visits to get per-visit cost.

\[
\text{per visit cost} = \frac{\text{ED expenditure}}{\text{num patient visits}}
\]

Unfortunately, this high-level analysis did not inform the CAO if a particular visit was actually profitable. He could assess if an overall average visit was becoming more or less costly per year, but couldn’t assess if a certain classes of visits were losing money while other classes of visits were subsidizing them. In managerial accounting terms, the CAO had “cost allocation” problem.

As a result, the CAO was under-equipped to direct the ED attention to classes of visits that would contribute the most to the financial sustainability of the ED through more
cost-efficient care. Also, the Chief of Emergency Medicine didn’t know which of his Attending physicians were most cost-efficient and hence potential role models.

2.1.3. Limited Breadth of Cost

To worsen the issue, the CAO’s dataset excluded the costs that the ED didn’t directly pay for but “caused” the hospital to spend in support of the ED’s business. So in reality, the CAO couldn’t even assess if the department as a whole was fiscally balanced inclusive of these shared costs.

1. Annual attending labor paid to HMFP (see 1.3.2 re: HMFP)
2. Costs that other departments – mainly radiology, lab, pharmacy, and blood bank – incurred to support the ED
3. Utility
4. Support teams such as IT and billing
5. Other hospital shared costs

To imprecisely compensate for this at the annual review, the hospital was charging ED an “indirect overhead” based on the ED’s square footage compared to the overall hospital real estate.

2.1.4. Current Approach Example

Hence, prior to this project, the following two visits couldn’t be distinguished in their costs because the “Cost to ED” of each visit was the average cost of all visits.

Table 2-1: Current Approach Example (pre-project)

<table>
<thead>
<tr>
<th></th>
<th>Visit A</th>
<th>Visit B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief Complaint</td>
<td>Abdominal Pain</td>
<td>Automobile Accident</td>
</tr>
<tr>
<td>Length of Stay</td>
<td>5 hours</td>
<td>10 hours (2 hours in obs)</td>
</tr>
<tr>
<td>Tests Run</td>
<td>1 set of blood test</td>
<td>1 set of blood test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MRI study</td>
</tr>
<tr>
<td>Supplies Used</td>
<td>1 bag of IV fluid with saline</td>
<td>1 half liter bags of blood</td>
</tr>
</tbody>
</table>
## 2.1.5. The Project Objective and Scope

To address these “lack of ruler” problems, this project focused on the following objectives and scope:

1. **Develop a cost accounting model** that estimates the full “variable cost” of each visit with the highest precision we could practically achieve in 3 months.

2. **Implement a software** that would estimate the variable cost of every visit on a daily basis according to the model and report those costs to the management in digestible format.

*All dollar figures in this paper are hypotheticals*

Notice that the average nurse labor cost per visit was “allocated” to both visits, despite the significant difference in complexity and the likely duration a nurse was occupied by each patient. Furthermore, blood, likely the most expensive component of the Visit B, is not included in the total cost because the ED administration doesn’t have visibility into the Blood Bank Department’s cost and lacks the information system to tie “orders” of blood to the “cost” of the blood.

<table>
<thead>
<tr>
<th></th>
<th>4 dosage of Vicodin</th>
<th>Sutures</th>
<th>Temporary Cast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nurse Labor</strong></td>
<td>$100</td>
<td>$100</td>
<td></td>
</tr>
<tr>
<td><strong>Technician Labor</strong></td>
<td>$20</td>
<td>$20</td>
<td></td>
</tr>
<tr>
<td><strong>...</strong></td>
<td><strong>...</strong></td>
<td><strong>...</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Medicine Cost</strong></td>
<td>Other department</td>
<td>Other department</td>
<td></td>
</tr>
<tr>
<td><strong>Blood Cost</strong></td>
<td>Other department</td>
<td>Other department</td>
<td></td>
</tr>
<tr>
<td><strong>Supply Cost</strong></td>
<td>$30</td>
<td>$30</td>
<td></td>
</tr>
<tr>
<td><strong>...</strong></td>
<td><strong>...</strong></td>
<td><strong>...</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost to ED</strong></td>
<td>$200</td>
<td>$200</td>
<td></td>
</tr>
</tbody>
</table>
The indirect cost (i.e. shared cost, overhead) were in scope, but wasn’t modeled out in the same precision as the variable cost was. BIDMC ED made this prioritization decision since it could more directly influence variable costs.

Also, we didn’t pursue a mathematically perfect cost accounting model that could prove exact cost of each visit in a closed-form. As cost accounting (aka managerial accounting) is intended to inform managerial actions, our objective was precise enough model that could still be explained simply and implemented within the project timeline.

We believe these prioritizations make this project as documented in this paper practical for other emergency departments to replicate for their use.
3. Literature Review on Cost Accounting

While there is very limited literature on cost accounting for Emergency Department specifically, this subject has been well studied in the manufacturing industry and more recently been applied to other parts of the healthcare delivery system. Therefore, we started this project with in-depth literature review of renowned accounting principles that would become the building blocks of our customized cost accounting model.

The following are highlights of our iterative literature review process, which informed the design of the cost accounting system implemented at BIDMC ED. We want to disclaim there were many other literature that informed the design and thank them.

3.1. Relevant Introduction to Managerial Accounting by Scott Keating [12]

MIT Sloan’s Prof. Keating’s book provides general survey of the managerial accounting terminologies and techniques that are utilized in the manufacturing floors and hospital floors alike.

3.1.1. Types of Costs

Cost Accounting discussed in this paper is an internal and managerial accounting process, by which administrators identify costs of operations and assess them. At the highest level, an organization’s costs break down into two categories.

- **Fixed cost** is a cost that does not change with the volume of activity or production.
- **Variable cost**, by contrast, varies with the volume of activity of a firm. It is important to identify which activity a particular variable cost varies with. For example, some hospital costs vary with the number of patients while others vary with the length of stay.

Often, accountants also divide costs into direct costs such as materials spent to produce goods versus indirects, i.e. overhead, such as utility that cannot be tied directly to a particular unit of good or service produced.
3.1.2. Standard Costs

In cost accounting, where one tries to understand the cost of producing a unit of product or providing a unit of service, managers are interested in being able to say “this unit costs x dollars” prospectively.

To do so, managers use historical cost data to decide standard cost for a particular unit of product or service. For example, if a stethoscope is made of metal, plastic, and rubber parts using an assembly tool by a technician, the standard cost of one unit can be defined based on one month of historical data. In other words, one month costs of all resources dedicated to production of stethoscopes are absorbed into the unit cost of each stethoscope.

Equation 3-1: Standard Cost Example

\[
\text{standard cost (per unit)} = \frac{\text{one month cost of metal} + \text{one month cost of plastic} + \text{one month cost of rubber} + \text{one month salary of technician} + \text{cost of a tool}}{\frac{\text{lifespan of a tool (months)}}{\text{number of units produced in a month}}}
\]

Once the standard cost is set, managers will use it as the estimate of any future unit of the same product (e.g. stethoscope) or service for decision making (e.g. pricing), until they update the standard cost.

Actually, the above equation only accounts for direct costs. Indirect costs – also referred to as overhead or period cost – are also divided by the expected unit production and absorbed into the standard cost of each unit.

3.1.3. Simple Multi-Product Cost Allocation
When an organization produces multiple products — for example, stethoscope and blood pressure cuff — the above process of determining standard costs become complex due to shared resources.

If the same technician assembles stethoscopes and blood pressure (BP) cuffs, his or her monthly salary needs to be absorbed into the units of both products produced in the past month.

Equation 3-2: Multi-Product Allocation Example

\[
\text{technician salary (per unit of Stethoscope or BP Cuff)} = \frac{\text{one month salary of technician}}{\text{number of units of stethoscope and BP cuffs produced in a month}}
\]

However, the above absorption wouldn't be appropriate if the technician takes twice as long to assemble a BP cuff than a stethoscope.

Simple multi-product cost allocation attempts to solve this by combining these shared resources into a pool of overhead, then allocating overhead to a unit of each product based on another metric such as direct cost. In that case, if stethoscope's standard cost excluding the technician salary was $100 and BP cuff's was $300, each unit of BP cuff would be allocated three times as much technician cost than a unit of stethoscope would.

3.1.4. Activity-based Costing

Activity-based costing is an alternative to traditional accounting in which a business's overheads (indirect costs such as lighting, heating and marketing) are allocated in proportion to an activity's direct costs as shown above. However, the above approach does not precisely reflect how different products utilize different resources at a different rate. [13]
To address this issue, Prof. Robert Kaplan of Harvard Business School introduced the following methodology of activity-based costing (ABC) in 1988. Using the technician example from above, a manager would perform ABC by:

- Listing all the activities the technician needs to do complete to produce a unit of Stethoscope and BP Cuff
- Asking the technician to estimate what percentage of his or her time is spent on each activity in a month
- Determining a standard cost of each activity
- Summing the cost of each activity for every activity required for Stethoscope, arriving at a standard technician cost for a unit of Stethoscope
- Doing the same for BP Cuff

Activity-based costing is valuable in healthcare delivery environment because almost every service shares resources with other services (e.g. two different types of surgeries would share the same nurse).

3.1.5. Transfer Pricing

If an organization has many departments, one department may consume services of another to produce goods such as a stethoscope. In that case, the supporting department would charge transfer price to the producing department.

In a hospital, a surgical unit would not only incur standard cost of a surgery such as appendectomy based on all the resources and activities consumed, it would also need to account for transfer price of medicine provided by the pharmacy department.

3.1.6. Performance Measurement

Accounting information is frequently used in the process of evaluating and rewarding people’s performances in organizations. For example, a hospital may reward cost-efficient surgeons and evangelize their surgical methods as best practices. To do so, the cost measurement has to be precise and accurate. Otherwise, the hospital can end up instituting a best practice that was incorrectly measured to be best. Hence, this project
focused on development and implementation of a cost accounting ruler with reasonable precision.

3.2. Time-Driven Activity-Based Costing

While the activity-based costing was an improvement over the traditional overhead allocation, it was difficult to get accurate cost measurements by surveying employees. It was also difficult to model service environments where an employee performed many different tasks. As a result, at one large bank’s brokerage operation, the ABC data-gathering process required 70,000 employees at more than 100 facilities to submit monthly reports of their time allocation. [14]

Therefore, Robert Kaplan introduced time-driven activity-based costing (TD-ABC) in 2004 where managers directly estimate the resource demands imposed by each transaction, product, or customer, to arrive at an equation as below. [14] Then, the manager can multiply the packaging time by per-minute salary of the packer to calculate the standard cost of packaging a special, air-shipping item.

Equation 3-3: Time-driven Activity-based Costing Example

\[
\text{Packaging Time (minute)} = 0.5 + 6.5 \text{ (if special packaging)} + 2.0 \text{ (if air shipping)}
\]

In the emergency room setting, TD-ABC can be used to estimate the labor cost of drawing blood for lab testing or other common tasks.

3.3. Nurse Workload Measures

While the traditional standard costing can cover materials cost and TD-ABC can cover procedure labor, we needed another method for modeling nurse and other labor cost incurred for the general patient care but not for specific procedures or activities.
For example, if a patient is held in the emergency department for observation after an acute treatment, nurses aren’t providing particular procedures that can be time-studied but are monitoring the patient vitals, communicating with the patient, and providing general care. Based on literature review, the following ICU (intensive care unit) nursing labor models provided best approximations of what we needed for the ED.

- **TISS (Therapeutic Intervention Scoring System)** – Developed in 1974, determines how much nursing time is required to care for an ICU patient for an hour based on acuity. TISS evolved in complexity till 1996 where TISS-28 categorized nurse cost based on 28 parameters not just acuity.

- **NEMS (Nine Equivalent of Nursing Manpower Score)** – Developed in 1997, where regression analysis was used to narrow down TISS-28 to none most influential variables and simplified the scoring process.

- **NAS (Nursing Activity Score)** – Published in 2003 as an evolution of TISS/NEMS to cover 81% of variations in nursing time as opposed to 60%.

In general, these models calculate labor requirement as the amount of nursing capacity different patients require based on several characteristics, i.e. parameters like age. This approach inspired our linear regression based estimation of non-procedure labor cost as discussed in section 4.2.1.3 Nurse Non-Procedure Labor.

### 3.4. Cost Accounting for Health Care Organizations

Finally, the 1994 article “Cost Accounting for Emergency Services” by John Moorhead, MD, informed how to combine the above accounting techniques to design a cost accounting system specifically for an emergency department.

According to Moorhead, costs that are generally of interest to ED managers are the “direct” cost of providing care, including variable and fixed direct cost. [15] To measure and track them, a manager can follow the below process. [16]
1. **Define cost elements**

First step is defining the categories of costs to be included in the accounting model. Moorhead listed direct labor, indirect labor, supplies, department overhead, and institution overhead as the common ED costs. Our project started with his list and added transfer costs of other departments’ resources consumed during the care of an ED patient visit.

2. **Define unit of cost**

Another step is defining the unit of cost. While the ultimate goal is to estimate the cost of each individual ED patient visit, there are many ways to break down the visit cost. Moore provided two examples.

First, every ED visit results in one or more diagnosis. Because each diagnosis is arrived at via a similar set of actions which consume similar resources, it is possible to determine a *standard cost* for each diagnosis. Then, the total cost of a visit will be estimated as the sum of standard costs of all the diagnosis provided.

Equation 3-4: Visit Cost via Diagnosis

\[
\text{Visit Cost} = \sum_{\text{each diagnosis given for that visit}} \text{Standard cost of diagnosis}
\]

Alternatively, every ED visit is also made of a list of procedures provided. Therefore, it is possible to determine a *standard cost* for each procedure. In this case, the total cost of a visit will be estimated as the sum of standard costs of all the procedures provided.

Equation 3-5: Visit Cost via Procedures

\[
\text{Visit Cost} = \sum_{\text{each procedure performed for that visit}} \text{Standard cost of procedure}
\]
Both approaches have drawbacks. BIDMC ED managers wanted to not only review cost retroactively, but also estimate them in real-time or prospectively. Therefore, estimating visit cost based on diagnosis which is given at the end of an ED visit was not suitable. On the other hand, time studying each procedure and identifying supplies consumed for each procedure is cost prohibitive.

Therefore, this project used per-procedure costing – also known as job order costing – but categorized the procedures into several buckets to simplify data collection. Furthermore, because each ED visit incurs costs that are not the result of a specific job order, we modeled it separately as non-procedure labor cost and overhead.

3. **Model direct nursing costs**

Nursing cost is the largest category of cost in emergency departments. When a nurse’s time is spent on executing procedures for a patient, it is direct nursing cost that can be modeled as a job order cost.

4. **Model indirect nursing costs**

Nursing activities like monitoring the vitals of a group of patients are not direct procedures, they can be categorized as indirect nursing labor costs.

5. **Model other labor**

Moorehead suggests modeling physician, technician, and other medical labor that aren’t directly tied to each procedure separately from the nursing labor costs.

6. **Model supply**

Each procedure incurs direct nursing cost and direct material cost, such as the cost of a syringe. Moorehead suggest mapping significant material cost (i.e. expensive items) to individual procedures while treating insignificant materials as a shared cost to be allocated or absorbed based on acuity or length of stay.

7. **Model overhead**

38
To complete Moorehead’s process, department and institution overhead must be modeled and incorporated.

The above 7-step process would allow a manager to determine standard cost of each procedure, absorption rate of non-procedure cost, and allocation of overhead to calculate the cost of each individual visit.

Our project largely followed Moorehead’s process but made different modeling decisions than his suggestions.
4. Literature Review on Healthcare IT

For the *system implementation* phase of our project, we relied less on the literature review and more on the team’s experience.

BIDMC ED Informatics team had an in-house capability to design, develop, and deploy software for immediate use on the ED floor and management suite. In fact, most of the IT system used in the ED were developed in-house, rather than purchased. Therefore, it was practical to develop the system how the informatics team was used to developing software, even if it deviated from the industry best practices.

For the more common cases where the IT implementation has to be performed by the hospital IT department, outside developers, or consultants*, it is important to consider best practices in software development methodologies. Therefore, we’ve included a brief literature review that can assist other EDs in planning their cost accounting system implementation.

*Outsourcing IT development is considered the best practice for healthcare organizations, outside of cases like BIDMC ED which acts as an R&D lab for the ED industry. [17]*

4.1. Choice of the Developer

First, the ED will need to choose an appropriate developer. The hospital might have an IT department who develops new IT systems as needed and understands existing systems well. The ED could also hire an outside vendor.

2004 IET journal *Manufacturing Engineer*, provides a helpful framework for making an outsourcing decision such as this. [18] As demonstrated below, an organization may choose to outsource for four different reasons.

*Figure 4-1: Reasons for Outsourcing*
For an emergency department, cost accounting software system can be considered `Strategic Outsourcing`. It means the project is a bottleneck to the organization’s strategic initiative but the primary goal of outsourcing isn’t to get it done cheaper.

Therefore, if the ED believes an outside vendor has successfully implemented cost accounting systems for other EDs, it is advisable to choose that vendor. If the hospital’s IT department has implemented cost accounting systems for other departments successfully, they should take on the ED cost accounting project in-house. Either way, the ED is advised against choosing a low-cost or generic vendor without a specialty in this strategic project.

If an emergency department decides to outsource, the following IEEE publications can guide it to form an outsourcing agreement, consider the outsourcing risks, and align the stakeholders:

- **Outsourcing Decisions & Models – Some Practical Considerations for Large Organizations.** [19]
- **The Ins and Outs of IT Outsourcing.** [20]
4.2. Development Process

Another important decision is which software development model the ED would employ.

At a high level, *Structured vs. Agile methods* provide the tradeoff of a stable plan versus flexibility. [21] In other words, agile methods such as *scrum* allow the developers to prototype small pieces of the system in successive *iterations* to be validated by the ED staffs, while structured methods like *waterfall* start implementation only after a thoroughly documented requirements and project plan are signed off.

Because the iterative, agile methods do not need to over-invest in the analysis and design stages to build a bullet-proof plan, it is intended to offer cost efficiency and faster time to market. [21] However, this is not always the case as a 76-sample study in Switzerland [22] and simulation in India [23] found. For example, the following table from the Indian study demonstrates not an absolute cost advantage for one model but how different stages of resources are consumed in each model.

![Figure 4-2: Waterfall vs. Agile Cost Model](image)

<table>
<thead>
<tr>
<th>Resource</th>
<th>Iterative Waterfall model</th>
<th>Incremental model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Analyst</td>
<td>8.60</td>
<td>2.27</td>
</tr>
<tr>
<td>Designers</td>
<td>20.10</td>
<td>6.22</td>
</tr>
<tr>
<td>Programmers</td>
<td>33.81</td>
<td>70.03</td>
</tr>
<tr>
<td>Testers</td>
<td>13.32</td>
<td>79.89</td>
</tr>
<tr>
<td>Maintenance man</td>
<td>5.78</td>
<td>5.24</td>
</tr>
</tbody>
</table>

For this project, the first phase – *cost accounting modeling* – generated in depth requirement and design of how the software should compute cost. Therefore, it was clear that the waterfall model would offer better economics for the remaining software work. Furthermore, we wanted to avoid the additional iterations interrupting the MDs from their core responsibilities.

4.3. Requirements Engineering
Requirement engineering is the first step of structured and agile models and critical to a successful project. For example, the below figure demonstrates the cost of correcting a mistake in requirement in a later stage. [24]

**Figure 4-3: Cost of a Software Defect**

In performing the requirements engineering IEEE recommends a five step approach [25].

1. **Software requirement elicitation:** Software user and the developer collaborate to discover, review, articulate, and understand the user’s needs.

2. **Software requirement analysis:** The developer thinks through the collected needs to understand them in terms of the software requirements.

3. **Software requirement specification:** The developer documents software requirements in clear and precise terms.

4. **Software requirement verification:** The developer and user confirm that the requirements address the user needs comprehensively. The developer also ensures that the software requirements specification is in compliance with the system requirements, conforms to document standards of the requirements phase, and is an adequate basis for the design phase.
5. **Software requirement management:** Throughout design, implementation, and QA phases, the developer maintains and updates the requirements elicitation, specification, analysis, and verification activities as needed and justified.

In our project, all five steps were completed in a handful of internal meetings within the ED Informatics Department due to a unique set of capabilities and experiences. At other ED sites, MDs, nurses, supply managers, and administrators should work closely with the software development team throughout the requirements phase.

### 4.4. Other Considerations

We believe the other considerations in software development are unique to different ED sites, their existing IT infrastructure, and the development team’s capabilities and preference.

For example, there isn’t one academically right answer on which design pattern to use for the general architecture of the system. This project used a variation of the model-view-controller (MVC) pattern but other approaches would have right as well.

Therefore, we advise other ED sites to make the remaining software development decisions based on their unique circumstances. To raise awareness of key factors, *Chapter 5* documents some of the decisions this project team made.
5. **Cost Accounting Model**

As discussed in the problem statement, the goal of this project was to develop a software that will precisely and accurately measure the cost of each patient visit at BIDMC ED. The ultimate goal is to repeatedly answer questions around the margin of each visit, opportunity areas to reduce cost, and best practices for cost efficiency.

To address this problem statement, the first phase was developing a customized accounting model by applying the various principles learned from the literature review. This chapter discusses our design decisions and the final model, which incorporates standard costing, absorption costing, time-driven activity-based costing, and more. While this model was customized for BIDMC ED, we believe it can be implemented in other emergency or ambulatory care sites as-is or with small modifications.

5.1. **Cost Breakdown**

Following the Moorehead's process from the literature review [16], we first identified the cost elements of BIDMC ED to be included in the scope. The total cost was broken down into components then grouped as variable or fixed. The following sections 4.2. *Variable Costs* and 4.3. *Fixed Costs* will discuss how each component of the ED cost can be best modeled for accurate and precise cost accounting.
Other labor and other consultations are examples of insignificant costs that were excluded from the scope. Research funding was excluded as that cost is for different business purpose than direct patient care.

5.2. Variable Costs

Variable costs consist of labor, supplies, and transfer prices of other departments' resources consumed. Procedure-driven variable costs are allocated to specific procedures and remaining variable costs are allocated across visits based on length of stay, acuity, and several other parameters.
5.2.1. Nurse Labor

Nurse labor is a part of the variable labor and the most significant single cost category for the entire emergency department. Therefore, allocating nurse labor to the appropriate procedures and visits is critical to the overall accuracy and precision of the accounting model.

To do so, we separated nurse labor into two categories: procedure labor and general care labor. Then, we applied time-driven activity-based costing and labor intensity model respectively.

**Nurse Procedure Labor**

An emergency department visit can be viewed as a collection of procedures intended to cure or stabilize the patient. Most of these procedures are performed by a registered nurse, either based on a physician order or nurse’s discretion. Most emergency departments, including BIDMC, record these discreet procedures in a computer system.

If we can estimate the labor cost of each procedure, then this digitized data format allows us to sum up the labor cost for the entire visit, helping us estimate the largest component of the per-visit cost. *(Remember that estimating the per-visit cost is the ultimate goal of this project.)* As discussed in the literature review, Robert Kaplan’s recent time-driven activity-based costing is a good method for determining the standard labor cost of each procedure. [1]

For example, we could time how long a sample of nurses take to administer a particular pain medication Hydromorphone via syringe and take the average as the standard time in hours (more likely fraction of an hour). Then, we can multiply the standard time by per-hour salary of an average nurse to arrive at the “standard labor cost for pain medication Hydromorphone administration via syringe”.

However, unlike the highly specialized surgical nurses and other hospital staff, ED nurses perform hundreds of different procedures like the Hydromorphone example. This
makes taking a sample of nurses to perform hundreds of tasks and timing them very impractical.

Therefore, we classified procedures into three categories and prioritized them.

<table>
<thead>
<tr>
<th>Time-consuming</th>
<th>Quick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>A</td>
</tr>
<tr>
<td>Infrequent</td>
<td>B</td>
</tr>
</tbody>
</table>

- **Type A**: Most frequent tasks that consume 80% of the nursing time.
- **Type B**: Infrequent tasks, which are unusually time consuming such that inclusion of that task in the course of a patient visit can significantly increase the amount of nursing labor consumed by that visit.
- **Type C**: Infrequent tasks, which aren’t unusually expensive.

Based on the Pareto Principle (i.e. 80-20 rule), we focused our time studies on **Type A** and **Type B** tasks. Furthermore, similar tasks in **Type A** were grouped together.

For example, the time it takes a nurse to administer *Hydromorphone* via syringe is much longer than oral administration as a pill. However, oral administration of most medicine such as *Hydromorphone* and *Acetaminophen* are relatively similar. Therefore, we grouped oral administration of all “pills” into one **Type A** task and time studied a sample of 50 administrations. Then, we used the median of that measurement – *let’s hypothetically say 3 minutes* – as the *standard time* for administering a pill. Finally, we multiplied the 3 minute with the standard per-hour salary of a registered ED nurse – *let’s hypothetically say $60 inclusive of all the benefits, training, and support costs* – to arrive at $3 per-procedure as the *standard cost* of administering a pill.

Based on the exemplified process, we estimated the following *standard times*. Note that the actual figures in minutes are arbitrary for the purpose of demonstration.
The table above shows averages that are typically higher than median. The standard deviation is significant compared to the average as well. This is primarily due to the following three variations resulting in a long-tail distribution of the observed times.

- **Variation across patients:** Depending on the patient demographic and clinical factors, certain tasks could take longer. For example, administering IV medication for an 80-year-old female takes longer than 30-year-old male because of the difficulty in accessing their vein. This variation can be modeled by regressing the nurse time on the relevant demographic and clinical factors. Based on the result, we could assign different standard time and standard cost to different patients. In this project, we did not pursue this layer to err on the side of simple and easier-to-implement system.

- **Variation across nurses:** Different nurses have different skill levels and can take a different length of time for the same task (assuming the same patient). However, since the patient is not requesting a particular nurse, the model should not assign higher cost to a visit because the assigned nurse was slower. Therefore, this project time studied the same task (or group of tasks) across several nurses to address the variation across the nurses.

- **Variation across tasks:** Finally, because the above statistics were for groups of similar tasks, the variation between tasks such as Hydromorphone pill and

### Table 5-2: Procedure Standard Times

<table>
<thead>
<tr>
<th>Task Group</th>
<th>Standard Time (median)</th>
<th>Average</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med – IV</td>
<td>7</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Med – PO (oral pill)</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Med – Nasal</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Vital</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Lab</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Radiology Escort</td>
<td>10</td>
<td>11</td>
<td>4</td>
</tr>
</tbody>
</table>

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- **Variation across tasks:** Finally, because the above statistics were for groups of similar tasks, the variation between tasks such as Hydromorphone pill and
acetaminophen pill will drive the standard deviation of Med-PO and make median (or average) an imprecise estimate for the standard time. The tradeoff is between precision of the standard time and number of standard times we have to time study.

Again, applying the Pareto Principle, the nursing leadership at BIDMC ED provided a list of around a hundred tasks that take far longer than their "group" does in the above table. Those tasks were categorized as Type B and marked for further time study.

However, to ensure a full-blown time study of those tasks will not delay our implementation, we modeled those long-duration tasks as Other Procedures and assigned 20 minutes of standard time based on a small sample. Future projects should time study Type B tasks one by one to ensure further accuracy of their models.

The following update to the table includes these other tasks.

Table 5-3: Procedure Standard Times, including "other procedure"

<table>
<thead>
<tr>
<th>Task Group</th>
<th>Standard Time (median)</th>
<th>Average</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med – IV</td>
<td>7</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Med – PO (oral pill)</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Med – Nasal</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Vital Check</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Blood Infusion</td>
<td>8</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Radiology Escort</td>
<td>10</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td><strong>Other Procedure</strong></td>
<td><strong>20, estimated</strong></td>
<td>did not sample</td>
<td>did not sample</td>
</tr>
</tbody>
</table>

Based on the above table, nurse per-procedure labor cost can be stated as follows:
Equation 5-1: Nurse Procedure Time

\[
\text{total procedure time} = \sum_{\text{IV orders}} 7\,\text{min} + \sum_{\text{PO orders}} 3\,\text{min} + \sum_{\text{Nasal orders}} 5\,\text{min} + \sum_{\text{vital check}} 3\,\text{min} + \sum_{\text{blood infusion}} 8\,\text{min} + \sum_{\text{rad escort}} 10\,\text{min} + \sum_{\text{other procedure order}} 20\,\text{min}
\]

Equation 5-2: Nurse Procedure Cost

\[
\text{nurse procedure cost} = \text{total procedure time} \times \text{nurse salary rate}
\]

**Nurse Procedure-Set Labor**

At BIDMC ED, some procedures consume nursing time in non-linear ways. Unlike the procedures in the previous section, the following three groups of procedures do not linearly grow in cost based on the number of procedures the physician orders.

- **Drawing Blood for Lab**: Drawing blood samples and sending them to the lab is the single most frequent group of tasks that an ED nurse performs. The physicians order tens of different lab tests and nurses draw blood into different containers (mostly tubes of different colors) for different lab tests.

  While shadowing the nursing team, we noticed that the time it takes for nurses to draw blood for one lab and eight labs did not differ significantly. This is because the actual process of waiting for the blood to fill up the small test tube makes up for less than 10% of the nursing time spent on executing on a batch of lab orders.

  The entire process consists of preparing the containers, finding a vein, drawing the blood, sealing the containers, documenting for the lab, and sending the samples up to the lab via a vacuum-drive transport system.
Therefore, this project followed the nursing team’s recommendation to estimate *standard time* for a batch of lab orders – *hypothetically say 8 minutes* – rather than individual lab orders to avoid double counting.

- **Collecting Urine Sample for Lab**: Collecting urine sample is similar to blood sample, while less frequent and typically taking longer for each set.

- **Radiology Escort**: ED physicians typically order multiple radiology scans at a time, such as *Chest X-Ray View #1, Chest X-Ray View #2, Head X-Ray View #7,* and *Head MRI View #3* for a single patient. The time an ED nurse spends escorting a patient to these radiology exams varied based on the number of different radiology rooms the patient was escorted to (*typically 1 or 2*) rather than the number of exams, since most of the time was spent on travelling and set-up. Therefore, the ED nurse labor of a radiology order was modeled as variable cost per set. Also, the patients are often escorted by a special transporter, which we excluded in this modeling exercise.

Finally, the comprehensive procedure-related standard time table incorporates these procedure-set standard times.

<table>
<thead>
<tr>
<th>Task Group</th>
<th>Standard Time (median)</th>
<th>Average</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med – IV</td>
<td>7</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Med – PO (oral pill)</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Med – Nasal</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Vital Check</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Blood Infusion</td>
<td>8</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Radiology Escort</td>
<td>10</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Other Procedure</td>
<td>20, estimated</td>
<td>did not sample</td>
<td>did not sample</td>
</tr>
<tr>
<td><em>Lab batch</em></td>
<td>8</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
Urine batch  |  12  |  11*  |  3  
Radiology per room** |  18  |  22  |  6  

*Average is lower than median as few urine sample collections took less than 3 minutes while the most took around 12 minutes, due to patient variation which we did not separately model in our project for simplicity.

The different components of nurse procedure-set cost can be combined together:

Equation 5-3: Nurse Procedure-Set Time

\[
\text{total procedure\_set time} = \sum_{\text{lab batches}} 8 \text{ min} + \sum_{\text{urine batch}} 12 \text{ min} + \sum_{\text{radiology room}} 18 \text{ min}
\]

Equation 5-4: Nurse Procedure-Set Cost

\[
\text{nurse procedure\_set cost} = \text{total procedure\_set time} \times \text{nurse salary rate}
\]

**Nurse General Care Labor**

As discussed in the section 3.3 Nurse Workload Measures, a nurse’s time is consumed executing on physician-ordered procedures and also providing general care for the ED patients. At BIDMC ED, this non-procedure labor was almost a half of a registered nurse’s workday.

The activity-based costing is inappropriate for modeling this general care work for two reasons. First, these general care tasks are not discreet assembly line tasks with an expected duration (i.e. standard time). Second, because BIDMC ED does not electronically record these tasks, standard cost for each general task cannot be directly allocated to each visit.

Upon further literature review, we found similar environment (i.e. general care) in ICU that was modeled using intensity of labor methods. For example, NEMS was published...
in 1997 as a way to predict the amount of nursing labor required by a patient in an hour of ICU stay based on nine independent variables.

Therefore, we modeled the nurse general care labor at BIDMC ED using linear regression.

\[
\text{general care intensity} = a_1\text{Age} + a_2\text{Gender} + a_3\text{EnglishSpeaking} + a_4\text{Acuity} + a_5\text{CanWalk}
\]

In the above equation, intensity is defined as minutes of nurse labor consumed for non-procedure general care during one hour of patient's ED stay. \(a_1\) is a positive number. So, each extra year of age increases the intensity of care required by the patient.

However, our model is not perfect. For example, age was modeled as a linear variable. Because children and the elderly require more intense care than young adults, age should be modeled non-linearly. However, since BIDMC ED generally direct below-teenage patients to the Boston Children's Hospital ED next door, this simplification was justified.

Any ED site can build a similar or better model following this process:

1. Select a large enough sample of patient visits.
2. For each visit, assign a time keeper to follow the patient with a stop watch.
3. The time keeper records the total time a nurse(s) spend providing general care to the patient. It is important that the time keeper exclude the time the nurse spends executing on physician-ordered procedures.
4. Fit a linear regression or another prediction model. Regress the recorded general care time on other factors about the patient that could matter, such as the five independent variables we modeled for BIDMC ED.
Once we know the intensity, we can multiply that by \textit{length of stay} to arrive at the nursing time spent on providing non-procedure general care to the patient.

\textbf{Equation 5-6: Nurse General Care Time}

\[ \text{general care time} = \text{general care intensity} \times \text{length of stay} \]

\textbf{Equation 5-7: Nurse General Care Cost}

\[ \text{nurse general care cost} = \text{general care time} \times \text{nurse salary rate} \]

\textit{Consolidated Nurse Labor Model}

Finally, all of the above components of nurse labor can be summarized into the following and be converted into hard dollars in cost.

\textbf{Equation 5-8: Nurse Labor Cost}

\[
\text{total nurse time} = \sum_{\text{procedure}} \text{standard time per procedure} \\
+ \sum_{\text{set of labs}} \text{standard time per set} \\
+ \sum_{\text{set of urine}} \text{standard time per set} \\
+ \sum_{\text{radiology room}} \text{standard escort time} \\
+ \text{general care time}
\]

\[ \text{nurse labor cost} = \text{total nurse time} \times \text{nurse salary rate} \]
5.2.2. Other Variable Labor

Nurses are not the only direct labor that is consumed by each patient visit. As discussed in the Section 1.3.3. Process Flow, greeters, triage nurse, medical technicians, and observers are other caregivers whose direct labor needs to be accounted for.

**Triage Nurse**

Triage nurses are registered nurses who see the ED patient before any other medical staff and assigns chief complaint(s) and acuity to the visit. This allows the patient to receive an appropriate priority in the ED. How long a triage nurse spends with a patient is not very varied – *in some cases standardized or even regulated*. Therefore, we can use the average cost as the standard cost per patient.

\[
\text{triage nurse cost} = \frac{\text{total triage nursing staff salary in a year}}{\text{number of ED visits in a year}}
\]

**Medical Technicians**

Medical technicians assist registered nurses in performing both physician-ordered procedures and non-procedure general care. Therefore, a patient who consumes more nurse labor will consume more technician labor. We can model technician labor cost per visit as follows. For BIDMC ED, we used one year as the *period*.

\[
\text{nursing labor consumption rate} = \frac{\text{nurse labor consumed by the visit}}{\text{nurse labor forecasted for the period}}
\]

**Equation 5-11: Technician Time**

\[
\text{technician time consumed} = \text{technician labor forecasted for the period} \times \text{nursing consumption rate}
\]
**Equation 5-12: Technician Labor Cost**

\[ \text{technician labor cost} = \text{technician labor consumed} \times \text{technician salary rate} \]

**Medical Observers**

Observers are more narrowly skilled direct labor. They monitor an emergency department patient who is placed in observation in the department. As they are assigned one-on-one to a patient, the cost can be calculated as below.

**Equation 5-13: Observer Labor Cost**

\[ \text{observer labor cost} = \text{length of observation} \times \text{observer salary rate} \]

**Other Direct Labor**

Other direct labor, such as registration clerk or unit secretaries do not account for a significant portion of the overall direct labor cost at BIDMC ED. Therefore, this project decided to allocate it based on length of stay (LOS) as if we were absorbing overhead on LOS basis. Other projects could allocate based on LOS, other metrics, or simply divide the annual cost evenly across all visits.

**Equation 5-14: Other Direct Labor Cost**

\[
\begin{align*}
\text{other direct labor cost} &= \frac{\text{annual cost of remaining direct labor}}{
\sum_{\text{every visit}} \frac{\text{length of stay of visit}}{\text{length of stay in a year}}}
\end{align*}
\]

**Consolidated Variable Labor Cost Model**

Combining the nurse labor and other variable labor gives us the total cost of all variable labor consumed by the patient visit.
Equation 5-15: Variable Labor Cost

\[
variable \text{ labor cost} = \\
(\text{total nurse time } \times \text{nurse salary rate}) \\
+ (\text{technician time } \times \text{technician salary rate}) \\
+ (\text{server time } \times \text{server salary rate}) \\
+ \text{triage nurse cost} + \text{other direct labor}
\]

5.2.3. Supplies

After direct labor (i.e. variable labor), materials and supplies are the largest buckets of variable cost for many service organizations [15]. This is true at BIDMC ED, where the supplies can be categorized into three buckets. Like the direct labor, some supplies are procedure specific like syringes while others are general use like towels.

Table 5-5: Supply Prioritization

<table>
<thead>
<tr>
<th>Procedure Specific</th>
<th>General Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medications</td>
<td>Yes</td>
</tr>
<tr>
<td>Blood Bank</td>
<td>Yes</td>
</tr>
<tr>
<td>Procedure Supplies</td>
<td>Yes</td>
</tr>
<tr>
<td>General Supplies</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Medications**

Medications are rigorously tracked in hospital IT systems for medical, financial, and regulatory purposes. Therefore, BIDMC ED has a detailed electronic records of which patient received what medication on which visit. This makes it easy to identify which patient visit was responsible for which set of medication costs the hospital incurred. However, how much those medications cost the hospital is more difficult to determine for three reasons:

- **Scope of Cost:** First, the cost accounting model has to consider what costs to include, without double counting any.
Will it only include the payments the hospital made to the suppliers of the medications? What about the cost of transportation, storage, and salary of the procurement team and pharmacy?

While there are many right design choices, this project only included the price of the medications paid the suppliers. The costs of operating pharmacy and procurement department were rolled into the institution overhead under fixed cost.

- **Metric of Standard:** Unlike the nurse salary rate which changes infrequently – typically as a result of an inflation raise or union negotiation, the price of medications and related costs fluctuate regularly.

The medication price fluctuates throughout the year depending on supply and demand, as well as availability of generics. The transportation cost fluctuates with gas prices while procurement department can become more expensive when overstaffed. Therefore, the model has to decide whether to use a snapshot at the beginning of the year, annual average, industry standard, or some other figure.

This project used the trailing one-year average of medication unit price only (i.e. payments to suppliers) as the standard cost for medications.

- **Granularity of Medication:** As we grouped similar nurse procedure tasks together to minimize time studies, the cost accounting model can group medicines together.

For example, a pain killer Morphine can be administered over IV in 1mg, 2mg, or 4mg quantities depending on the patient need. Should they be assigned different standard costs? What if the hospital stocks 4mg vials only and discards the leftover even if only 1mg if administered? What if the hospital purchases 2mg and 4mg vials but they do not differ significantly in purchase price?
Again, there are many *right choices* depending on the hospital’s drug procurement policies and the amount of sophistication desired in the model. For BIDMC ED, we treated different dosages of the same medication as different supplies which required its own standard costs.

However, because it was not practical to historically track the price trend of almost 5,000 different dosages of several hundred medications used at BIDMC ED, we used the Pareto Principle again to track around 400 of them while using the average for the rest.

Table 5-6: Medication Prioritization

<table>
<thead>
<tr>
<th></th>
<th>Under $10</th>
<th>Over $10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequently Used</td>
<td>200 medication-dosages tracked</td>
<td></td>
</tr>
<tr>
<td>Infrequently Used</td>
<td>$5 was used as the standard cost for this group</td>
<td>200 medication-dosages tracked</td>
</tr>
</tbody>
</table>

Once the standard cost is determined for each medication-dosage, the model can *allocate* them to the patient visit which consumed those supplies.

Equation 5-16: Medication Supply Cost

\[
\text{medication cost} = \sum_{\text{medication-dosage prescribed}} \text{standard cost}
\]

**Blood Bank**

Some of the most expensive supplies consumed in an ED are the blood transfusion bags provided by a blood bank, costing hundreds of dollars per one half-liter bag of blood. Just like medications, blood transfusion orders are rigorously documented and the standard costs of these bags require determination of scope, metric, and granularity.
Again, there are many right choices. This project used the blood supply price charged to the patient (or payer) as the standard cost. We determined this standard cost for every unique type and volume of blood product regardless of frequency of use, since they were all expensive enough to drastically change the overall cost of an ED visit.

With this setup, the blood bank cost can be rolled up to each patient visit as:

Equation 5-17: Blood Bank Supply Cost

\[
\text{blood bank cost} = \sum_{\text{blood type and dosage prescribed}} \text{standard cost}
\]

 Procedure Supplies

To set standard prices for procedure-specific supplies like syringes and temporary cast, we need to consider the same three modeling decisions: scope of cost, metric of standard, and granularity of supply. For BIDMC ED, this project used the trailing year average unit price paid to distributors.

For the procedure-specific supplies, we also had to decide how to handle shrinkage, i.e. loss of supplies due to breaking, theft, and misplacement. This project decided to report them separately and exclude them from per-visit cost.

Shrinkage applies to medications and blood supplies as well, especially due to expiration. However, medication and blood bank shrinkage is not as significant and factored into the institution overhead. Hence, we didn’t want to double count it by incorporating into variable supply cost.

As the result, the procedure-specific supplies are modeled the same as the previous two supply types.
Equation 5-18: Procedure Supply Cost

\[
\text{procedure supply cost} = \sum_{\text{procedures orders}} \text{standard cost}
\]

**General Supplies**

Finally, as nurses performed non-procedure general care tasks, some supplies are for general care of ED patients and not procedure specific. Most frequent examples include towels, bed sheets, examination gloves, and lunchboxes. At BIDMC ED (and likely at other EDs), each usage of a towel is not electronically recorded.

Most of these supplies are used once per visit or throughout the length of the visit. This project decided to allocate this cost based on length of stay similar to how we modeled the medical observer labor.

Equation 5-19: General Supply Cost

\[
\text{general supply cost} = \text{total annual price paid to distributors for general supplies} \\
\times \left( \frac{\text{length of stay of visit}}{\sum_{\text{every visit in a year}} \text{length of stay}} \right)
\]

The above equation uses the total amount of dollars paid to distributors in a year. This implies LIFO (last in, first out) method and assumes that the quantity of supplies purchased in the fiscal year is same as the amount used in that year. These are simplifying assumptions and opportunities for future improvements to the model.

**Consolidated Supply Cost Model**

The above components of the supply cost can be combined into the total supply cost of the visit.

Equation 5-20: Supply Cost
Supply Cost = Medication Cost + Blood Bank Cost
+ Procedure Supply Cost + General Supply Cost

5.2.4. Transfer Costs

Transfer costs – also known as transfer prices – are incurred when one department (A) consumes resources of another (B) to serve customers of A. As discussed in section 3.1.5. Transfer Pricing, this process allows the parent company to recognize B’s contribution to A’s business.

BIDMC emergency department (A in this case) commonly uses the resources of lab, radiology, and cardiology departments (B’s) to treat its patients (A’s customer). As these resource consumption varies depending on patient condition and ED physician’s usage, we need to model the transfer costs these departments charge the ED – or ED’s payer – as variable costs.

Lab Cost

When nurses collect blood or urine samples, the lab “department” processes them and electronically sends the results back to the emergency department. Because the labs orders are placed by ED physicians and electronically recorded, the cost accounting model can aggregate the transfer costs to the patient visit the labs were conducted for.

Equation 5-21: Lab Transfer Cost

\[ \text{lab transfer cost} = \sum_{\text{each lab ordered}} \text{transfer price} \]

As a company, it is important to set appropriate transfer price in the above equation. Otherwise, ED’s margin may look inaccurately high or low. For our project, we used the patient charges for the labs as the transfer price. This could have been too high since charges are usually higher than the actual costs. However, to identify the true cost of running a unit of lab, we would need to conduct a full-blown cost accounting modeling exercise like this one for the lab department.
Radiology Cost
Radiology provides X-Ray, MRI, CT Scan, and Ultrasound upon ED physician's order. The order and results are electronically recorded.

Equation 5-22: Radiology Transfer Cost

\[
\text{radiology transfer costs} = \sum_{\text{each scan ordered}} \text{transfer price}
\]

Again, patient charges were used for transfer price and could have been over-estimations. Because the radiology equipments are expensive, how the radiology department’s cost model accounts for depreciation can significantly alter the transfer price.

Cardiology Cost
Cardiology related costs include diagnostic studies such as electrocardiography (ECG), stress tests and echocardiograms (heart ultrasound) for emergency department patients. The resources consumed for this service can be modeled similarly as other transfer costs.

Equation 5-23: Cardiology Transfer Cost

\[
\text{cardiology transfer cost} = \sum_{\text{each service performed}} \text{transfer price}
\]

Consolidated Transfer Cost Model
The above components of the transfer costs can be combined into the total transfer cost of the visit.

Equation 5-24: Transfer Cost

\[
\text{transfer cost} = \text{lab cost} + \text{radiology cost} + \text{cardiology cost}
\]
To be detailed, some ED patient visits require the resources of other departments such as OBGYN often through consultations. Specifically, the ED often requests the consultations of other departments such as Cardiology, Neurology, Surgery, OBGYN, etc. in caring for complex patients. Cardiology consults are common and therefore included in the transfer costs. The other consults are rarer and it is impractical to model every other department in the hospital. Therefore, these costs are included in the institution overhead fixed cost.

5.2.5. Variable Cost Summarized Model

Modeling variable cost for emergency department is a complex exercise. Activities in service industry in general are extremely diverse and often no direct relationship between input and output exists. Services also cannot be stored [17]. ED is an exaggerated example of such an environment where a nurse performs hundreds of different tasks, many of them at the same time for different product (i.e. patients). [16] This is a big contrast to assembly-line manufacturing environment. Therefore, a single canonical cost accounting method cannot model the full ED environment.

To address this, we broke BIDMC ED’s variable costs into different major components and applied appropriate cost accounting methods in a customized manner. Based on this exercise, the following is the full model of the BIDMC ED’s variable costs.

Equation 5.25: Variable Cost (of a patient visit)

\[
\text{variable cost of a patient visit} = \\
(nurse\ procedure\ cost + nurse\ procedure\_set\ cost + nurse\ general\ care\ cost) + \\
(triage\ nurse\ cost + technician\ labor\ cost + observer\ labor\ cost + other\ direct\ labor\ cost) + \\
(medication\ cost + procedure\ supply\ cost + general\ supply\ cost) + \\
(lab\ transfer\ cost + radiology\ transfer\ cost + cardiology\ transfer\ cost)
\]

Various cost accounting methods used to model different components of BIDMC ED variable costs is summarized.
### Table 5-7: Variable Cost Allocation Method Summary

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Labor - Nurse</td>
<td>Nurse Procedure</td>
<td>per procedure</td>
</tr>
<tr>
<td></td>
<td>Nurse Procedure-Set</td>
<td>per set</td>
</tr>
<tr>
<td></td>
<td>Nurse General Care</td>
<td>per LOS</td>
</tr>
<tr>
<td>Direct Labor - Other</td>
<td>Triage Nurse</td>
<td>per visit</td>
</tr>
<tr>
<td></td>
<td>Medical Technician</td>
<td>per nurse procedure cost</td>
</tr>
<tr>
<td></td>
<td>Medical Observer</td>
<td>per length of observation</td>
</tr>
<tr>
<td></td>
<td>Other Direct Labor</td>
<td>per length of stay</td>
</tr>
<tr>
<td>Supplies</td>
<td>Medication</td>
<td>per dosage</td>
</tr>
<tr>
<td></td>
<td>Procedure Supply</td>
<td>per unit of supply</td>
</tr>
<tr>
<td></td>
<td>General Supply</td>
<td>per LOS</td>
</tr>
<tr>
<td>Transfer Costs</td>
<td>Lab Transfer Cost</td>
<td>per lab test</td>
</tr>
<tr>
<td></td>
<td>Radiology Transfer Cost</td>
<td>per radiology study</td>
</tr>
<tr>
<td></td>
<td>Cardiology Cost</td>
<td>per cardiology test</td>
</tr>
</tbody>
</table>

### 5.3. Fixed Costs

Fixed cost, by definition, is a cost that does not change with the volume of activity or production [12].

In practice, managers sometimes include cost components that vary based on volume of service but are insignificant in size or difficult to track what it varies on into fixed costs. For example, the section 4.2.3.1 Medications discussed this project’s decision to include the direct labor cost of the pharmacy department incurred in providing medications for ED patient visits into the institute overhead under fixed cost.

Furthermore, cost that is fixed in short-term can be variable in the long run. On the flip side, cost that can be theoretically variable may be better modeled as fixed, if the management cannot manipulate the quantity of that resource consumed in providing services. Therefore, this project considered any cost that the Chief of Emergency Medicine cannot vary in the short-term as a fixed cost.
After identifying the full scope of fixed cost, we allocated each component of the fixed cost appropriately to individual visits as we did with the variable costs.

5.3.1. Emergency Department Fixed Labor

BIDMC ED employs many roles whose workload does not vary in the short term based on the patient volume, patient mix, and physician-ordered procedures. Therefore, these labor costs are fixed for the purpose of our cost model.

**Attending Labor (HMFP Contract)**

As described in section 1.3.2 Organizational structure, the Attending physicians at BIDMC ED are not direct employees of the hospital. Instead, they are employed by Harvard Medical Faculty Physicians (HMFP).

Specifically, HMFP is affiliated with BIDMC ED and provides a skilled labor supply. Furthermore, BIDMC ED maintains a stable level of Attending labor each week regardless of the actually observed demand to ensure capacity in case of spike in ED demand and to guarantee high-quality learning environment for its residents.

Given this environment, the Chief of Emergency Medicine plans the attending labor volume annually. Therefore, the attending labor is fixed for the most part within a fiscal year.

There are several possible ways to allocate attending labor – one of the most significant cost components of an ED – to appropriate patient visits. The following are few possible choices, where some of the options treat the attending labor as variable cost:

- **Time-driven Activity-based Costing**: As with the nurse procedure labor, an attending labor can be broken down into different types of tasks the MD carries out. Then, each type could be time studied to assign a standard time, which can be multiplied by hourly salary rate to arrive at standard cost per each attending task.
However, because a routine task like reading a lab report varies significantly in duration depending on the patient condition, the standard cost may need to be a probabilistic distribution, complicating the model.

Furthermore, unlike many nurse tasks which are triggered by electronically recorded physician orders, physician tasks in the upstream are not electronically recorded rigorously. They may be recorded in physician notes. But the notes are not structured or complete. Therefore, even if we had standard cost per attending task, we could not identify which visit consumed how many units of which physician task.

- **Labor Intensity Model:** As with the nurse general care labor, an attending labor can be modeled based on intensity of consumption. A regression model can estimate attending labor intensity based on attributes of the patient. The following is a hypothetical example of what such a model could look like.

  Equation 5-26: Attending Labor Intensity

  \[
  \text{attending labor intensity} = a_1 \text{Age} + a_2 \text{EnglishSpeaking} + a_3 \text{Acuity} + a_4 \text{Consult}
  \]

  Then, an equitable fraction of the annual Attending contract cost can be absorbed by each patient visit based on the Attending labor intensity metric.

  Equation 5-27: Attending Fixed Labor Cost (on intensity)

  \[
  \text{attending labor cost} = \text{annual total attending labor cost} \times \left( \frac{\text{attending labor intensity}}{\sum_{\text{every visit in a year}} \text{attending labor intensity}} \right)
  \]
Based on Other Resource: We could hypothesize that a patient who consumes more of a nurse's time will consume more of the Attending's time as well. If this is proven true, we can allocate Attending labor cost based on nurse labor cost, as we did with the medical technician labor cost. If the nurse time and Attending time consumption rates are not correlated, we could continue to look for other resource usage rates that correlate.

The following examples demonstrate how this approach could be modeled if nurse time correlates with Attending time.

Equation 5-28: Nursing Labor Consumption Rate

\[
\text{nursing consumption rate} = \frac{\text{nurse labor consumed by the visit}}{\text{nurse labor forecasted for the period}}
\]

\[
\text{attending labor consumed} = \text{attending labor capacity for the year} \\
\times \text{nursing consumption rate}
\]

Equation 5-29: Attending Fixed Labor Cost (on nursing labor consumption)

\[
\text{attending labor cost} = \text{attending labor consumed} \times \text{HMFP contract cost}
\]

The Attending labor cost can be allocated based on other resources or metrics as well. Total variable cost, length of stay, or other relevant metrics could be used in place of the nurse labor cost.

Even Allocation: Finally, the simplest method is to evenly distribute the Attending labor cost across all visits.

Equation 5-30: Attending Fixed Labor Cost (even allocation)

\[
\text{attending labor cost} = \frac{\text{annual HMFP contract cost}}{\text{number of ED visits in a year}}
\]
This project chose the *even allocation* for two reasons. First, it is simple and in-line with how we allocated other fixed costs. Second, because BIDMC ED will *prepare* a certain amount of Attending time for each patient visit even if the visit turns out to require less Attending time, it makes sense to use fixed allocation.

We believe labor intensity model and basing allocation on other resources are also reasonably practical methods that future projects should consider.

**Resident Labor**

BIDMC emergency department employs and provides hands-on training in Emergency Medicine to 39 residents\(^3\). There are similar set of options for allocating the resident salary. This project decided on the *even allocation*.

\[
\text{Equation 5.31: Resident Fixed Labor Cost}
\]

\[
\text{resident labor cost} = \frac{\text{annual resident salary}}{\text{number of ED visits in a year}}
\]

There are additional costs to running the residency teaching program. For example, academic materials and program administration labor are required. However, these costs are excluded from the scope of this project as they are not consumed directly for the purpose of immediate patient care.

**Administrative Labor**

BIDMC ED employs administrative staff whose tasks are purely non-clinical. The Chief Administrative Officer, coding staff, and executive assistants are obvious examples. Additionally, some physicians and nurses have administrative roles in addition to clinical roles. For example, the *Chief of Emergency Medicine* works up to two shifts on the ED floor a week. However, the majority of his time is spent directing BIDMC ED and its

---

\(^3\) BIDMC ED offers 3-year residency program with 13 students per class year. Therefore, in any year, there are total of 39 residents in training.
network of seven ambulatory care sites. Therefore, his clinical time is included in the Attending labor cost and managerial time is included in the administrative labor.

Because the amount of administrative is not directly related to the volume of emergency care provided, our model allocates administrative labor evenly across all patient visits.

Equation 5-32: Administrative Clinician Salary

\[
\text{administrative clinician salary} = \text{clinician salary} \times \frac{\text{hours of non clinical work}}{\text{total hours of work}}
\]

Equation 5-33: Administrative Fixed Labor Cost

\[
\text{administrative labor cost} = \frac{\text{annual administrative staff salary} + \text{administrative clinician salary}}{\text{number of ED visits in a year}}
\]

The administrative labor – which is mostly managerial and secretarial – does depend largely on the number of other employees in the ED. However, because all administrative personal at BIDMC ED are full-time, their salary cost does not vary in the short term.

**Consolidated ED Fixed Labor Model**

The major components of ED fixed labor cost discussed above can be summarized as follows.

Equation 5-34: Fixed Labor Cost

\[
\text{fixed labor cost} = \frac{\text{annual attending labor} + \text{resident salary} + (\text{administrative staff salary} + \text{administrative clinician salary})}{\text{number of ED visits in a year}}
\]
5.3.2. Emergency Department Overhead

BIDMC ED pays for many resources and services beyond what’s discussed so far. We call these shared resources overhead or shared resource cost.

- **Equipment & Maintenance**: BIDMC ED purchases, uses, and maintains many clinical and administrative equipments from Stryker patient beds to physician iPads to furniture for the administrative office. Some of these equipments are purchased through the BIDMC procurement department for economies of scale while others are independently purchased and maintained.

- **Cleaning, security, and other upkeep**: After each patient stay, the patient room has to be cleaned for the next patient. Since the ED receives mentally ill patients and involve other risky scenarios, security is an important expense for the department. There are other upkeeps that is cost of doing business for the ED.

Our model allocates the cost of these resources evenly across visits.

Equation 5-35: ED Overhead Cost

\[
ED \text{ overhead cost} = \frac{\text{annual ED overhead total}}{\text{number of ED visits in a year}}
\]

5.3.3. Institution Overhead

Some resources that BIDMC ED consumes to care for patients are neither paid for by the ED nor charged to the ED by the hospital procurement department. Major examples are real estate, utility, and support departments.

Section 4.2.3 Medications discussed how the direct labor of pharmacists consumed in providing ED with necessary medications is not included in ED variable cost while actually medicine costs are. The hospital’s cost of running the pharmacy exclusive of the price of medications – which can be charged to each patient visit – is included in the
institution overhead. Other examples include billing department, employee shuttle service, and even the hospital executives.

Because the institution is paying for this overhead consumed by all clinical departments (i.e. revenue centers), there are two levels of allocation decisions to make.

- **Allocation across departments:** To understand which of its revenue centers are contributing to the hospital's margin or getting subsidized, the hospital Chief Financial Officer (CFO) has to determine how much of the hospital's overhead each department is responsible for. This is a critical exercise for large teaching hospitals where hospital overhead can be almost half of the operating cost.

  Therefore, every CFO employs what he believes to be the most appropriate allocation of hospital overhead (OH) across different departments. BIDMC uses a custom equation using key independent variables such as square footage of each department.

  This project is focused on enabling the Chief of Emergency Medicine and his staff to make informed cost decisions. Therefore, we focused on modeling the cost within the ED according to the real world and used the hospital overhead that ED as charged to as a given. We call this amount "ED Share" of institute overhead.

- **Allocation within emergency department, across different patient visits:** Once we know the ED share of institute overhead, ED can decide how to allocate that amount across ED patient visits. Just like other fixed costs, this project allocated it evenly across all visits.

  

  \[ \text{Institute overhead cost} = \frac{\text{"ED share" of institute overhead}}{\text{number of ED visits in a year}} \]

  

  **Equation 5-36:** Institute Overhead Cost
5.3.4. Fixed Cost Summarized Model

Finally, the major components of ED fixed cost can be summarized as follows.

Equation 5.37: Fixed Cost (of a patient visit)

\[
\text{fixed cost per visit} = \frac{\text{annual attending labor} + \text{resident salary} + \left(\text{administrative staff salary} + \text{administrative clinician salary}\right) + \text{annual ED overhead} + \text{"ED Share" of annual institute overhead}}{\text{number of ED visits in a year}}
\]

5.4. Conclusion of Accounting Modeling

The problem statement for this project was to develop a software that will precisely and accurate measure the cost of each patient visit at BIDMC ED. To do so, the first step was developing, validating, and populating the appropriate cost accounting model for the ED environment.

Therefore, this chapter #5 described the various cost components of the ED, how they behave in the real world, possible modeling choices we considered, and what this project actually implemented and populated. For example, choosing the right allocation method was obvious for some costs while requiring novel approaches for other costs. Since a triage nurse spends very similar amount of time across patients, it was obvious to allocate triage nurse cost evenly across all visits. However, we learned that the nurse time spent on drawing blood for lab is varied on number of batches not individual lab count only by spending time on the ED floor. Therefore, the value of time on the floor and watching the data (not just collecting it) cannot be stressed enough.

We hope that our learning process, literature review, and unique factors of the ED environment documented in detail will serve as a resource for future cost accounting projects. Furthermore, we hope the cost accounting model this project built for BIDMC ED will be a good baseline sample for the future ED cost accounting models to improve upon.
5.4.1. Final Accounting Model

To conclude this chapter, our final cost accounting model incorporates all major components of BIDMC ED as shown below.

Equation 5-38: Total Visit Cost (top layer)

\[
\text{total visit cost} = \text{variable cost} + \text{fixed cost}
\]

Equation 5-39: Total Visit Cost (middle layer)

\[
\text{total visit cost} = (\text{variable labor cost} + \text{supply cost} + \text{transfer cost}) + (\text{annual fixed labor cost} + \text{ED overhead cost} + \text{institution overhead cost}) \frac{\text{number of ED visits in a year}}{
\text{number of ED visits in a year}}
\]

Equation 5-40: Total Visit Cost (full blown model)

\[
\text{total visit cost} = \\
\text{Variable Cost} \quad \text{nurse labor cost}
\]
\[
\begin{align*}
&= \left( \sum_{\text{procedure}} \text{standard time per procedure} + \sum_{\text{set of labs}} \text{standard time per set} \\
&\quad + \sum_{\text{set of urine}} \text{standard time per set} + \sum_{\text{radiology room}} \text{standard escort time} \\
&\quad + \text{general care time} \right) \times \text{nurse salary rate} \\
&\quad + \frac{\text{total triage nursing staff salary in a year}}{\text{number of ED visits in a year}} \\
&\quad + \frac{\text{nurse labor consumed by the visit}}{\text{nurse labor forecasted for the period}} \times \text{total technician staff salary in a year} \\
&\quad + \text{length of patient observation} \times \text{observer salary rate} \\
&\quad + \text{annual cost of remaining direct labor} \times \left( \frac{\text{length of stay of visit}}{\sum_{\text{every visit in a year}} \text{length of stay}} \right) \\
&\quad + \sum_{\text{medication}} \text{standard cost} \frac{\text{dosage prescribed}}{} \\
&\quad + \sum_{\text{procedures}} \text{standard cost} \frac{\text{orders}}{} \\
&\quad + \left[ \text{total annual price paid to distributors for general supplies} \right. \\
&\quad \times \left( \frac{\text{length of stay of visit}}{\sum_{\text{every visit in a year}} \text{length of stay}} \right) \\
&\quad + \sum_{\text{each lab}} \text{transfer price} \frac{\text{ordered}}{} \\
&\quad + \sum_{\text{each radiology}} \text{transfer price} \frac{\text{scan ordered}}{} \\
&\quad + \sum_{\text{each cardiology}} \text{transfer price} \frac{\text{test ordered}}{} \\
&\text{Fixed Cost}
\end{align*}
\]
annual attending labor + resident salary 
+ administrative staff salary 
+ administrative clinician salary 
+ annual ED overhead 
+ "ED Share" of annual institute overhead

number of ED visits in a year

5.4.2. Result: Finalized Model vs. Current State

The below table from Section 2.1.4 illustrated BIDMC ED’s inability to differentiate low cost visits from the high cost visits, lacking a ruler that measures cost of each visit.

*Note: All dollar figures in this section are hypothetical

Table 5-8: Current Approach Example (pre-project)

<table>
<thead>
<tr>
<th>Visit A</th>
<th>Visit B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief Complaint</td>
<td>Abdominal Pain</td>
</tr>
<tr>
<td>Length of Stay</td>
<td>5 hours</td>
</tr>
<tr>
<td>Tests Run</td>
<td>1 set of blood test (all basic)</td>
</tr>
<tr>
<td>Supplies Used</td>
<td>1 bag of IV fluid with saline</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Nurse Labor</td>
<td>$100</td>
</tr>
<tr>
<td>Technician Labor</td>
<td>$20</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Medicine Cost</td>
<td>Other department</td>
</tr>
<tr>
<td>Blood Cost</td>
<td>Other department</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Total Cost to ED</td>
<td>$200</td>
</tr>
</tbody>
</table>
Using equation 5-40 as the ruler, we can now differentiate Visit A and B based on actual resources that each patient consumed as shown in Table 4-9 below. Aside from highlighting the total cost differences of almost four times, this new model provides other important insights. For example, while $2/3$ of Visit A’s cost is in overhead (i.e. not due to the patient attributes or clinician actions), $8/10$ of Visit B’s cost is in variable cost.

Also, medicine, blood bank, and other costs that were previously neglected are now included giving us a more realistic cost of each visit. The full detail is in the next page.

Table 5-9: Model Application Example (post-project)

<table>
<thead>
<tr>
<th></th>
<th>Visit A</th>
<th>Visit B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nurse Labor</td>
<td>$15</td>
<td>$158</td>
</tr>
<tr>
<td>Triage Nurse Labor</td>
<td>$10</td>
<td>$10</td>
</tr>
<tr>
<td>Medicine Cost</td>
<td>$18</td>
<td>$8</td>
</tr>
<tr>
<td>Blood Cost</td>
<td>$0</td>
<td>$250</td>
</tr>
<tr>
<td>Variable Cost</td>
<td>$100.84</td>
<td>$818.14</td>
</tr>
<tr>
<td>Fixed Cost</td>
<td>$206</td>
<td>$206</td>
</tr>
<tr>
<td><strong>Total Cost to ED</strong></td>
<td><strong>$306.84</strong></td>
<td><strong>$1,124.98</strong></td>
</tr>
</tbody>
</table>

Although this new ruler is not simple—equation 5-40 takes over a page to write—it is powerful. This model measures (or estimates) each visit cost with significantly improved accuracy and precision. The model also provides a drill down view of which component is driving the variations in cost as demonstrated in Table 5-9.

Given the obvious value of this model, our project proceeded to implement it into an electronic cost accounting system at BIDMC ED. Chapter 6 will describe our software development process, software design choices, and the final implementation. Chapter 7 will discuss results and findings of this project, picking up from this result section.
We hope that this section has demonstrated the value of cost accounting at emergency departments. We also hope that this Chapter 5 will help other EDs design a cost accounting model, Chapter 6 will help them implement a system, and Chapter 7 will show them immediate ways to leverage the system to improve ED costs.

Finally, the following is the full application of BIDMC ED cost model on the Visit A and B that Table 5-9 summarized.

**Nurse Labor Cost**

\[ A' \text{'}s \text{ procedure time} = \frac{7\text{min}}{IV} \times 1 \text{ IV order} = 7 \text{ min} \]
\[ A' \text{'}s \text{ procedure set time} = \frac{8\text{min}}{blood \ set} \times 1 \text{ blood set} = 8 \text{ min} \]
\[ A' \text{'}s \text{ nurse labor cost} = (7 \text{ min} + 8 \text{ min}) \times 60/\text{hour} = 15 \]

\[ B' \text{'}s \text{ procedure time} = \left(\frac{3\text{min}}{PO} \times 4 \text{ doses of PO}\right) + \left(\frac{20\text{min}}{other \ procedure} \times [4 \text{ blood} + 1 \text{ suture} + 1 \text{ cast}]\right) = 132 \text{ min} \]
\[ B' \text{'}s \text{ procedure set time} = \left(\frac{8\text{min}}{blood \ set} \times 1 \text{ blood set}\right) + \left(\frac{18\text{min}}{radiology \ room} \times 1 \text{ radiology room}\right) = 26 \text{ min} \]
\[ B' \text{'}s \text{ nurse labor cost} = (132 \text{ min} + 26 \text{ min}) \times 60/\text{hour} = 158 \]

**Other Direct Labor Cost**

Assume total annual triage nursing staff salary = $500,000

triage nurse cost for A, B, or other visits =

\[ \frac{$500,000}{50,000 \text{ visits a year}} = 10/\text{visit} \]

Assume annual nursing staff salary and all benefits = $10,000,000

Assume annual technician staff salary and all benefits = $1,000,000

\[ A' \text{'}s \text{ nursing labor consumption rate} = \frac{15}{10,000,000} = 1.5^{-7} \]
A's technician labor cost = $1.50
B's nursing labor consumption rate = \( \frac{\$150}{\$10,000,000} = 1.58^{-6} \)
A's technician labor cost = $1.58^{-6} \times \$1,000,000 = $15.80

A's observer labor cost = 0 minutes in observation \times \$15/\text{hour} = \$0
B's observer labor cost = 60 minutes in observation \times \$15/\text{hour} = 30

Assume annual cost of remaining direct labor = $1,000,000
Assume sum of all LOS in a year = 300,000 hours
A's other direct labor cost = 5 hours/300,000 hours \times \$1,000,000 = $16.67
B's other direct labor cost = 8 hours/300,000 hours \times \$1,000,000 = $26.67

A's other direct labor cost = $10 + $1.50 + $0 + $16.67 = $28.17
B's other direct labor cost = $10 + $15.80 + $30 + $26.67 = $82.47

Supply Cost
Assume annual general supply cost = $1,000,000
Assume sum of all LOS in a year = 300,000 hours

A's medication cost = \( \frac{\$15}{\text{IV bag}} \times 1 \text{ IV bag} = \$15 \)
A's blood bank cost = $0
A's procedure supply cost = \( \left( \frac{\$10}{\text{IV supply}} \times 1 \text{ IV order} \right) + \left( \frac{\$1}{\text{lab Tube}} \times 8 \text{ lab orders} \right) = \$18 \)
A's general supply cost = 5 hours/300,000 hours \times \$1,000,000 = $16.67
A's supply cost = $15 + $0 + $18 + $16.67 = $49.67

B's medication cost = \( \frac{\$2}{\text{Vicodin Dose}} \times 4 \text{ Vicodin Doses} = \$8 \)
B's blood bank cost = \( \frac{\$250}{\text{type A blood half liter bag}} \times 1 \text{ type A half liter bag} = \$250 \)
B's procedure supply cost = \( \left( \frac{\$15}{\text{transfusion supply}} \times 1 \text{ blood bag order} \right) \)
+ \left( \frac{\$1}{\text{labTube}} \times 14 \text{ lab orders} \right) + \left( \frac{\$10}{\text{suture kit}} \times 1 \text{ suture} \right) + \left( \frac{\$50}{\text{cast}} \times 1 \text{ cast order} \right) = \$89

B's general supply cost = 8 \text{ hours}/300,000 \text{ hours} \times \$1,000,000 = \$26.67
B's supply cost = \$8 + \$250 + \$89 + \$26.67 = \$373.67

**Transfer Cost**

\[ A's \text{ transfer cost } = \sum_8 \text{ basic labs } \$1 = \$8 \]

\[ B's \text{ transfer cost } = \sum_8 \text{ basic labs } \$1 + \sum_4 \text{ specialized labs } \$4 + \sum_3 \text{ MRI scans } \$60 = \$204 \]

**Fixed Cost**

Assume annual HMFP contract (sans teaching portion) = \$3,000,000
Assume annual resident salary = \$1,500,000
Assume annual administrative staff salary = \$1,000,000
Assume annual administrative clinician salary = \$800,000
Any visit's fixed labor cost = \((\$4M + \$1.5M + \$1.5M + \$1M)/50,000 \text{ visits} = \$126\)

Assume annual ED overhead = \$2,000,000
Any visit's ED overhead cost = \$2,000,000/50,000 \text{ visits} = \$40

Assume annual ED share of institution overhead = \$10,000,000
Any visit's institute overhead cost = \$2,000,000/50,000 \text{ visits} = \$40

\[ \text{Any visit's fixed cost } = \$126 + \$40 + \$120 = \$206 \]

**Total Visit Cost**

\[ A's \text{ variable cost } = \$15 \text{ nurse labor cost} + \$28.17 \text{ other direct labor cost} \]
$49.67 + 8 transfer cost = 100.84

Any visit’s fixed cost = $126 ED fixed labor + $40 ED overhead
+$40 institute overhead = 206

A's total visit cost = $100.84 VC + $206 FC = $306.84

B’s variable cost = $158 nurse labor cost + $82.47 other direct labor cost
+$373.67 supply cost + $204 transfer cost = 818.14

Any visit’s fixed cost = $126 ED fixed labor + $40 ED overhead
+$40 institute overhead = 206

B’s total visit cost = $818.14 VC + $206 FC = $1,124.98
6. Cost Accounting System

The goal of this project was to develop a software that will precisely and accurately measure the cost of each patient visit at BIDMC ED. The ultimate goal is to repeatedly answer questions around the financial impact of each visit, opportunity areas to reduce cost, and best practices for cost efficiency. To address this problem statement, the first phase was developing a customized accounting model. Chapter #4 described the modeling work and results in detail.

This chapter describes the second phase — system implementation, in several parts:

1. The software requirements at BIDMC ED, which may be different from the needs at other emergency departments.
2. Choice of programming language, which influences the cost of development, performance of the finished product, and extensibility of adding more features.
3. Environment setup, namely what machine the system will run on and how it will be triggered.
4. Data sourcing strategies for various types of data needed for calculating standard costs and allocating them to the appropriate visits.
5. Finally, three major components of the system — standard cost calculator, per-visit cost allocator, and reporting tools — and their implementation.

Unlike the final model in Chapter #4, the final implementation and decisions along the way described in Chapter #5 is very specific to BIDMC ED. It depended on the ED’s managerial needs, existing IT infrastructure and capability, and data structure and availability. Therefore, the final system implementation is not as portable to other ED sites as the final model in Equation 5-40 is.

However, to implement their own detailed cost accounting system, other emergency departments will need to consider some or all of the factors documented here. Therefore, we believe the engineering details and overall process detailed in this chapter will inform future ED cost accounting projects.
6.1. Software Requirements

At a high level, software requirements can be categorized into three buckets: business requirement, user requirement, and system requirement [26]. The three buckets together dictate the overall design of the software system.

6.1.1. Business Requirements

“Business requirements describe why the organization is undertaking the project.” [26] It includes problem statement, vision, scope, and what the software should produce.

Table 5-1 below provides samples of the formal business requirements of this project, intended to provide insights to the future projects on how to draft business requirements.

Table 5-1 also demonstrates one way of documenting and organizing software requirements. In this minimalistic format, each requirement has an ID, name, description, and priority. ID helps group similar requirements together and priority indicates the importance of the requirement. Based on this project team’s industry experience, a priority ranking like the following can be helpful:

- P1 = Must have. Do not launch without.
- P2 = Required. But okay to launch without, if a plan is in place to add later.
- P3 = Nice to have.

Table 6-1: Business Requirements

<table>
<thead>
<tr>
<th>Requirement ID</th>
<th>Name &amp; Description</th>
<th>Priority</th>
</tr>
</thead>
</table>
| 1.1           | **Per-Visit Cost**
|               | Calculate the total per-visit cost of every ED patient visit, as the sum of all component costs based on the cost accounting model: Equation 5-40 | P1       |
| 1.2           | **Component Cost**
|               | Calculate each of the major VC and FC components of the per-visit cost for every ED patient visit | P1       |
1.3 Speed of Reporting
For each visit, the calculated per-visit and component costs are available to the users the day after

6.1 Medication Cost
Medication Cost is calculated as the sum of the standard costs of all medications used for the visit

6.2 Medication Standard Cost
Medication standard cost is the trailing one-year average of the actual price that pharmacy department paid suppliers; for simplicity, the average is not volume-weighted

6.3 Medication Standard Cost Update Frequency
Medication Standard Cost is updated monthly

*The list of requirements in this document (sections 5.1.1, 5.1.2, and 5.1.3) should be used as samples rather than ready-made list for another ED cost accounting project. For one, this document does not include the complete list of requirements for the BIDMC ED project for brevity. More importantly, even if the full list was included, the list would not be applicable as-is to another ED site.

6.1.2. User Requirements
User requirements describe what the user does and how the user interacts with the system. Our project had three different users – management, Attending physicians, and other systems – and the requirements to satisfy all of their needs. [26]

User requirements can be defined in a tabulated text format like the business requirements above. For more precise or complex interactions, design mockups or animations can be used.

6.1.3. System Requirements
System requirements describe how the proposed system will accomplish business requirements and user requirements. In a way, the system requirements provide the set of constraints that the software designer must work within. [26]

In a hospital environment, system requirements are critical in describing security and robustness that the system must perform within. For example, the following sample requirements were particularly influential to our architectural decisions described in the next section.

Therefore, we hope these samples will inform future projects as well.

<table>
<thead>
<tr>
<th>Requirement ID</th>
<th>Requirement</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td><strong>Performance</strong></td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td>This new system shall not slow down the existing, patient serving information systems</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td><strong>Privacy</strong></td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td>This new system shall comply with HIPAA</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td><strong>Security</strong></td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td>This new system shall comply with BIDMC Information Technology department’s security standards for new non-clinical software</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td><strong>Automation</strong></td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td>This software will run daily, without an operator</td>
<td></td>
</tr>
</tbody>
</table>

6.2. Programming Language

To implement the above requirements into a software system, we chose R as the programming language, because it is fast, free, and fully-featured. More specifically, R is fast at the type of math we need, comes with a comprehensive analytics tools for free, and is peer-supported by an active developer community.
Two downsides were the lack of pre-existing R skillset at the ED Informatics Department and R’s limitations as a web-service. However, we looked at this project as an opportunity to develop R knowledge. Also, if this system needed to evolve into a full-fledged web-service, PHP or other server-side language could be used as a wrapper around the R functionalities to provide a robust web-service node.

R’s speed, analytics library, and limitations as a web-service are further explained below.

6.2.1. Fast Vector Math

Cost accounting calculations involve a lot of vector math.

For example, to calculate medication cost of each visit, we start with a list of thousands of ED patient visits. Then, we find a list of medicines used for each visit. Afterwards, we multiply the dosages of each medicine by its standard cost. Finally, we sum up those numbers for each visit to arrive at medication cost per visit.

Doing this in an object-oriented language would result in a nested loop as demonstrated below. The resulting complexity will be $O(n)$, where “$n$” = number of physician orders and require significant computing power.

Equation 6-1: Nested Loop Pseudo Code

```plaintext
For(each visit “x”){
    For(each physician order “y”){
        if(y.type != medicine){
            break;
        } else{
            x.med_cost += y.med_unit * med_stdCost_hashMap(y.med_name);
        }
    }
}
```
Instead, we decided to leverage R’s simple yet powerful instructions for vector math to achieve sufficient runtime performance without slowing down other systems (system requirement 1.1). The resulting code below reduced the complexity to $O(1)$.

Equation 6-2: Vector Math Pseudo Code

```r
all_orders = merge(all_orders, med_std_cost, on="MedicineDosageName");
all_orders$medicine_cost = all_orders$med_unit * all_orders$med_std_cost;
```

While other query languages such as SQL would’ve allowed similarly elegant code, R’s in-memory computation is one of the fastest. Also, being able to perform vector math without setting up and integrating a database layer resulted in a faster time-to-market.

### 6.2.2. Free Analytics Library

The scope of this project was to build a ruler to measure the cost of each ED patient visit and its component costs. That does not require analytics tools.

However, one of the applications of knowing the cost is identification of opportunities to reduce cost and best practices for doing so. Statistical and other data analytic techniques are necessary to discover such opportunities and best practices. Furthermore, there was an interest in setting up simulations to understand how different levers can change the average per-visit cost of the ED.

Many professional software products such as JMP and SAS allow analytics and simulation work. However, their professional licenses can cost upwards of ten thousand dollars per license.

R provides similar functionalities as packages for free ([http://www.cran.r-project.org/web/packages/](http://www.cran.r-project.org/web/packages/)). There are 6,409 packages as of this writing covering most published analytics techniques from Cox-PH Hazards model to many different clustering models (note – not all packages are for analytics, as many are for visualization and other
specialties). While it requires more programming to use these packages, there is an active and large community of developers who answer each other’s questions.

6.2.3. Limitations as a Web-Service

R is a mathematical scripting language like MATLAB and not a proper server-side language like PHP or .NET. In other words, you normally wouldn’t have R program running for months as a server waiting for another system to make an API request or HTTP request.

Therefore, if BIDMC ED wants to build sophisticated user interface for cost reporting that pulls from the server, additional hooks have to be built to transfer the data. Same is true if another service wants to dynamically pull ED cost data for further computations.

6.3. Environment Setup

R software can run on many different environments. For example, it is compatible with all major operating systems including Windows, iOS, and Linux. Furthermore, due to its efficient performance and compact code, R software can run on relatively small hardware.

Given this flexibility, we chose to run the ED Cost Accounting software on the Linux server owned by ED Informatics Department and operated by BIDMC IT, for the following reasons:

- **Existing Knowledge**: The department owned the machine and deployed most of its home grown information technology tools on this 64-core, 256GB machine. Therefore, the MD-programmers of the department knew the machine’s characteristics well and how to work with it.

- **Pre-existing Data Paths**: As discussed in section 5.2.4, the cost accounting software pulls data from multiple ED and hospital databases and exports data files for other programs to use. Because this server had data paths to the rest of the ED systems and the hospital built in for pre-existing programs, we could avoid creating new data paths exclusively for this project.
• **Permissions:** Informatics Department controlled the permissions within the machine, making deployment faster and future updates to the software easier.

• **Financials:** Informatics Department owned the entire server, paid for by ED Informatics research fund (i.e. ED Research Funding overhead from diagram 4-1). Therefore, this project could be allocated the computing resource without long approval process at the institution level.

Within the Linux machine, we set up the cost accounting software to run as a *daily scheduled job*. We decided this was the simplest way to fulfill business requirement 1.3 around no more than 24-hour delay in the occurrence of the visit and estimation of that visit’s cost. We could’ve had a continuously running calculator pulling from the production database to generate visit cost instantaneously. However, we wanted to avoid pull data from the daily achieve database to fulfill the system requirement 1.1 around not increasing the load of the patient-care systems.

We believe this project’s environment setup decisions are good examples of how key requirements drive architectural decisions that further influence how the software system works.

### 6.4. Data Sourcing and Preparation

Next, we determined three different strategies for sourcing the necessary data depending on their type.

#### 6.4.1. Daily Dynamic Sourcing

Dynamically sourcing data as they are generated guarantees fresh and timely data. In the real world, however, this is possible only under the following conditions:

• **Availability:** The data has to be available to be downloaded dynamically. In IT systems, this typically requires a web-service that can provide the latest data
upon request or direct access to a live database. While the ED maintained a web-service for providing patient care status, Pharmacy did not have a web-service for medicine costs.

- **Access:** Even if there is a web-service or database to dynamically pull data from, the ED cost accounting system will need to be granted access to them. In software engineering, such access is typically controlled through authentication or whitelisting. The ED provided ID and password for the cost system to access patient care information such as length of stay. However, Pharmacy keeps its drug cost database internal.

- **Bandwidth:** Even if the above two conditions are met, we may not want to ping the web-service or database every millisecond for the data, as it will slow down our system and the data provider. If the data provider also serves other mission critical purposes, any unpredictable load may not be worth the benefit in timeliness.

Therefore, the cost accounting software sourced the following data from ED patient care information archive on daily basis. These data were necessary for identifying how much resource each visit used, rather than determining the standard cost of each resource which could be performed less frequently.

- **Visit-level Data:** Visit_ID, Patient_ID, Age, Gender, Ethnicity, Language, Current_Medications, Chief_Complaints, Datetime_In, Datetime_Out, Waitroom_Time, First_Attending(s), Resident(s), Nurse(s), Length_of_Stay, Length_Of_Observation, Diagnosis, Discharge_vs_Admit

- **Order-level Data:** Order_ID, Visit_ID, Datetime_of_OrderPlacement, Type, Subtype, Detail

### 6.4.2 Periodic Sourcing
When we could not pull data dynamically from a web-service or database, we needed a policy to receive the data file from the data owners.

For example, Pharmacy would need to securely send to ED Informatics team a CSV file containing the last period’s medicine purchases and the price they paid for each dosage of medicine. Then, ED Informatics team’s staff would need to upload that file into the ED Informatics Linux server, so the cost accounting software can access it.

The following is the list of data that we decided to source periodically. They are cost data for determining the standard cost of a resource, which does not need to be updated frequently. These data weren’t available via a web-service or outbound database at the time of this project. However, because the manual process is prone to error and require labor each upload, future projects should change these to dynamic sourcing where possible.

- **Pharmacy**: Pharmacy department provides data on medicine purchases: Medicine_Name, Medicine_Dosage, Medicine_Format, Purchase_Date, Price_perDosage. This data can be used to determine the standard cost of each dosage of medicine.

- **Lab**: Lab did not provide their detailed cost data. Therefore, we used the following periodic dump of charge data from the finance department to determine the standard cost of each lab: Order_ID, Visit_ID, Department, Product, Charge. Using the true cost of lab is a big opportunity for improvement going forward.

- **Radiology**: Radiology cost data was handled same as the lab cost data.

- **Cardiology**: Cardiology cost data was handled same as the lab cost data.

- **ED Supply**: ED supply manager, who reports to the director of nursing, manages the ED-specific supplies. He provides an annual report on the supply purchases,
in a data dump including: Purchase_Date, Supply_Category, Supply_Name, Unit_Price, Total_Price.

- **ED Fixed Labor & Overhead**: The Chief Administrative Officer provides an annual breakdown of ED fixed labor and other overhead costs.

- **Institution Overhead**: The hospital finance department provides an annual summarized report of institution overhead and ED’s share of it. The format is not necessarily a neat CSV file and requires data cleaning to be imported into the ED cost accounting system.

6.4.3. **Manually Generated Data**

Finally, some new data had to be generated specifically to make the ED cost accounting system run.

- **Manual Mapping**: At the time of this project, BIDMC ED did not maintain a database of which procedure uses which resource.

  For example, the nurses knew which vial to use when the physician ordered 2mg of Ondansetron via IV. However, the IT system did not understand that particular order #9320033 would consume 2mg of Ondansetron which costs $3 and an IV setup which costs $15.

  Therefore, we manually created a mapping file linking orderable to resource to the cost. For example, in this new scheme, “2mg Ondansetron via IV” is a unique orderable that any physician can order, consuming $3 of Ondansetron and $15 of IV setup.

  Unless BIDMC ED develops and maintains database of these mappings for broader purposes, the ED Informatics team maintaining the cost accounting system going forward will have to periodically update the mapping file manually,
or risk estimating $0 cost for new orderables or new resources for existing orderables.

- **Nurse Labor Time Study**: As discussed in section 4.2.1, we implemented time-driven activity-based costing of the nurse labor based on manual time studies. Therefore, data such as minutes spent to execute on the Ondansetron IV order from the above example were collected manually.

To ensure the ED cost accounting system will continue to estimate visit costs accurately, nurse labor rates have to be updated periodically via new time studies.

### 6.5. Software Components & Implementation

Based on the requirements, environment setup, and data sourcing strategies, ED cost accounting system was designed in three parts following the **MVC design pattern**. This breakdown allowed each component to be developed, modified, and executed regardless of the changes to the other two components.

#### 6.5.1. Model

In MVC design pattern (rather than cost accounting), model is a specific representation of data that can be re-used by the control layer for various computations. In this system implementation, the model component was responsible for loading the necessary cost, visit, order, and mapping data then making them available for the control layer.

**Loading Cost Data, periodically**

First, the software will load the cost data files (.CSV) in a dedicated upload folder as dataframes in R (i.e. equivalent to tables in a database).

For example, the Cost Files folder would contain the latest iteration of annual medicine purchase price file from the pharmacy, uploaded there manually by an ED Informatics Department staff. The software will first load the contents of that file into a dataframe.
named *medicine_purchase_prices* with the following columns: Medicine_Name, Medicine_Dosage, Medicine_Format, Purchase_Date, Price_perDosage. Then, it will average Price_perDosage as a standard cost for that format-dosage of each medicine. The following real code illustrates how efficiently R can achieve this.

**Equation 6-3: Medicine Load & Average R Code**

```r
med_prices <- read.csv("medicine_purchase_price_latest.csv");
med_prices$medID <- paste(med_prices$Medicine_Name, 
                       med_prices$Medicine_Format, 
                       med_prices$Medicine_Dosage, sep=" ");
med_costs <- aggregate(Price_perDosage ~ medID, mean);
colnames(med_costs) <- c("medID", "stdCost");
```

The software will repeat the above or similar steps for all the periodically uploaded cost data files, until the full list of standard cost data frames are created.

**Table 6-2: Standard Cost Data Frames**

<table>
<thead>
<tr>
<th>Data Frame</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>direct_labor_costs</td>
<td>Standard costs for all direct labor resources:</td>
<td>Provided annually by ED nursing director</td>
</tr>
<tr>
<td></td>
<td>o Nurse procedure cost per procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Nurse procedure set cost per set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Nurse non-procedure cost per LOS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Triage nurse cost per visit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Observer cost per observation hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Tech cost per nurse dollar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Other labor cost per nurse dollar</td>
<td></td>
</tr>
<tr>
<td>med_costs</td>
<td>Standard costs for all unique combinations of medicine, format, and dosage</td>
<td>Provided quarterly by Pharmacy</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Table Title</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>bb_costs</td>
<td>Standard costs for all blood bank products</td>
<td>Provided quarterly by Blood Bank</td>
</tr>
<tr>
<td>supply_costs</td>
<td>Standard costs for ED procedure supplies and general supplies</td>
<td>Provided annually by ED supply manager</td>
</tr>
<tr>
<td>ED_charges</td>
<td>Standard costs for lab, radiology, and cardiology derived from patient charges for the ED visits</td>
<td>Provided monthly by Finance Department</td>
</tr>
<tr>
<td>ED_fixed_labor</td>
<td>Annual costs for ED fixed labor resources</td>
<td>Provided annually by ED CAO</td>
</tr>
<tr>
<td>ED_overhead</td>
<td>Annual costs for ED non-labor overhead resources</td>
<td>Provided annually by ED CAO</td>
</tr>
<tr>
<td>Institute_overhead</td>
<td>Annual costs of the hospital’s overhead resources and ED’s share percentage</td>
<td>Provided annually by Finance Department</td>
</tr>
</tbody>
</table>

**Loading Visit & Order Data, dynamically**

After the cost data have been loaded, the software will download the visit and order (i.e. procedure) information dynamically from ED patient care information system via HTTP requests. Since the software will run daily (section 6.3 Environment Setup), this download will happen daily from the archive server rather than production server. Again, this dynamic data sourcing is possible only for the structured data that is made available through web-services.

Specifically, the cost accounting software will make two separate HTTP requests for the visit metadata then for the list of physician orders. After the download, the R program will clean up the data and represent them as data frames with the columns discussed in section 6.4.1 Daily Dynamic Sourcing.

The below is a simplified R code sample demonstrating one way of making the HTTP request then structuring the data.
# Include the XML handler package

```r
install.packages("XML")
library(XML)
require(XML)
```

# Download raw data about patient visits

```r
visit_query <- [http request]
visit_download <- postForm([server URL], pass=password, q=visit_query, stype="POST")
```

# Convert to XML

```r
visit_XML <- xmlTreeParse(visit_download)
visit_XML_top <- xmlRoot(visit_XML)
```

# If the XML is hierarchical rather than flat, it must be “flattened” first; another option is to separately save away the hierarchical portions, then merging them on later to the data frame

# Convert to Data Frame

```r
visit_list <- xmlToList(visit_XML_top)
visit_df <- as.data.frame(visit_list)
visit_df <- as.data.frame(t(visit_df)) # Transposing the data frame
```

# Most likely, text data has to be cleaned and re-typed

```r
visit_df$ID <- sub("\s", "", visit_df$ID) # e.g. remove whitespace
visit_df$ID <- as.integer(visit_df$ID) # e.g. convert from string to integer
visit_df$ChiefComplaint <- as.character(visit_df$CC) # e.g. convert from factor to string
visit_df$Time_In <- as.character(visit_df$Time_In) # e.g. convert from factor to string
visit_df$Time_In <- strftime(visit_df$Time_In, "%m/%d/%y %H:%M") # e.g. then, convert to datetime
```
Loading Mapping Tables, manually

Finally, the software will load the manually created mapping files into data frames. This is a critical step that allows the allocation logic in the control module to assign the standard costs to appropriate procedures and visits.

The following is a sample of a mapping data frame. The first column is a list of unique orders physicians can place. The second column is the matching item in the medicine-format-dosage standard cost generated via Equation 6-3.

Notice that Ondansetron 4mg vial maps to three different dosages of order. It's because even if only a portion of the vial is used, the rest is discarded. This allows the allocation logic to look up the standard cost of Ondansetron 4mg vial then assign them to the visits for which doctors ordered one of the three Ondansetron IVs.

Because Tylenol pills are purchased in smaller granularities, the mapping is one-on-one.

Table 6-3: Medicine Cost Mapping Data Frame

<table>
<thead>
<tr>
<th>Orderable</th>
<th>medID</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>Ondansetron</td>
</tr>
<tr>
<td>IV</td>
<td>Ondansetron</td>
</tr>
<tr>
<td>IV</td>
<td>Ondansetron</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>PO</td>
<td>Acetaminophen</td>
</tr>
<tr>
<td>PO</td>
<td>Acetaminophen</td>
</tr>
<tr>
<td>PO</td>
<td>Acetaminophen</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.5.2. Control

In MVC design pattern, the control module is responsible for the majority of computations.

The MVC pattern allows the control module to assume certain data structure to be made available by the model module, so that each module can be changed without requiring change in the other as long as the data structure is maintained. For example,
changing how nurse labor cost is allocated across visits does not change how the nurse labor needs to be loaded into the system.

In BIDMC ED’s cost accounting system, there are two separate control modules: allocation logic and analytics logic. The allocation logic is responsible for assigning the appropriate costs to each visit. Its output is the per-visit cost for each patient visit and its breakdown. Analytics logic consumes that output and generates additional reports such as cost efficiency of each Attending physicians.

The following is a sample R code on how the allocation logic was implemented. Analytics will be further discussed in Chapter 7 - Findings & Applications.

Equation 6-5: Allocation Logic R Code

# At a high level: for each cost types, allocation logic adds a new column to the visit table, calculates that column, then increments Total.Cost of the visit.

# The following is a sample code for nurse procedure cost, one of the variable costs
# Step 1 – For all physician orders, attach the amount of nurse labor cost specific to that procedure (e.g. IV); the column will be named stdCost
order_df <- merge(order_df, nurse_procedure_stdcost, by="Type", all.x=TRUE)
# Step 2 – Roll up the cost to visit level
visit_df <- merge(visit_df, order_df[,c("FN", "stdCost")], by="FN", all.x=TRUE)
# Step 3 – Rename "stdCost" to “Nurse.Procedure.Cost”
colnames(visit_df) <- c("FN", ..., "Nurse.Procedure.Cost")
# Step 4 – Increment total cost
visit_df$Total.Cost <- visit_df$Total.Cost + visit_df$Nurse.Procedure.Cost

# The following is another sample for observer cost, which is not procedure specific
# Step 1 – For all visits, multiply the length of observation with observer per minute cost
visit_df$Obs.Cost <- visit_df$Time.Under.Obs * labor_rates$Observer
# Step 2 – Increment total cost
visit_df$Total.Cost <- visit_df$Total.Cost + visit_df$Obs.Cost

# The following is another sample for Attending physician labor, a fixed cost
# Step 1 – Add Attending physician labor evenly to each visit
visit_df$Att.Cost <- fixed_labor_annual$Attending / fixed_labor$AnnualVisits
# Step 2 – Increment total cost
visit_df$Total.Cost <- visit_df$Total.Cost + visit_df$Att.Cost

6.5.3. View

Once the total cost is calculated, the system can show the estimated per-visit cost and breakdown to the users. This “showing” is the job of the View module.

In fact, the MVC pattern allows us to develop multiple views, each with a different purpose. Also, the views assume a certain “shape” of output from the control. As long as that structure is maintained, views or controls can be modified without affecting each other.

Examples of views we built are:

- **Daily Cost Report**: Report of the per-visit cost and cost breakdown for every visit from the day before, based on the output of the allocation control module.
- **Chief Complaint Cost Report**: Report of the cost statistics by chief complaints, based on the output of the analysis control module.
7. **Findings & Applications**

The goal of this project was to develop a software that will precisely and accurately measure the cost of each patient visit at BIDMC ED. The ultimate goal was to repeatedly answer questions around financial impact of each visit, opportunity areas to reduce cost, and best practices for cost efficiency.

To address this problem statement, the first phase was developing a customized accounting model. *Chapter #5* described the modeling work and results in detail. The second phase was implementing the cost accounting system. *Chapter #6* described the implementation and software engineering considerations in detail. Those modeling and implementation decisions were grounded in the literature review, detailed in *Chapters #3 and 4*.

This chapter discusses how those project works helped us achieve the goal. The following sections will demonstrate that BIDMC ED can now assess the margin of each visit, identify opportunity areas to reduce cost, and discover best practices as the direct result of the project works. The sections also discuss exactly how BIDMC ED is using its new cost accounting system to address those problem statements.

### 7.1. Visibility into Cost vs. Reimbursement

The first finding is the ED’s new ability to assess the financial impact of each patient visit.

As described in the *Section 5.4 - Conclusion of Accounting Model (table 5-8)*, ED can now precisely estimate the cost of each patient visit. Then, ED can compare the cost to the reimbursement amount from the payer to understand financial margin as exemplified below.

In the *Table 7-1*, “Charged Amount” is the ED’s income for the visit and “Total Cost of Visit” is the comprehensive variable and fixed cost of the visit. Furthermore, the Charged Amount can be compared to “VC” only to make economic decisions on the margin since the total fixed cost does not change based on taking on the additional visit or prescribing additional medicine.

This financial optics is particularly useful in identifying problem areas in cost and determining which site is better suited for a certain type of urgent care.
7.2. Identification & Prioritization of Cost Saving Opportunities

Once the ED can understand the cost and margin of each visit, the next big application is identifying big opportunities for reducing the cost without compromising on quality. Many techniques can be helpful in doing so.

It is this project’s finding that BIDMC ED could follow the following process to identify and prioritize cost saving opportunities for further investigation:

1. Group all patient visits in a year by a category (e.g. chief complaint)
2. Drill down deeper into a group that represents a larger annual spending (e.g. abdominal pain, as opposed to bat bites) or has high variation of costs
3. Repeat steps #1 and 2 until a relatively large group is identified whose cost variations are MD-driven rather than patient-driven (i.e. hospital can change the care process to lower cost)

The key to this process is identifying opportunities large and sub-optimal enough to make a difference if improved. Discovery and validation of other methodologies would be good future work to following this project.

Figure 7-1 below visualizes the above process that BIDMC ED found useful.
The following three pages of steps and tables are simplified for the purpose of demonstration of the overall process. All figures are completely fictitious.

(1) Aggregate visit cost by a category, in this case the Chief Complaint. The resulting table below (at a high level) demonstrates that Abdominal Pain accounts for 10% of all of ED’s expenses in a year. Also, ABD PAIN visits have relatively high variation in cost (200 standard deviation and 67% coefficient of correlation).

<table>
<thead>
<tr>
<th>Chief Complaint</th>
<th>Number of Annual Visits</th>
<th>Average Cost</th>
<th>Cost Standard Deviation</th>
<th>Annual Cost</th>
<th>% of Total Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABD PAIN</td>
<td>4000</td>
<td>300</td>
<td>200</td>
<td>$1,200,000</td>
<td>10%</td>
</tr>
<tr>
<td>CHEST PAIN</td>
<td>2000</td>
<td>400</td>
<td>100</td>
<td>$800,000</td>
<td>7%</td>
</tr>
<tr>
<td>S/P FALL</td>
<td>1000</td>
<td>500</td>
<td>300</td>
<td>$500,000</td>
<td>4%</td>
</tr>
<tr>
<td>HEADACHE</td>
<td>900</td>
<td>200</td>
<td>100</td>
<td>$180,000</td>
<td>2%</td>
</tr>
<tr>
<td>SHORTNESS OF BREATH</td>
<td>800</td>
<td>200</td>
<td>100</td>
<td>$160,000</td>
<td>2%</td>
</tr>
<tr>
<td>FEVER</td>
<td>700</td>
<td>200</td>
<td>100</td>
<td>$140,000</td>
<td>1%</td>
</tr>
<tr>
<td>DYSPNEA</td>
<td>600</td>
<td>200</td>
<td>100</td>
<td>$120,000</td>
<td>1%</td>
</tr>
<tr>
<td>BACK PAIN</td>
<td>500</td>
<td>200</td>
<td>100</td>
<td>$100,000</td>
<td>1%</td>
</tr>
<tr>
<td>BAT BITE</td>
<td>20</td>
<td>1000</td>
<td>100</td>
<td>$20,000</td>
<td>0%</td>
</tr>
</tbody>
</table>

(2) Drilling down further into Abdominal Pain visits by acuity level (ESI), the following bar chart shows that ABD PAIN – ESI 3 is worth 7.5% of all ED expenses. Furthermore, the ABD PAIN – ESI 3 visits vary significantly cost, indicating a potential room for improvement.

(3) The following chart statistically visualizes ABD PAIN – ESI 3 visit costs by Attending physicians.
The physicians on the left treated a larger number of patient visits in the sample period. Therefore, the sample size is over ten times larger for MD #1 than MD #40 as an example. The horizontal middle line is the average cost across all Attending physicians for ABD PAIN – ESI 3 visits. Individual whisker plots show the average and variation of cost by Attending physician.

At a high level, there are enough differences across the 40 physicians at BIDMC ED to suggest a hypothesis that some physicians are more cost efficient (in absolute cost and variability of cost).

(4) In fact, the cost-efficient Attending physicians (75th percentile in efficiency) order certain scans and labs less frequently than other physicians do. Those scans and labs are “bolded” in the below table. Therefore, the cost-efficient pattern of scans and labs deserve further investigation as potential best practices.
(5) Finally, our regression analysis indicated no statistically significant correlation between the physician’s quality of care and cost-efficiency, pattern of labs, or pattern of scans.

(6) Therefore, the next step is for the cost-efficient pattern of labs and scans from above to be rigorously considered by an experienced medical faculty before being pilot tested.

7.3. Discovery of Best Practices

The above Section 7.2 discussed an important finding of this project, i.e. how BIDMC ED can use the new cost accounting system to identify and prioritize cost saving opportunities large enough to matter. As the next step, this project also found that the ED can use the cost accounting system to data mine best practices for those opportunities in question.

However, it was a critical finding that the analytic methods can only highlight candidate best practices. Afterwards, every candidate has to be rigorously considered by experienced medical faculty before being pilot tested. At the time of this writing, no new standardized best practice had been piloted.

Nevertheless, more generic tools were implemented to encourage organic adoption of best practices. The first tool is provider cost, process, and quality report cards and the second compares similar metrics across different ED sites. Both tools are further described below.

7.3.1. Provider Performance Management & Best Practice

The following Table 7-2 is a sample of the Attending physician performance report implemented at the BIDMC ED as a result and application of this project. There are many ways to implement a similar report. The actual data and Dr. House are fictitious for demonstration only.

It reports on three types of metrics to give a comprehensive view of the Attending’s cost performance:

- Basis of comparison (e.g. number of visits)
- Cost performance
• Process performance that relates to the cost (e.g. LOS, discharge rate)
• Quality metrics to ensure it is not jeopardized (e.g. 72-hour return rate)

This report, automatically generated monthly by the cost accounting system, also highlights metrics the Attending is outperforming the average at and vice versa. The report also allows year-over-year comparison to track improvements.

This report can be “narrowed down” to a particular set of chief complaints or patient types to show which Attending physicians are most cost-efficient at caring for certain patients. Therefore, this report is an application that demonstrates how the accounting system can be useful in finding best practices for treating certain patients.

The Chief of Emergency Medicine also receives aggregated Excel report showing every Attending's performance.

Table 7-2: Attending Performance Report

<table>
<thead>
<tr>
<th>metric</th>
<th>Dr. House - curr yr</th>
<th>Dr. House - prev yr</th>
<th>vs. average</th>
</tr>
</thead>
<tbody>
<tr>
<td>NumVisits</td>
<td>8000</td>
<td>9999</td>
<td>1557</td>
</tr>
<tr>
<td>AveVisitCost</td>
<td>300</td>
<td>300</td>
<td>555.999</td>
</tr>
<tr>
<td>Visit Cost Variation</td>
<td>1</td>
<td>2</td>
<td>0.648</td>
</tr>
<tr>
<td>Labor Cost</td>
<td>184.548</td>
<td>184.548</td>
<td>255.999</td>
</tr>
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<td>Non-Labor Cost</td>
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<td>98.546</td>
<td>130.526</td>
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<td>Cost ESI-Distance</td>
<td>-0.024</td>
<td>-0.024</td>
<td>0.03</td>
</tr>
<tr>
<td>LOS</td>
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<td>250.699</td>
<td>401.483</td>
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<td>LOS Variation</td>
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<tr>
<td>Consult per Visit</td>
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<td>0</td>
<td>0.481</td>
</tr>
<tr>
<td>Observation per Visit</td>
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<td>50</td>
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<tr>
<td>Admission per Observation</td>
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<td>0</td>
<td>21.586</td>
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<td>Discharge Rate</td>
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<td>58.974</td>
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<tr>
<td>Admission Rate</td>
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<td>37.423</td>
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<tr>
<td>Transfer Rate</td>
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<td>0</td>
<td>1.167</td>
</tr>
<tr>
<td>72-Hour Return Rate</td>
<td>3.000</td>
<td>3.917</td>
<td>3.105</td>
</tr>
<tr>
<td>Patient Satisfaction Survey</td>
<td>4.82</td>
<td>4.82</td>
<td>4.723</td>
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<tr>
<td>Resident Evaluation Survey</td>
<td>4</td>
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<td>4.482</td>
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</table>
7.3.2. Multi-Site Performance Management & Best Practice

Based on this project, BIDMC ED also developed a template to find best practice amongst different sites.

The template compares different sites across three types of metrics over a set time period (e.g. a year, a quarter, etc):

- **Operational Metrics**: Number of Visits, Average ESI, Median ESI, Top-5 Chief Complaints, Total Physician Hours (Attending vs. Resident), Total Nurse Hours

- **Cost Metrics**: Average Visit Cost, Median Visit Cost, Visit Cost Standard Deviation, Labor VC per Visit, Non-Labor VC per Visit, FC per Visit, Cost ESI-Distance\(^4\)

- **Process Metrics**: Average LOS, Median LOS, LOS Standard Deviation, Observations per Visit, Average Observation Duration, Observation Duration Standard Deviation, Consults per Visit, Admission Rate, Discharge Rate, Transfer Rate

- **Quality Metrics**: 72-Hour Return Rate, Patient Satisfaction Survey Metrics, (if teaching hospital) Resident Evaluation Survey Metrics

The goal is to compare cost metrics across the sites. The operational metrics such as average ESI (acuity metric) helps normalize the cost metrics and the process smetrics provide context. Finally, the quality metrics help ensure the better cost is not achieved at the expense of quality.

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\(^4\) Cost ESI-distance is an acuity-normalized cost metric we developed for this project. For a specific patient visit, it is the number of standard deviations the visit cost above or below the average visit of that ESI acuity. For a group of visits, it's the un-weighted average of individual visits' ESI-distances. For example, an attending physician's Cost ESI-distance is the average of the Cost ESI-distances of all the patient visits he treated.
As with the Attending performance report, the scope of report can be narrowed down to specific chief complaint or patient types to identify which site is most cost-efficient for that type and learn from that best practice.
8. Next Steps & Enabled Future Research

To recap, BIDMC ED like other healthcare organizations are in search of cost reduction without quality compromises. However, the ED couldn’t pin point the high leverage opportunities for reducing cost or best practices to implement. Worse yet, it couldn’t even track the progress of cost-improvement projects because it lacked the ruler to measure the cost of each visit with.

This project developed a cost accounting model for estimating various cost components of an ED visit. This project also implemented a software system that will report on the estimated cost and breakdown of every visit on daily basis and provide additional analytics (e.g. Attending cost performance).

As a result, BIDMC ED is now able to (1) understand the cost of each visit, breakdown of the cost, and the resulting margin, (2) analytically identify and prioritize big-enough opportunities for reducing cost, and (3) data mine best practices across providers and sites. The Chapter 7 discussed these findings and applications in detail.

However, as this was the first implementation of a cost accounting system at the ED, there are many improvements to be made. Furthermore, having access to this reliable cost data that distinguishes expensive vs. cost-efficient visits allows plethora of impactful future studies.

The following is a brief summary of the next steps and future studies that are now enabled and likely to be followed through by the faculty at BIDMC ED.

- Refine Accounting Model
  - Improve precision of labor cost model via further time studies
  - Identify true variable costs of other departments
  - Map every material to usage

- Extend Software Applications
  - Implement an interactive dashboard
  - Extend the software to other performance metrics (e.g. throughput), other departments, and other hospitals
• Publish Follow-Up Studies
  – Data mining techniques for cost-saving best practices
  – Cost of an occupied bed in the ED
  – Cost of observation in the ED vs. inpatient observation
  – Most cost-efficient EDs in the country
  – Relationship between the provider cost efficiency and personality

In fact, there will be many more research topics on ED cost management. Therefore, this project team hopes that future research will enrich the knowledge of ED cost management. Furthermore, we hope that other departments and hospitals will use this project as a baseline to implement their own cost accounting systems and begin to systematically and continuously improve cost performance.

By doing so, each hospital will address Robert Kaplan and Michael Porter’s ultimate problem statement we started with: “a fundamental source of escalating costs is the system by which those costs are measured” [1] and will be able to help the U.S. and other nations improve the cost of urgent care without compromising on quality.
9. Bibliography


