IDENTIFYING OPTIMAL IT PORTFOLIOS TO PROMOTE HEALTHCARE QUALITY

Research-in-Progress

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Abstract

Healthcare organizations continue to make large investments in health information technology to improve quality of care and lower costs. Therefore, there is an ever-growing need to have an ever-clearer understanding of how IT investments impact these organizations. In this paper, we present an extensive review of literature on the impact of health information technology on quality. We identify a research gap where past studies have explored the impact of individual technologies or aggregate all technologies based on overall investment, but do not explore the impact of specific portfolios of information technology and their synergistic effects on healthcare quality. Based on the past studies on portfolio theory, we then develop an approach for identifying such optimal portfolios and exploring the presence of such synergistic effects among the components of the portfolio. We then present preliminary results to demonstrate the feasibility of this approach.

Keywords: Healthcare Information Systems, Quantitative analysis, Data mining, Logistic regression, Synergy
Introduction

Healthcare organizations continue to make large investments in health information technology to improve quality of care and lower costs (Monegain 2009; Pizzi 2007). Research and Markets reported that in 2008, the value of the global Healthcare IT (HIT) market was estimated at $11 billion. They further estimate that by 2015, this value will more than double to $24 billion (Business_Wire 2009). Other sources agree that the Healthcare IT market in the United States is anticipated to grow annually at a rate of more than 24% from 2012 to 2014 (Healthcare_IT_News 2011). Furthermore, the United States government has promoted the Healthcare IT market by providing grants and financial incentives for research in, and the use of HIT systems. Examples of such health information technologies include large systems such as electronic medical records as well as specific components such as ePrescribing. Given the large investments, wide variety of technologies, and the critical nature of healthcare, there is clearly a need for a more thorough understanding of the impact of health information technology on healthcare. Specifically, it is important to evaluate and identify how specific technologies or a combination of technologies designed to support patient care impact the quality of care services and health outcomes. Although there have been several recent studies on the impact of IT on quality (Jamal et al. 2009; Piontek et al. 2010), conflicting findings on the impact of HIT on quality (Swanson Kazley and Diana 2011), and the narrow technology focus of many studies (Wakefield et al. 2010), has left the nature of the relationship between HIT and quality unclear. Most studies investigate individual information technologies or aggregate all information technologies into broad functional clusters without comparing the effect of specific combinations of technologies and their synergistic effects on quality of care. There is limited literature that explores the effect of portfolios of information technology and their effect on quality, and more specifically the optimal combination of technologies that result in the realization of quality benefits for healthcare organizations.

In this paper, we propose a quantitative approach to investigate if there exist portfolios of information technology that are associated with a positive effect on quality of care, and if there exist synergistic effects between the individual components of the portfolio. We begin with an extensive review of literature in the next section to identify studies that explore the effect of information technology on quality in healthcare, and also to identify theoretical models that explore the relationship between information technology investments and performance. We then present our approach for identifying optimal portfolios that are positively associated with better quality outcomes, and investigate if a synergistic effect is present in the portfolios. We then conclude with discussion of future research.

Literature Review

In order to more fully understand the relationship between information technology and quality, we explore the research question what affect does healthcare IT have on quality, and are there specific technologies or a combination of technologies that lead to a positive impact on quality of care. To develop a thorough understanding of how HIT effects healthcare quality a systematic review of relevant literature was conducted.

The literature search strategy involved executing a search on the PUBMED database seeking English language articles published between January 1, 2000 and November 12, 2011. The search terms used were “Health Information Technology” AND Quality. These terms were sought in all fields. The search returned 321 results. Many of the articles detailed healthcare worker or patient experiences or perceptions dealing with the use of IT systems. Others offered best practices to maximize benefits or IT investments. Each of the articles’ was reviewed, and from this pool only relevant articles were considered for inclusion in the analysis. Articles meeting the following criteria were considered relevant:

The article reported on formal research conducted in empirical studies.
The primary focus of the study is the implementation or use of HIT.
The study identifies the effects of the implementation or use of HIT on the quality of service or patient outcomes.

Applying these criteria resulted in 39 articles. While the list of articles identified through our search
process is not exhaustive, it is a fair representation of recent domain literature, and provides a cross-section of not only technologies frequently studied but also of common implementation environments.

**Observations**

Each article was reviewed and where available details about study attributes were recorded. This included the specific HIT system, disease conditions under study, research methodology, extent of user base, context of technology use and adoption, outcome measures and facilitators and barriers to this adoption.

In terms of technology, Electronic Medical Records (EMR) were the most commonly investigated technologies (Adams et al. 2003; Bardach et al. 2009; Campbell et al. 2008; Cochran et al. 2011; DesRoches et al. 2010; El-Kareh et al. 2009; Gaylin et al. 2011; Gluck 2009; Hunt et al. 2009; Kern et al. 2009; Keyser et al. 2009; McCullough et al. 2010; Morin et al. 2009; Nirel et al. 2010; Nirel et al. 2011; O’Connor et al. 2005; Pillemer et al. 2011; Romano and Stafford 2011; Russell et al. 2010; Schnall et al. 2011), followed by Computerized Physician Order Entry (CPOE) (Koppel et al. 2005; McCullough et al. 2010; Roberts et al. 2010; Russell et al. 2010; Swanson Kazley and Diana 2011), Clinical Decision Support (CDS) (DesRoches et al. 2010; Fraenkel et al. 2003; Jean-Jacques et al. 2011; Roberts et al. 2010; Romano and Stafford 2011; Russell et al. 2010), and Adverse-Drug-Event Systems (Piontek et al. 2010; Roberts et al. 2010). Both qualitative and quantitative research methodologies were employed to investigate the impact of HIT on quality with some authors using both methodologies (Campbell et al. 2008; DesRoches et al. 2010; Golob et al. 2008). However, in further analysis, only those studies utilizing quantitative analysis methods were used to maximize relevance to the proposed research. Most studies focused on a wide variety of health outcome measures commonly measured in primary care settings. However, there is also much research on the effects of HIT on individual diseases and within specific healthcare specialties such as asthma (Kern et al. 2009), HIV (Schnall et al. 2011) and breast cancer (Loiselle et al. 2010). The most attention was devoted to how HIT affects diabetic patients (Hunt et al. 2009; Keyser et al. 2009; Morin et al. 2009; O’Connor et al. 2005).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Positive</th>
<th>Neutral</th>
<th>Negative</th>
<th>Inconclusive</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPOE</td>
<td></td>
<td>McCullough, et al., 2010; Swanson &amp; Diana, 2011</td>
<td>Koppel, et al., 2005; Roberts, et al., 2010</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Golob, et al., 2008; Davis &amp; Pavur, 2011; Menachemi, et al., 2008; Piontek, et al., 2010; Yu &amp; Houston, 2007; Spielberg, et al., 2011; Lucero, et al., 2011</td>
<td>Davis &amp; Pavur, 2011</td>
<td>Purukawa &amp; Adam 2008; Loiselle, et al., 2010; Gluck, 2009</td>
<td>Savage, et al., 2010</td>
</tr>
</tbody>
</table>

Most studies use one of two units of analysis when determining if benefits had been realized after implementation. About half of the studies focused on the facility by comparing a facility’s performance...
measure (e.g. mortality rate) (Piontek et al. 2010) pre and post implementation to judge results. The remaining half used the patient as the unit of analysis (e.g. glucose levels, blood pressure) (Hunt et al. 2009) to determine impacts.

As is evident in Table 1, there is no clear consensus regarding a positive or a negative impact of information technology on healthcare quality. While many studies offered strong support for the implementation of HIT (Nirel et al. 2011; Wakefield et al. 2010), almost as many found either marginal benefits (Romano and Stafford 2011; Swanson Kazley and Diana 2011), improvements to quality from some IT systems and not others (DesRoches et al. 2010), or benefits for only some patients (Loiselle et al. 2010).

Interestingly, according to the Yu & Houston (2007) study, it also appears that the quality performance of an health care system is a strong predictor of IT adoption, but information technology adoption is not a strong predictor of improved quality. This indicates that technology adoption alone is not sufficient to realize quality benefits, and that the way in which technology is used does have a significant influence on the direction and extent of quality impacts. This is also reinforced by the Tavakoli et al. (2008) study where workflow changes combined with existing technology is shown to yield better quality outcomes.

In some literature evaluating the impact of technology on healthcare quality, patterns emerged that are in line with the DeLone and McLean model for Information System success (DeLone and McLean 1992). Specifically, system quality, information quality, and use are identified in many papers as being key factors that influence the realization of quality benefits of information systems (Furukawa and Adam 2008; Hynes et al. 2010). However, other studies counter these arguments by concluding patient socio-economic status (Loiselle et al. 2010) or information system mix (Myung Ko and Osei-Bryson 2004) where stronger predictors of quality. Some studies also indicate that quality focused information systems such as quality reporting and benchmarking (Hunt et al. 2009) or drug interaction and adverse drug event systems offered more benefits than general health information technologies such as EMR when evaluated with respect to impact on quality (DesRoches et al. 2010).

When looking at results from multiple studies, it appears that HIT’s impact on the quality of healthcare is ambiguous at best. However, what is clearer is that there are mitigating aspects affecting the impact of these technologies, and in some cases these dynamics are impeding their potential benefits. A more thorough understanding needs to be developed of these factors through an in-depth examination of dependent and independent variables.

Theoretical foundations

In order to address this gap in research, domain literature was once again reviewed to identify an appropriate model or theoretical framework on which to base the proposed research. This review looked at evaluations of information technology investments as well as examples of evaluations of capital investments in healthcare. Where possible, articles were specifically sought that combined both domains by reporting on evaluations of IT investments in healthcare.


Several theories have been used to evaluate impact of IT on performance. Select papers used mature and well accepted tools such as DeLone and McLean’s IT Success model (Chatterjee et al. 2009), the UTAUT model (Hennington and Janz 2007), and Data Envelopment Analysis (Bendoly et al. 2009; Valdmanis et al. 2008). Others more recently proposed models include the Actor-Network model (Cresswell et al. 2010), and Triangle model (Ancker et al. 2011).

While the studies above contribute significantly to help develop an understanding of the impact of information technology on healthcare, many of the studies either consider the impact of specific information technologies in isolation, focus on productivity and financial metrics, or aggregate several technologies into functional clusters rather to investigate their impact on hospital performance. Specifically, there is a no literature that explores specific combination of technologies and the synergies
between various information technologies and their impact on quality of care. Portfolio theory is a potential theoretical framework that can help investigate the impact of synergies between information technologies. Portfolio theory suggests that a collection of diverse resources are used to minimize risk and maximize business opportunities (Lin et al. 2006). In order to understand the impact of portfolios and synergies we identified and evaluated a subset of articles that explored the impact of technology portfolios on organizational performance (Table 2). These articles are particularly relevant as they provide a precedent for using the portfolio theory in the analysis of both information technology and healthcare investments. Lin, et al. indicate, “...a synergistic effect is expected so that the value of a technology portfolio can add up to more than the sum of its separate parts” (2006). Furthermore, Bridges, et al. (2002) confirm that portfolio theory is an appropriate choice for simultaneous analysis of multiple healthcare investments. The complimentary effects of IT systems are well supported by Zhu’s (2004) examination of firms’ technology infrastructure and e-commerce capabilities, Thrasher et al.’s (2010) research into the synergies realized from integration of multiple healthcare alliance networks, and Setia et al.’s (2011) analysis of how the assimilation of IT applications affect the financial performance of healthcare organizations.

Table 2 Studies Evaluating IT and Healthcare Investments Using Portfolio Concept

<table>
<thead>
<tr>
<th>Study</th>
<th>Context of Study</th>
<th>Guiding Theoretical Framework</th>
<th>Constructs and Measures</th>
<th>Data and Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges, et al., 2002</td>
<td>Multiple interventions to standardize returns</td>
<td>Portfolio Theory</td>
<td>Synergy between health investments</td>
<td>Cost effectiveness analysis</td>
</tr>
<tr>
<td>Lin, et al., 2006</td>
<td>Identify is patent diversity reduces risk</td>
<td>Technology portfolio strategy</td>
<td>Synergy from IT portfolio</td>
<td>US Patent applications</td>
</tr>
<tr>
<td>Zhu, 2004</td>
<td>114 companies using e-commerce</td>
<td>Resource-based theory</td>
<td>Complementary IS</td>
<td>Inventory of IT, financial records</td>
</tr>
<tr>
<td>Setia, et al., 2011</td>
<td>IT application assimilation and use</td>
<td>IT portfolio Theory</td>
<td>IT systems and net income</td>
<td>HIMSS &amp; California OSHPD</td>
</tr>
<tr>
<td>Thrasher, et al., 2010</td>
<td>Health Alliance networks</td>
<td>Thompson’s Interdependence Theory</td>
<td>Complementary IS</td>
<td>Financial and quality results performance</td>
</tr>
</tbody>
</table>

Identifying Optimal IT Portfolios

Based on the past research that indicates the complementarity and the synergistic effects between technologies in a portfolio is a key factor in influencing performance, in this study we seek to identify such optimal portfolios that positively influence service and outcome quality at healthcare organizations. Specifically, this research is guided by the following two objectives:

Research Objective 1

*Identify optimal portfolios of information technology, that are positively associated with better than average quality performance at healthcare organizations*

Research Objective 2

*Identify if synergistic effects exist between the components of the optimal IT portfolio. Specifically, are individual technologies more positively associated with quality when used in conjunction with other technologies within an IT portfolio than when used in isolation?*

Data and Approach

In order to address the research question regarding HIT’s impact on quality, we propose an analysis of hospital IT adoption records in conjunction with hospital quality results. Specifically, we propose a multi-source approach to data collection using the 2008 HIMSS Analytics database (formally The Dorenfest
An IT portfolio consists of any combination of two or more IT systems. The IT portfolio construct (independent variable) in this model will be comprised of combinations of IT systems currently implemented within healthcare facilities as reported by each facility’s chosen healthcare administrator. These systems, as detailed in the HIMSS database, are identified in Table 3. The Service Impacts and Patient Impacts are the dependent variables as reported by the Medicare.gov data source.

The multiple predictor variables (IT systems) will offer a large number of possible combinations. To deal with the volume of permutations, as well as the facility heterogeneity, datamining techniques will be used to narrow the search space. Specifically, the C4.5 decision tree algorithm will be used to identify combinations of IT systems closely associated with positive results on healthcare quality metrics. These combinations will be operationalized as IT Portfolios. Portfolios identified by these algorithms with then
be subjected to ordinal logistic regression analysis for testing the synergistic effect among the portfolio components.

**Preliminary Results**

In order to test the feasibility of our approach to identify optimal IT portfolios, we selected the sample quality metric of *heart attack rate* to test our methodology. Of the facilities in our dataset, 243 earned a *better than the national average* rating, 2363 were rated *equal to the national average*, and 508 were rated *worse than the national average* for this metric. In our preliminary analysis, we evaluated the effect of aggregated specialized information systems used in specific departments such as labs, cardiology, radiology etc. on the heart attack rate metric. Using the entire dataset as a training set, we then reviewed random tree, random forest and C4.5 decision tree algorithms. Our primary purpose for the use of data mining algorithms is as a search tool to identify candidate optimal portfolios which can then be tested for portfolio effects using ordinal regression. We propose the use of decision tree algorithms since the tree-like outputs of such algorithms can be helpful for constructing and identifying candidate portfolios that are more likely to be associated with positive results. Specifically, we chose branches of the decision tree that resulted in higher than average performance, and operationalized them into portfolios. We selected the results from the C4.5 algorithm since it had a higher accuracy level among the algorithms we selected and included branches that predicted higher than average performance. A sample section of the C4.5 decision tree is shown in Figure 1.

<table>
<thead>
<tr>
<th>Cardiology &gt; 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiology &lt;= 0</td>
</tr>
<tr>
<td>Labor_and_Delivery &lt;= 0</td>
</tr>
<tr>
<td>OR_Surgery &lt;= 0</td>
</tr>
<tr>
<td>Lab &lt;= 2: Below Average Results (2.0/1.0)</td>
</tr>
<tr>
<td>Lab &gt; 2: Above Average Results (9.0/4.0)</td>
</tr>
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</table>

*Figure 1. Partial Decision Tree Output for Identifying Optimal IT Portfolios*

In our preliminary analysis, we tested the synergistic effects of a single portfolio from among those identified by the C4.5 for synergistic effects. Specifically, we evaluated the impact of a portfolio of Cardiology, Pharmacy and Lab information systems on heart attack rates in hospitals (1656 facilities contained this portfolio while 63 reported only Cardiology, 71 with Lab only, 29 with Pharmacy only and 116 facilities without either Cardiology, Lab or Pharmacy). The ordinal logistic regression model used to test the portfolios is given by:

\[
y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_1 x_2 x_3
\]

where \( b_0 \) is the constant and \( b_1 \) and \( b_2 \) are the coefficients for the predictor variables \( x_1 \) (cardiology information systems), \( x_2 \) (pharmacy information systems) and \( x_3 \) (lab information systems), and \( y \) represents the quality outcome (heart attack rate) with values below average, average, and above average. The interaction form \( (b_3 x_1 x_2 x_3) \) depicts the portfolio of cardiology, pharmacy and lab information systems. The regression results are given in Table 4 below.

*Table 4. Ordinal Regression Results*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>P Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiology</td>
<td>-1.0252</td>
<td>1.56e-08***</td>
<td></td>
</tr>
<tr>
<td>Lab</td>
<td>-1.0277</td>
<td>1.08e-09***</td>
<td></td>
</tr>
<tr>
<td>Pharmacy</td>
<td>0.6798</td>
<td>5.58e-05***</td>
<td></td>
</tr>
<tr>
<td>Cardiology:Lab:Pharmacy</td>
<td>1.0679</td>
<td>6.76e-08***</td>
<td>←Synergistic effects</td>
</tr>
</tbody>
</table>
We observe that in this case, the interaction term has a positive coefficient and is also significant, whereas both cardiology information systems and lab information systems have a negative coefficient. While pharmacy information systems have a positive impact, the coefficient is smaller than that of the combined portfolio. Thus, we can infer that cardiology information systems and lab information systems have a negative effect on the quality performance of hospitals when used in isolation, however, when all three systems are used in conjunction, there is an overall significant positive effect on the quality performance of the healthcare organization.

Likewise, radiology systems may also offer a similar synergistic effect when used in conjunction with cardiology information systems to impact the heart attack quality metric. Using our approach, we identified those portfolios including radiology in combination with cardiology and lab systems may also exhibit the portfolio effect. In each of the portfolios identified in Table 5, the regression results although not statistically significant, indicate that individual technologies in isolation were negatively associated with the heart attack quality metric, but when used in conjunction with other technologies in the portfolio, the effect appeared to be positive. While the results cannot be considered as definitive at this stage, they are worthy of further examination with more granular and larger datasets.

Table 5: Potential Candidates for Optimal IT Portfolios

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Individual Effect</th>
<th>Portfolio Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiology, Radiology</td>
<td>Cardiology: Negative effect (-0.2165)</td>
<td>Cardiology + Radiology:</td>
</tr>
<tr>
<td></td>
<td>Radiology: Negative effect (-0.1727)</td>
<td>Positive effect (.01009)</td>
</tr>
<tr>
<td>Radiology, Lab</td>
<td>Radiology: Negative effect (-0.2537)</td>
<td>Radiology + Lab:</td>
</tr>
<tr>
<td></td>
<td>Lab: Negative effect (-1.582)</td>
<td>Positive effect (.09071)</td>
</tr>
<tr>
<td>Radiology, Cardiology, Lab</td>
<td>Radiology: Negative effect (-0.03454)</td>
<td>Radiology + Cardiology + Lab:</td>
</tr>
<tr>
<td></td>
<td>Cardiology: Negative effect (-0.21299)</td>
<td>Positive effect (.10870)</td>
</tr>
<tr>
<td></td>
<td>Lab: Negative effect (-0.22486)</td>
<td></td>
</tr>
</tbody>
</table>

Discussion and Future Research

In this paper, we present an extensive review of literature on the impact of health information technology on quality. We identify a research gap where past studies have explored the impact of individual technologies or aggregate all technologies based on overall investment, but do not explore the impact of specific portfolios of information technology and their synergistic effects on healthcare quality. Based on the past studies on portfolio theory, we then develop an approach for identifying such optimal portfolios and exploring the presence of such synergistic effects among the components of the portfolio. We then present preliminary results to demonstrate the feasibility of this approach.

There are several limitations in this research in progress study that we intend to address in future research. Specifically, we will extend our approach to explore and compare alternative data mining algorithms to identify optimal portfolios. Next, we will extend our analysis of synergistic effects by controlling for hospital size, location, ownership and case mix. Furthermore, we will explore causal relationships by including time series data from multiple years.

Other limitations that need to be addressed include endogeneity due to adoption and use of IT, extent of system use and user training and could potentially be addressed with additional survey data. However, the large sample size should still provide realistic averages. While we have conducted our preliminary analysis at an aggregate level, in future research we intend to increase the granularity of analysis to specific components of integrated information system products.

The results of this research have significant implications for both theory and practice. Our exploration of optimal portfolios and synergistic effects adds to the knowledge base on impact of portfolios on organizational performance by extending it to the case of healthcare and healthcare quality. In practice, the optimal portfolios and their synergistic effects will inform CIO’s and hospital organizations in their IT
investment and planning decisions to help achieve a better return on improve quality of care. Additionally, implications for research and practice include:

1. A clearer understanding of HIT's impact on service and quality, and therefore may help guide decision-makers when planning and implementing future IT investments.
2. The identification of systems that have no, or relatively minor, impact quality may inform the design of future versions of these systems.
3. Understanding the inter-system synergies will guide strategic planners of facilities based on systems previously adopted.

References


