Chapter 9
A Quantitative Approach to Identify Synergistic IT Portfolios

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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. 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 introduce an approach, utilizing data mining techniques and logistical regression, to identify such optimal portfolios, and explore the presence of such synergistic effects among the components of the portfolio. This multi-step approach is then applied to publically-available datasets, and the resulting candidate IT portfolios are presented. Statistical analysis is then used to test these results and demonstrate the feasibility of this approach.

Keywords Healthcare information technology • Data mining • Logistic regression • Synergy • Portfolio • Quality

9.1 Introduction

As the average age of the population in the United States increases, the demand for healthcare to treat them also rises. To support this growing need for healthcare, organizations seek ways to meet this need while simultaneously improving their performance. To this end, healthcare organizations continue to make large investments in health information technology to improve quality of care and lower costs (Monegain 2009; Pizzi 2007). Given the large investments, wide variety of technologies, and the critical

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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. In this chapter, we introduce and outline a new approach to identify combinations of IT systems that demonstrate synergistic effects and exhibit positive effects on healthcare quality. We then this test this proposed approach using publically available datasets and detail the results.

9.2 Literature Review

Healthcare and Information Technology are two examples of domains which contain a wealth of empirical research. Each broadly defined domain offers an abundance of research, and while the subset of research encompassing both healthcare *and* IT is smaller, it is still extensive. In order to more fully understand the relationship between information technology and healthcare quality, in this research we explore several questions. What affect does healthcare IT have on quality? Are there specific technologies or a combination of technologies that lead to a positive impact on quality of care, and if there are, what systems are involved? To develop a response to these questions, we began with a systematic review of relevant literature.

The literature search strategy involved executing a search on the PUBMED database (www.ncbi.nlm.nih.gov/pubmed) seeking English language articles published between January 1, 2000 and June 30, 2013. While the list of articles identified through the 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.

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 technologies, Electronic Medical Records (EMR) (DesRoches et al. 2010), Computerized Physician Order Entry's (CPOE) (Swanson Kazley and Diana 2011), and Clinical Decision Support Systems (CDSS) (Romano and Stafford 2011) were the most commonly investigated technologies. Systems examined were in operation at multiple facilities and in various departments.

Most studies use one of two units of analysis when determining if benefits had been realized after implementation. 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 of an HIT system to judge results. The remaining half of the studies used the patient as the unit of analysis (e.g. glucose levels, blood pressure) (Hooper et al. 2013; Hunt et al. 2009) to determine impacts. In almost all cases, longitudinal data was required to ensure temporality and thus support the author's causality conclusions.

As is evident in Table 9.1, 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).

Some of the papers reviewed were of particular interest as they offered specific insights from their study's perspective, but when taken in totality offer clear trends in research results. For instance, Piontek et al. (2010) pointed out that medical errors and undesirable outcomes are costly. Therefore, as facilities' severity-adjusted mortality rates declined due to the implementation of an adverse-drug-event (ADE) alert system, so did pharmacy and variable drug costs. Additionally, in the process of protecting

Table 9.1 Summary of empirical research on impact of IT on healthcare quality

Technology	Positive	Neutral	Negative	Inconclusive
EMR	Adams et al. (2003), Campbell et al. (2008), El-Kareh et al. (2009), Gaylin et al. (2011), Gluck (2009), Hunt et al. (2009), Nirel et al. (2009), Cochran et al. (2011), Hazelhurst et al. (2012), Restuccia et al. (2012)	DesRoches et al. (2010), McCullough et al. (2010), O'Connor et al. (2005), Romano and Stafford (2011), Pillemer et al. (2011)	Kern et al. (2009), Morin et al. (2009)	Bardach et al. (2009)
CPOE		McCullough et al. (2010), Swanson Kazley and Diana (2011)	Koppel et al. (2005), Roberts et al. (2010)	
CDSS	DesRoches et al. (2010), Fraenkel et al. (2003), Jean-Jacues et al. (2011), Shelley et al. (2011)	Romano and Stafford (2011)	Roberts et al. (2010)	
Other	Golob et al. (2008), Davis and Pavur (2011), Menachemi et al. (2008), Piontek et al. (2010), Yu and Houston (2007), Spielberg et al. (2011), Lucero et al. (2011), Sharkey et al. (2013), Virga et al. (2012), Restuccia et al. (2012), Frimpong et al. (2013), Cohen et al. (2013), Hooper et al. (2013)	Davis and Pavur (2011)	Furukawa and Adam (2008), Loiselle et al. (2010), Gluck (2009)	Savage et al. (2010), Deily et al. (2013), Campion et al. (2013)

patient health, a peripheral benefit of HIT systems may be physician education. Roberts et al. (2010) reveal the number of true positive alerts from an ADE alert system declined over time. This may indicate that the alerts caught by the system informed prescribers who in turn became more familiar with drug interactions; thereby reducing the occurrence of prescription errors. Contrarily, Savage et al. (2010) warns that the more complex an ePharmacy (and by extension, any HIT system) is, the more opportunity exists for the introduction of errors. When healthcare providers begin to rely entirely on the computerized system to make decisions regarding dosage, drug interaction and discharge orders, oversights can occur. These errors are almost always a result of incomplete or inaccurate information entered on the patient's behalf.

When looking at results from multiple studies, it still appears that HIT's impact on the quality of healthcare is ambiguous at best. However, there are growing signs that HIT is maturing, and benefits are beginning to be realized more reliably. Nine of the ten most recent articles included in this research reported favorable results compared to only five of the ten oldest articles appearing in this review. While only an antidotal observation, this may warrant further research as systems become more comprehensive, user friendly, and interoperable. 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.

9.3 Methods

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 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.

The resulting review revealed recent articles that evaluated investments in the business (Bendoly et al. 2009; Menon et al. 2000) and healthcare (Ancker et al. 2012; Chatterjee et al. 2009; Cresswell et al. 2010; Hennington and Janz 2007; Menon et al. 2000; Myung Ko and Osei-Bryson 2004; Thrasher et al. 2006; Valdmanis et al. 2008) domains.

9.3.1 Theory Development

Several theories have been used to evaluate impact of IT on performance. However, it appears that no single theory dominates IT investment evaluation. The authors of the reviewed articles were guided by numerous models, theories and frameworks. 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. 2012).

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 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 9.2). 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. (2010) research into the synergies realized from integration of multiple healthcare alliance networks, and Setia et al. (2011) analysis of how the assimilation of IT applications affect the financial performance of healthcare organizations.

Based on the past research that indicates that the complementarity and the synergistic effects between technologies in a portfolio is a key factor in influencing performance, in this study we sought to identify such optimal portfolios that positively

Table 9.2 Studies evaluating IT and healthcare investments using portfolio concept

Study	Context of study	Guiding theoretical framework	Constructs and measures	Data and method
Bridges et al. (2002)	Multiple interventions to standardize returns	Portfolio theory	Synergy between health investments	Cost effectiveness analysis
Lin et al. (2006)	Identify is patent diversity reduces risk	Technology portfolio strategy	Synergy from IT portfolio	US Patent applications
Zhu (2004)	114 companies using e-commerce	Resource-based theory	Complementary IS	Inventory of IT, financial records
Setia et al. (2011)	IT application assimilation and use	IT portfolio theory	IT systems and net income	HIMSS & California OSHPD
Thrasher et al. (2010)	Health alliance networks	Thompson's interdependence theory	Complementary IS	Financial and quality results performance

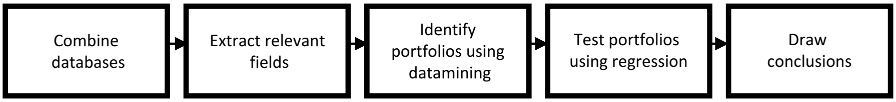

Fig. 9.1 Research approach used to identify portfolios

influence patient-outcome quality at healthcare organizations. The interactions between IT systems and the varying levels of synergies they provide may help explain the discrepancies reported by the authors of studies discussed earlier.

Specifically, this research was guided by the following two objectives:

Research Objective 1
Identify optimal portfolios of information technology that are positively associated with above average quality performance at healthcare organizations

Research Objective 2
Identify if synergistic effects exist between the components of the optimal IT portfolios. 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?

To build on the portfolio theory applications outlined in the previous section, we tested the approach depicted in Fig. 9.1.

The process begins with locating and securing suitable datasets. A suitable dataset would contain data on multiple healthcare providers, the information technology systems and applications they use, and the results of one or more healthcare quality metrics. For this research multiple datasets had to be combined in order to meet these requirements. Once the dataset was successfully merged, the required fields were identified and imported into a new database for ease of manipulation.

The third step involved applying data mining techniques through the use of decision tree classifiers to highlight candidate portfolios. These candidate portfolios where then subjected to statistical analysis to reveal intersystem synergies. Finally, optimal portfolios were identified and discussed. The rest of Sect. 3 details the process in each of these steps.

9.3.2 Data Collection, Merge and Manipulation

In order to address the research question regarding HIT's impact on quality, an analysis of hospital IT adoption records in conjunction with hospital quality results was completed. Specifically, a multi-source approach to data collection was used incorporating the 2009 HIMSS Analytics database,[1] and the 2010 version of the Medicare.gov Hospital compare database.

[1] The Dorenfest Institute for H.I.T. Research and Education, HIMSS Foundation, Chicago, Illinois, 2010.

9.3.3 Independent Variables

This data source identifies the IT applications in use (independent variables) for more than 34,000 healthcare facilities within the United States. These applications were clustered into clinical (e.g. electronic medical records (EMR) and picture archiving and communication system (PACS)) and business/strategic groupings (e.g. general ledger and payroll). These clusters were adapted from Setia et al. (2011) and Bhattacherjee et al. (2007) with the additional classifications of recently introduced applications. The clustering HIT in this manner has been extensively validated, and is commonly used by researchers in this field (Burke and Menachemi 2004; Burke et al. 2002; Dorenfest 2000; Menachemi et al. 2006; Pare and Sicotte 2001). The Clinical HIT cluster included applications designed to improve patient care. Because the direct impact of IT systems on healthcare outcomes was sought, only these clinical systems were used in the analysis.

9.3.4 Dependent Variables

The Medicare's Hospital Compare database provided quality measures representing patient results (dependent variables) for 4,726 facilities nationwide. The readmissions, complications and deaths details were utilized for this research. Within this portion of the data, healthcare facilities were rated with one of three ordinal values, *above the national average, equal to the national average* or *below the national average* for each of six quality measures (Heart Attack Mortality, Heart Attack Readmission, Heart Failure Mortality, Heart Failure, Readmission, Pneumonia 30 Day, and Pneumonia Readmission). The resulting combined dataset contained 3113 facilities with live and operational systems.

9.3.5 Portfolio Definition

Because synergies might be found between any two IT systems, the IT portfolio construct was defined as a combination of two or more clinical IT applications (independent variables). Many applications are present within a given facility. The applications under consideration in this research are currently implemented within healthcare facilities as reported by each facility's chosen healthcare administrator.

Step 1: Data Mining to Narrow the Search Space

The 57 predictor variables (IT applications) offered a large number of possible combinations. To deal with the volume of permutations, as well as the facility heterogeneity, data mining techniques were used to narrow the search space.

Step 2: Regression Analysis to Identify Synergies

In the next phase of the approach, the recommended portfolios were subjected to an ordinal logistic regression analysis for testing the synergistic effects among the portfolio components. This was accomplished using statistical computing and graphics software in conjunction with the original unbalanced dataset.

The generalized form of the ordinal logistic regression model used to test the portfolios is given by:

$$y = b_0 + \sum_{i=1}^{n} b_i x_i + b_{n+1} \prod_{i=1}^{n} x_i + \sum_{k=1}^{4} b_{n+1+k} z_k$$

where b_0 is the constant and $\sum_{i=1}^{n} b_i x_i$ is the term for the predictor variables when working in isolation. $b_{n+1} \prod_{i=1}^{n} x_i$ represents the interaction of the systems, and identifies the coefficient of the portfolio. The term $\sum_{k=1}^{4} b_{n+1+k} z_k$ represents the four control variables used, and y represents the quality outcome (dependent variable) with values *above the national average*, *equal to the national average* or *below the national average*.

To identify if synergies exist, an interaction term was developed. While there are many ways to construct such a term, the most usual, and simplest, is to multiply the independent variables that may be involved by each other, and add that term to the equation (Flom and Strauss 2003; Harrell 2001).

9.3.6 Control Variables

Because the focus of this research is to analyze the quality performance of hospitals, other healthcare related factors that might impact this performance were controlled. Past literature has held that a facility's quality performance is likely to be influenced by size, type, ownership and case mix (Friesner et al. 2007; Setia et al. 2011). Therefore, these confounding variables were controlled using additional variables found in the Medicare dataset. The number of beds was used to control for facility size. Facilities were identified and grouped in one of three categories (General Medical, Specialty, and Critical Access). The resulting classification was used to control for facility type. Ownership data provided was identified in the dataset as—government, nonprofit and proprietary. To control for case mix, the facilities' case mix index (CMI) was retrieved from a third data source also provided by the Centers for Medicare and Medicaid Services. The provider number was once again used to match the index value to the facility.

9.4 Results

The data mining process produced extensive decisions trees for each of the quality metrics with each branch representing a different portfolio. Each branch (portfolio) was associated with one of the quality ratings (above average, average, below average). Those portfolios associated with *above average* results were extracted and identified as recommended portfolios. The data mining process identified multiple recommended portfolios for each quality outcome.

9.4.1 Intersystem Synergies Identified

To test for the existence of synergies, a logistic regression was run on each of the recommended portfolios reported in Stage One (data mining). Each regression result returned a list of component systems and their corresponding coefficient. Additionally, the regression results identify the coefficient for combinations of systems. The coefficient indicates to what extent that system (or combination of systems) is correlated with *above the national average* results. Intersystem synergies were identified where the coefficient for the portfolio was greater than the sum of the component coefficients (Flom and Strauss 2003). Each synergistic effect identified was significant at a level of .05. The following synergies were identified within the regression results:

Heart attack mortality	
	Estimate
EDIS	−1.316550
Pharmacy_Management	−0.665235
Dictation	−1.661559
CDSS	−0.213957
Radiology_MRI	0.044432
Cardiology_IS	−3.707143
CDSS:Cardiology_IS	4.804806
Radiology_MRI:Cardiology_IS	4.468318
EDIS:Pharmacy_ Management:Dictation	1.088635

Portfolio HAM-1

Clinical Decision Support System, Cardiology Information System
Facilities with this portfolio: 847

A clinical decision support system (CDSS) is an application that healthcare providers use to analyze data in the process of making clinical decisions. A CDSS is an adaptation of the decision support system used most commonly to support business and management decision making. The cardiology information system (CIS) allows physicians to access their patients' cardiac histories as well as results when and where they are needed. Both of these systems allow physicians to access data remotely thereby offering the opportunity to consult with colleagues at different facilities in real-time. These features may account for the synergistic effect identified.

Portfolio HAM-2

Radiology: Medical Resonance Imaging, Cardiology Information System
Facilities with this portfolio: 834

The noninvasive medical diagnostic technique known as Medical Resonance Imaging (MRI), analyses the body's absorption of high-frequency radio waves. This technique is commonly used for diagnosis and treatment of cancer. An MRI system may enhance the performance of a CIS by providing the necessary imaging to monitor and manage pacemaker recipients. Cardiovascular imaging is used extensively during pacemaker implantation and is a required component to offer the coronary angiography service. The tight coupling of these two systems may account for the synergies identified between these two systems.

Portfolio HAM-3

Emergency Department Information System, Pharmacy Management, Dictation
Facilities with this portfolio: 1211

Emergency Department Information Systems (EDIS) are designed to automate and streamline the department's workflow and deliver patients a more efficient and improved quality of care. These systems are specifically designed to meet the unique needs of emergency room patients and physicians. Pharmacy management systems primarily manage data with respect to the dispensing of prescriptions. However, they also control inventory, assist with the billing of claims, and ensure compliance with laws and regulations. A hospital's dictation system allows physicians to create voice recordings. These recordings allow hands-free documentation of procedures in real-time as well as providing out-of-station physicians with the ability to leave patient instructions and orders. In the busy emergency room, all three of these systems may play a pivotal role in increasing the speed of care delivered to the patient which, in turn would impact quality outcomes.

Heart attack readmission	
	Estimate
OR_Scheduling	–0.767901
Lab_Outreach Services	−11.043843
Dictation with Speech Recognition	–5.556865
OR_Scheduling:Lab_Outreach	15.285874
OR_Scheduling:Dictation_SR	8.091687
OR_Scheduling:Lab_Outreach:Dictation_SR	3.208897

Portfolio HAR-1

Operating Room Scheduling, Laboratory Outreach Services
Facilities with this portfolio: 265

An operating room scheduling system provides physicians and administrators with information on each surgical procedure that is planned, currently underway, or has been completed. The system also assists with material management, material requirement planning, and pre-admission consultations. It also offers an opportunity to record clinical notes for procedures, sterilization management, and transcription. Laboratory outreach is service offered by facilities where a facility's laboratory services are made available to outpatients as well as patients of other facilities and physicians. The laboratory outreach service can benefit the hospital by increasing revenues and filling unused capacity, as well as building relationships with patients and physicians in the community. However, while financial benefits are clear, laboratory outreach has not been traditionally associated with improved quality of care. Identifying a possible synergy is difficult between these two seemingly distantly-related areas of care. There may be a tie between the patients who receive laboratory services, and the results of those tests necessitating operative services.

Portfolio HAR-2

Operating Room Scheduling, Dictation with Speech Recognition
Facilities with this portfolio: 458

As mentioned earlier, a dictation system allows physicians to record patient instructions. However, an enhanced dictation system equipped with speech recognition allows the recordings to be converted into a digital format and easily imported into the computer as text. Conversely, the speech functions also allows patient statistics such date of birth, medical history and patient instructions to be transferred from the computer onto the recording. This system, together with the operating room scheduling system may offer a synergistic effect through automating note taking during procedures and thereby reducing documentation error.

Portfolio HAR-3

Operating Room Scheduling, Laboratory Outreach Services, Dictation with Speech Recognition
Facilities with this portfolio: 130

All three member systems have been introduced in previous portfolios. However, this portfolio has been adopted by relatively few facilities. In this combination of systems, we have effectively a merger of the previous two portfolios. The synergistic effects would be expected as laboratory outreach services and dictation with speech recognition have both demonstrated a positive synergy when associated with an operating room scheduling system.

Heart failure mortality	
	Estimate
Order_Entry	0.026469
Chart_Track	−0.703990
Laboratory_IS	0.185730
Microbiology	−1.446710
Order_Entry:Chart_Tracking	1.591157
Laboratory_IS:Microbiology	1.661938
	Estimate
Cardiology_Cath.Lab	−1.016270
Pharmacy_Management	−0.152552

Heart failure mortality	
	Estimate
Chart_Tracking	0.160954
Anatomical_Pathology	0.151822
Cardiology_Cath.Lab:Pharmacy_Management:	
Chart_Tracking:Anatomical_Pathology	1.592765

Portfolio HFM-1

Order Entry, Chart Tracking
Facilities with this portfolio: 1512

An order entry system is a component of an electronic medical records system which allows patient orders to be entered directly into the electronic record at the point of service. It also provides a mechanism to communicate those orders to external parties such as pharmacies and laboratories. These orders are typically communicated via encrypted Internet connections. A chart tracking system is also usually a module of a larger electronic medical records (EMR) management tool that is designed to manage the patient's paper-based records. Chart tracking systems can significantly streamline the processes and reduce the workload associated with records management. As subcomponents of a common EMR, these systems are closely related, and therefore lend themselves to leveraging the other's benefits.

Portfolio HFM-2

Laboratory Information Systems, Microbiology
Facilities with this portfolio: 1514

Care givers use laboratory information systems (LIS) to manage an assortment of inpatient and outpatient medical testing, including hematology, chemistry, oncology, immunology and microbiology. As a specialized LIS, the microbiology system is designed to seamlessly integrate into the microbiology testing workflow enabling laboratories to achieve standardized, precise, and consistent results while maximizing lab efficiency. These two systems are also very closely related, and were present in a large percentage of hospitals analyzed. The overlap in functionality between these two systems may offer insight into intersystem synergies.

Portfolio HFM-3

Cardiology: Catheterization Laboratory, Pharmacy Management, Chart Tracking, Anatomical Pathology
Facilities with this portfolio: 463

The Cardiology: Catheterization Laboratory system collects, stores, maintains and protects still images and video created during cardiac catheterization procedures. These visual elements are necessary to maximize the efficacy of these procedures. Whereas the links between the pharmacy management and chart tracking system are not readily apparent, any synergy they provide the cardiology system would naturally enhance the heart failure mortality quality metric.

Heart failure readmission	
	Estimate
Blood_Bank	0.123467
Microbiology	–0.025624
Obstetrical_Systems	–0.558120
Radiology_MRI	–0.143150
Blood_Bank:Microbiology:	
Obstetrical_Systems:Radiology_MRI	2.672228
	Estimate
Blood_Bank	0.048369
Microbiology	0.127110
Consumer_Portal	1.142723
Anatomical_Pathology	1.627532
CPOE	0.373514
Blood_Bank:Consumer_Portal:CPOE	3.713268
Microbiology:Anatomical_Pathology:CPOE	4.281513

Portfolio HFR-1

Blood Bank, Microbiology, Obstetrical Systems, Radiology: Medical Resonance Imaging
Facilities with this portfolio: 820

A blood bank information system is a multi-module application that assists in areas such as donor recruitment, blood collection, inventory control, donor testing, shipping, transfusion, and billing. An obstetrical information system receives analog information from various monitors which is digitized before being input. OB systems typically have admission, transfer, edit, and discharge functions. This portfolio is rather unique for two reasons. First, it is one of only two portfolios that incorporates four IT systems; and second, these systems represent four distinct departments within the healthcare facility. This portfolio offers further opportunity to explore the causes behind the synergies observed.

Portfolio HFR-2

Blood Bank, Consumer Portal, Computerized Physician Order Entry
Facilities with this portfolio: 120

A consumer portal provides patients with direct access to their personal information regarding their health plan coverage, medical history and treatment plans, as well as offering patient services such as appointment scheduling and prescription refill ordering. A computerized physician order entry system (CPOE) allows entering of medication orders or other physician instructions electronically instead of on paper charts. The use of a CPOE system can help reduce errors related to illegible handwriting or transcription of medication orders. This recommended portfolio was found in the fewest facilities in this study. It is also the only one to include the consumer portal. It is possible that relative scarcity of consumer portals reflects untapped synergies.

Portfolio HFR-3

Microbiology, Anatomical Pathology, Computerized Physician Order Entry
Facilities with this portfolio: 336

An anatomical pathology laboratory information system (APLIS) logs specimens, records microscopic findings, regulates laboratory workflow, formulates reports, distributes them to the intended recipients throughout the healthcare system, and supports quality assurance measures. They also support asset tracking and digital imaging. The results entered into the microbiology system and APLIS are accessible to the physicians through their CPOE. Therefore promoting the accuracy of, and expediting the access to these test results may generate the synergies identified.

Pneumonia 30 day mortality	
	Estimate
Dictation	–0.314298
Abstracting	–0.257044
Radiology_Angiography	1.931669
Dictation:Abstracting	0.886240
	Estimate
Radiology_DM	–0.040562
Radiology_Nuclear	0.140742
Operating_Room_Pre	0.770414
OR_Scheduling	0.055803
Radiology_DM:Operating_Room_Pre:OR_Scheduling	3.855601

Portfolio PM-1

Dictation, Abstracting
Facilities with this portfolio: 1570

A coding and abstracting information system efficiently summarizes clinical data. The abstracting process supports later activities such as coding and reimbursement, quality improvement initiatives, billing audits, and clinical research. This two member-system portfolio was the most commonly found at the facilities under review. Interestingly it is also the only portfolio to include an abstracting information system. Both of these systems help expedite the administration function, and allow care providers to devote more of their time and attention to providing care to the patient.

Portfolio PM-2

Radiology: Digital Mammography, Operating Room: Pre-Operative, Operating Room Scheduling
Facilities with this portfolio: 660

A digital mammography system collects, stores, manages and disseminates x-ray images created during breast exams. The resulting images are analyzed for abnormalities which may indicate cancerous tissue. The pre-operative system assists anesthesiologists in pre-operative patient assessment and application of anesthesia. Pneumonia is of grave concern for patients recovering from surgery - particularly in the elderly.

Maximizing the quality of care during all stages of the surgical process may reduce the occurrence of pneumonia and thereby positively affect this metric.

Pneumonia readmission	
	Estimate
Radiology_DR	−0.883888
Dictation	−0.646310
Radiology_DF	1.330881
Operating_Room_Post	−1.059171
Radiology_DR:Dictation	0.375184
Radiology_DR:Radiology_DF:Operating_Room_Post	2.447464

Portfolio PR-1

Radiology: Digital Radiography, Dictation
Facilities with this portfolio: 1297

A digital radiography system offers advancement over the traditional film x-ray. Images are held digitally and are available immediately. This eliminates the need to wait for film development, and allows physicians to more quickly review and diagnose patients. Since a chest x-ray is the primary means by which physicians diagnose pneumonia, it stands to reason that any tool which improves upon the functionality or speed of this treatment would positively affect a facilities performance in the frequency of patients readmitted because of pneumonia.

Portfolio PR-2

Radiology: Digital Radiography, Radiology: Digital Fluoroscopy, Operating Room: Post-Operative
Facilities with this portfolio: 940

Digital fluoroscopy is a digital x-ray imaging system similar to digital radiography; however, the images are dynamic. Digital fluoroscopy is a form of x-ray that allows physicians to inspect deep tissues in the body in real-time on a computer monitor. It provides detailed images of the function and structure of areas like the lungs, the liver, the heart and kidneys. A post-operative care system can give consultative and decision support to surgical recovery staff with the goal of reducing surgical site infections, heart attacks, blood clots, and postoperative pneumonia. Once again, this portfolio contains systems which directly relate to either the diagnosis or prevention of pneumonia. Therefore, the synergistic effects identified are not surprising.

9.4.2 Negative Synergies Identified

Interestingly, synergistic effects can affect patient quality outcomes in both a positive as well as negative manner. While most portfolio coefficients revealed little to no synergistic effects, and several portfolios (as detailed above) indicated a positive synergistic effect, four portfolios reported a negative impact on quality. Three of these portfolios apply to the heart attack readmission metric, and the fourth deals with heart failure readmission.

Heart attack readmission	
	Estimate
Operating_Room_Scheduling	3.044564
Radiology_DR	2.808544
EDI	2.752098
CPOE	1.803123
Operating_Room_Scheduling:EDI	−3.535674
Operating_Room_Scheduling:CPOE	−4.989675
Radiology_DR:CPOE	−8.012095

In these results we see that the operating room scheduling, radiology: digital radiography, electronic data interchange (EDI), and computerized physician order entry (CPOE) have been combined into a single portfolio. An EDI system allows the transfer of information between two disparate systems of networks (2013). These tools are often used to allow legacy within a facility to communicate or allow the transfer of patient records between facilities. Each of these systems have a moderately positive correlation with better than average results. However, when operating room scheduling is joined with EDI or CPOE the combined scores are significantly negative. Likewise, when radiology: digital radiography is joined with CPOE, we see an even greater change to the results. Since most of these systems appear in one or more of the candidate portfolios, we cannot simply dismiss the systems as offering little value in a portfolio environment. However, it is clear that for at least the heart attack readmission quality metric, intersystem dynamics are present which may be hampering quality.

Heart failure readmission	
	Estimate
Blood_Bank	0.048369
Microbiology	0.127110
Consumer_Portal	1.142723
CPOE	0.373514
Blood_Bank:Microbiology:Consumer_Portal:CPOE	−4.927736

The heart failure readmission results above reveal that the blood bank, microbiology, consumer portal and CPOE systems have nearly a neutral influence on quality. However, when all four systems are combined, they offer a strong negative impact. The commonality between these two examples is the inclusion of CPOE in the portfolios. As documented by Koppel et al. (2005), CPOE systems produce the opportunity to introduce medical errors into the system, and thus negatively impact quality.

The causes of these negative effects are not fully apparent. However, what is clear from these results is that the introduction of additional IT systems into a healthcare environment may not always prove to be advantageous, and in some cases may result in a detriment to patients and the organization. This finding directly supports the Yu and Houston (2007) contention discussed earlier that IT adoption is not a strong predictor of quality performance.

9.5 Discussion

The results outlined previously illustrate that synergistic effects are occurring between multiple IT systems within the healthcare arena. The purpose of this research was to introduce an approach to identify portfolios that harness these synergies and to provide a mechanism to confirm their existence. Specifically addressing the research objectives:

Research Objective 1
Identify optimal portfolios of information technology that are positively associated with above average quality performance at healthcare organizations.

As identified earlier, the data mining phase of the approach identified many portfolios associated with *better than national average* quality results. Many of these portfolios contained systems which were individually associated with *above average results*. It would be expected that when combining these systems into a portfolio, the resulting accumulative effect on quality would also be positive. Therefore, a portfolio's positive correlation with better than the national average is not sufficient to predict that it contains a synergistic effect. However, these portfolios would be suitable candidates for further analysis using logistic regression.

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?

Using the second step of the recommended approach, logistic regression we were able to support the presence of synergistic effects between select IT systems. These synergistic effects were specific to individual quality metrics and their effects seem to be mitigated by the presence, or lack of presence, of other IT systems.

9.6 Research Contribution and Impact

The results of this research have significant implications for both theory and practice. The 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. By applying the portfolio theory to information technology investments within the healthcare context, insights have been gained into a lightly explored subject area using concepts rarely applied in this arena.

Specifically, contributions from this research include:

1. A clearer understanding of HIT's impact on quality, and therefore may help guide decision-makers when planning and implementing future IT investments. Healthcare administrators seeking to bolster or maximize a particular patient outcome for their

facility, can compare their current IT system mix to those recommended portfolios, and identify those systems which may provide the greatest return on investment.

2. Understanding the inter-system synergies will guide strategic planners of facilities based on systems previously adopted. Those facilities with the recommended systems already in place, but that are not performing well on the quality metric, will have additional information to inform their performance improvement efforts.
3. The identification of systems that have no, or relatively minor, impact on quality may inform the design of future versions of these systems. Identifying combinations of systems with lower than expected interactions can aid HIT system vendors seeking to enhance their offerings by providing an area of focus for future development.
4. A unique application of Portfolio Theory. To date, the Portfolio Theory has been used extensively but almost exclusively within the finance arena (Bridges et al. 2002). Extending the application of this well-defined and well-understood theory to the healthcare domain supports the validity of this research while also expanding the usefulness of the theory.
5. Interdisciplinary Approach: bridging three domains. The approach outlined by this research draws from three independent domains. The Portfolio Theory is borrowed from the economics and finance, the data mining techniques are drawn from information technology, and the examination of HIT systems reflects the healthcare domain.

9.7 Research Limitations

The data used for this research was provided to the public in the form of two datasets. Neither dataset was designed specifically for this research. Therefore, the data structure and granularity were not ideal. The process of ranking the facilities by their quality metric into the three classifications (*above the national average, equal to the national average or below the national average*) was not fully detailed. The dataset documentation did not indicate through what mechanisms these facilities were assigned their rating. Furthermore, a large majority of the facilities obtained an *equal to the national average rating* on each metric. This indicates the parameters for this rating must have been rather large. If facilities were ranked into more than three categories, the requirements to receive an average ranking were constrained, or if the facilities performance was reported as a numerical value, greater precision could be attained.

The IT systems reported in the HIMSS dataset did not include extent of system use or user training levels which would helpful to combat endogeneity concerns. However, we believe the large sample size still provides realistic averages.

More current, comprehensive, accurate and robust datasets with finer granularity are available, and will continue to be made available. As future generations of systems advance and mature, their synergistic relationships will surely evolve. Therefore regular application of this approach to updated datasets will be required.

Biography

Ken Pinaire Ken has been teaching at the graduate level since 2002. His areas of interest include promoting healthcare quality through the use of technology and data mining. He seeks to assist healthcare systems maximize the value of their technology through targeted investments. He is currently studying the synergistic effects of information technology systems in the healthcare arena.

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