An Empirical Investigation into the Adoption of Open Source Software in Hospitals

Gilberto Munoz-Cornejo, Carolyn B. Seaman, A. Gunes Koru
Department of Information Systems, University of Maryland Baltimore County, MD, USA
1000 Hilltop Circle, Baltimore, MD 21250
(P) 410 455 3937, (F) 410 455 1073
gilberto1, cseaman, gkoru@umbc.edu

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Abstract

Open source software (OSS) has gained considerable attention recently in health care. Yet, how and why OSS is being adopted within hospitals in particular remains a poorly understood issue. This research attempts to further this understanding. A mixed-method research approach was used to explore the extent of OSS adoption in hospitals as well as the factors facilitating and inhibiting adoption.

The findings suggest a very limited adoption of OSS in hospitals. Hospitals tend to adopt general-purpose instead of domain-specific OSS. We found that software vendors are the critical factor facilitating the adoption of OSS in hospitals. Conversely, lack of in-house development, as well as a perceived lack of security, quality, and accountability of OSS products were factors inhibiting adoption. An empirical model is presented to illustrate the factors facilitating and inhibiting the adoption of OSS in hospitals.

Keywords: Medical informatics; open source software; technology adoption; information systems; hospitals.

1. Introduction

The Open Source Software (OSS) phenomenon has become an important area of interest in information systems research due in part to the large and fast-growing number of OSS users and software products in a large variety of domains. OSS is already being adopted and used as a software platform in a number of fields other than health care (Jason Dedrick & West, 2003; J. Dedrick & West, 2004; Norris, 2004; Waring & Maddocks, 2005), and it has the potential to be equally promising for the hospital industry (Fitzgerald & Kenny, 2004). Studying OSS adoption in any domain can help reveal patterns and phenomena that are applicable to adoption in general, in addition to revealing insights into the domain being studied. In particular, the adoption and use of OSS in a hospital context remains a poorly understood phenomenon; only a handful of researchers have addressed the factors inhibiting or facilitating such adoption. Such an understanding is important in helping hospitals make better decisions about whether, and how, adoption of OSS could benefit them.

The first step in developing a better understanding is to explore the current state of OSS adoption, and the factors inhibiting and influencing it, in hospitals. Such an exploration is the goal of this study. Once this current state is well described, then it will be possible to seek answers to higher-level questions about the pros and cons, the costs and benefits, the advantages and disadvantages of OSS adoption in this domain, which is the second goal.

Therefore, the present study is of considerable interest for both practitioners and researchers. It will provide hospitals and health care organizations that are considering the adoption of OSS technologies with an understanding of how technological, environmental and organizational factors affect the adoption process. This way hospital IT practitioners, or others attempting to introduce OSS technology into hospitals, can prepare against the expected barriers

and can utilize the facilitators for successful adoption. This research also provides scholars with an empirical model for better understanding facilitating and inhibiting factors, as well as providing the foundations for further research that may validate and expand on the empirical model in other health care organizations and other domains.

The main objective of this investigation was to explore and analyze the extent of OSS adoption in hospitals, along with the factors influencing or inhibiting this adoption process. Hospital IT managers were chosen to represent the hospitals' perspective on this topic. The following three questions guided this investigation:

1. What are the types and names of OSS products that hospitals choose to adopt?

2. What is the extent of OSS adoption for these products in hospitals?

3. What are the factors facilitating and inhibiting the adoption of OSS in hospitals?

To research these questions, a survey and interviews were used to acquire both breadth and depth of understanding. The purpose of the survey was to answer the first two questions—to explore and characterize the types of OSS products adopted in hospitals and to discover the extent to which these products have been adopted. The interviews were used to answer question three—to attain a deeper understanding of the factors that are facilitating and inhibiting the adoption of OSS in hospitals.

In the following sections of this paper, we first present the related work in this area. Then, we introduce the methodology for our survey and interview studies. After that, we present our data analysis and results. Then, we introduce our empirical model of the adoption of OSS in hospitals. Finally, we present our conclusions and the implications of our work.

2. Literature Review

2.1 Open source software adoption in health care

Over the past few years, a small number of researchers have focused on the study of the potential advantages and risks of adopting and implementing OSS in the health care domain. Prior research encouraged the adoption and use of OSS in health care organizations because of OSS's potential to both enhance health care delivery, and lower software acquisition costs (Carnall, 2000; Kantor, Wilson, & Midgley, 2003; McDonald et al., 2003; Valdes, Kibbe, Tolleson, Kunik, & Petersen, 2004).

OSS could potentially be more reliable and secure than proprietary software because its source code can be inspected and reviewed (Carnall, 2000). Past research introduced and extended the idea of OSS as a software development model that could definitively improve clinical and research software in the field of medical informatics (Yackel, 2001). A paper by Kantor, Wilson, & Midgley (2003) also presents the potential benefits that OSS could provide in the area of primary care. Kantor et al., also proposed that the adoption of OSS would reduce the excessive costs, the frequent turnover of vendors, and the lack of common data standards that are afflicting electronic medical records (EMR) systems in primary care.

More recently, McDonald, Schadow, Barnes., et al.,(2003) also investigated the potential role that the OSS model of software development may have in the medical informatics area. They also described a number of OSS products that have been used in the medical informatics domain over the years, including: OpenEMed, a patient record system; OSCAR, a family practice office management and medical record system; as well as the internationally well-known VistA system, a Computer-Base Patient Records system (CBPR) developed in MUMPS (Massachusetts General Hospital Utility Multi-Programming System) by the U.S. Department of Veteran's Affairs (Brown, Lincoln, Groen, & Kolodner, 2003; Longman, 2007). A more recent study by Valdes et al., (2004) also pointed out that OSS could be an effective solution for the

problems that distress the health care industry such as high costs, business failures and barriers of standardization (Valdes et al., 2004). Other papers by Erickson, Langer, and Nagy (2005), Scarsbrook (2007) and Nagy (2007) supported the growth and adoption of OSS in radiology because OSS may significantly lower the entry cost for standards-compliant practices in the health care industry. They also proposed that OSS might allow rapid scientific advancement due to the sharing of information and software (Erickson et al., 2005; Scarsbrook, 2007; Van Latum et al., 1998). Other authors such as DeLano (2005) presented some reasons for the potential success of OSS predicting that the pharmaceutical research and development process may benefit from the OSS development model.

2.2 Open source software adoption in hospitals

A case study of OSS adoption was conducted at the Beaumont Hospital in Ireland, where the IT department, under limited financial resources, made the decision to adopt OSS. Several OSS products were adopted and implemented successfully. The authors reported that there were important initial start-up and future operational costs when OSS products were preferred in the hospital (Fitzgerald & Kenny, 2004).

Another study by Glynn, Fitzgerald and Exton (2005) investigated the commercial adoption of OSS using an innovation adoption theory framework based on Tornatzky and Fleischer's (1990) model. They derived a framework that was then used to investigate the adoption process of OSS in the case of the Beaumont Hospital (Fitzgerald & Kenny, 2004).

The OSS products and processes were also seen promising in terms of enabling rapid evolution and proliferation of applications in the medical domain through their use of open standards and higher degrees of interoperability (Raghupathi & Gao, 2007). The authors argued that the development processes in the Eclipse project (http://eclipse.org) could improve

scalability, prevent vendor lock–ins, and reduce costs in the medical information systems including electronic health record and clinical decision support systems.

There are some recent studies focusing only on the managerial and technical barriers to the adoption of OSS (Holck, Larsen and Pedersen, 2005). Past research on OSS and health care also proposed that OSS would reduce the number of bugs and failures in medical systems, as well as reduce their overall cost (Yackel, 2001). A study by Hogarth and Turner (2005) focused on creating a catalogue of existing OSS clinical projects and on determining metrics for their viability. The authors mentioned that many of the factors that are required to make a "successful and vibrant" OSS community within the mainstream software applications systems (e.g. Linux, Apache, etc.,) may not necessarily be applicable to the clinical software applications systems.

Another study by Kantor, Wilson, and Midgley (2003) presented a set of potential advantages that the adoption of OSS may provide with regards to lowering the resistance of hospitals to the adoption of Electronic Medical Records (EMR). These included: 1) the potential of OSS to reduce EMR ownership and software development costs, 2) the removal of vendor lock-in, and 3) the adherence of OSS to standards for the compatibility and data interchange among systems.

In another study by Valdes, Kibbe, Tolleson, et al., (2004) dealing with the barriers to the proliferation of Electronic Health Records/Electronic Medical Records (EHR/EMR), the authors concluded that OSS is a viable solution to the barriers of high cost, business failure and standardization that the health care industry is facing when adopting EHR/EMR. The authors mentioned that, for example, interconnectivity problems are more easily solved when using OSS, since no technical information can be hidden. They also added that OSS can help alleviate the high costs associated with the adoption and implementation of EHR/EMR (Valdes et al., 2004).

Although this paper presents a good case for the adoption of OSS solving the barriers that EHR/EMR is facing, the authors do not support their case with empirical data.

In summary, even though we have witnessed a widespread significant OSS research and industry adoption of OSS, there are still few studies on OSS adoption and use, especially in the hospital industry. Only a handful of researchers have addressed the factors inhibiting or facilitating OSS adoption in hospitals (Carnall, 2000; Glynn, Fitzgerald, & Exton, 2005; Kantor et al., 2003; Valdes et al., 2004). Each of the aforementioned studies in this section found that top management support, limited financial resources, past experiences using OSS-like systems, and the flexibility to modify, combine, and tailor OSS are the most important facilitating factors for the adoption of OSS within a hospital scenario. The factors inhibiting adoption range from the fear of IT personnel becoming de-skilled by not using mainstream commercial applications, the lack of OSS-literate IT personnel, the lack of other successful OSS examples in the industry, to the lack of reliable procurement models for the adoption of OSS. Finally, many of the papers and studies reported are cases from European countries, with health care systems that are very different from that in the U.S. Table 1 presents only a summary of the facilitators and inhibitors shown to influence the adoption of OSS as found in the literature.

Table 1: Main facilitators/inhibitors of OSS adoption

	Author(s)	Major Factor Findings	
		Facilitators	Inhibitors
Adoption of Open Source Software in Hospitals	**Fitzgerald and Kenny (2004)**	▪ Limited financial resources ▪ Top management support ▪ Software functionality ▪ User's past experience	▪ Lack of support from vendors ▪ Perception that OSS would threaten local proprietary software companies ▪ Fear by users to become de-skilled
	Gynn, Fitzgerald and Exton (2005)	▪ Perception that the benefits of OSS outweigh its disadvantages ▪ OSS-literate IT personnel ▪ Top management support ▪ Personal support for OSS ideology ▪ Network externalities ▪ The OSS champion example	▪ Perception of work under-valued if using OSS products ▪ Having to change operating model to OSS ▪ Fear by users to be de-skilled ▪ Lack of OSS champion example ▪ Lack of tolerance to technical problems with OSS ▪ Favorable arrangements with proprietary vendors
	Holck, Larsen	▪ Limited financial resources	▪ Lack of reliable procurement models

Adoption of Open Source Software in Health Care	**and Pedersen (2005)**	▪ Pressure to upgrade IT systems ▪ Top management support ▪ User's past experience ▪ Government support	-Legal (licenses) -Technical (functionality, security, usability) -Corporate and business policy (vendor, customer support, and software alliances)
	Tomas Yakel (2001)	▪ Access to real-world systems ▪ Reduction of bugs in medical systems ▪ Reduction of software ownership and development cost	▪ Lack of a mature OSS beyond prototype phase ▪ High level of technical expertise required for OSS ▪ Proprietary mindset of the medical community ▪ Technology complexity of the medical domain ▪ Lack of OSS-IT personnel support, specifically for medical software applications
	MacDonald et al., (2003)	▪ Public policy encouraging that all software developed by the government must be released under an OSS license ▪ Information mechanisms to disseminate to the community about OSS developments and benefits	▪ Medical software currently in use is proprietary software ▪ Leadership and top management in health care is risk adverse ▪ Elimination of in-house personnel due to outsourcing ▪ Technology complexity of the medical domain
	Hogarth and Turner (2005)	▪ Reduction of software ownership and development cost ▪ Disappearance of vendor lock-in ▪ OSS adherence to standards for compatibility and data interchange	▪ Lack of OSS-IT personnel support, specifically for medical software applications ▪ Technology complexity in the medical domain ▪ Success of mainstream applications might not translate to clinical software
	Kantor et al., (2003)	▪ OSS can reduce EMR ownership and development cost ▪ Disappearance of the vendor lock-in ▪ OSS adherence to standards for compatibility and data interchange	

3. Methodology

A mixed methods design was used in this research to explore the extent of OSS adoption in hospitals as well as to investigate the influencing and inhibiting factors. The exploratory approach of this study is warranted by the fact that, as of yet, the adoption and use of OSS in U.S. hospitals has not been accompanied by any theoretical grounding or by empirical analysis that explains how or why OSS products are being adopted and used. That is, thus far, there are few existing conceptual frameworks to guide a research effort in this area. Similarly, there are no theoretical guidelines that have been empirically evaluated to support a rigorous understanding

of the complex factors that inhibit the adoption and successful implementation of OSS technologies in hospitals. For these reasons, a mixed methods approach using a grounded theory perspective was selected over a confirmatory or causal research design approach. Grounded theory is a systematic, qualitative research procedure used to develop an inductively grounded theory that explains a process, an action, or interaction about a phenomenon (Charmaz, 2006; Creswell, 1994, 2005; Glaser, 1978, 1999; Glaser & Strauss, 1967; Strauss & Corbin, 1998).

3.1 Study design

The data collection methods used in this research are a survey and interviews, allowing both breadth and depth of information concerning the adoption of OSS in hospitals. We focused on Baltimore, Washington and Northern Virginia (BWNV) area hospitals instead of a nationwide area. This allowed us to spend more time cultivating each contact from the target population through initial phone calls, and to obtain richer data in the form of personal face-to-face and telephone exchanges.

First, a survey was used to gather data from a wide variety of hospitals dispersed across a geographic area. This was done in order to explore and characterize the extent and the types of OSS products adopted by hospitals. Following the survey, semi-structured interviews were conducted in-person and by telephone with IT managers in order to attain deeper understanding of the factors that facilitate or inhibit OSS adoption in hospitals. Interviews are the quintessential qualitative method for data collection and one of the most widely used techniques for acquiring qualitative data in order to collect impressions and opinions about the particular research issue (Patton, 2002; Tashakkori & Teddlie, 1998).

The target population for the study consists of hospital executives, directors and managers that are involved in IT within BWNV area hospitals. Although we selected the BWNV

area largely because of our own location, it is an appropriate choice because it is one of the most diverse areas in the U.S. socioeconomically, politically, and culturally. The survey sample was selected from the Healthcare Information and Management Systems Society (HIMSS), from their electronic mailing list database of Chief Information Officers (CIO), Chief Technology Officers (CTO), Vice Presidents (VP) (of Information Technology (IT), Information Systems (IS) and Management Information Systems (MIS)), and Directors and Managers of other IT departments within hospitals. HIMSS was selected because it is a leading non-profit organization dedicated to improving health care through the application of information technology (HIMSS, 2006). This research takes a key informant approach that allowed the responses of the IT managers to represent those of the hospital being surveyed. The use of managers as key informants has been successfully applied in many IT studies that involve organizations (Chau & Tam, 1997; Eyler et al., 1999; Gatignon & Robertson, 1989; Goode, 2005; Huff & Munro, 1985).

3.2 Survey administration

Prior to sending the survey invitation e-mail out, an attempt was made to contact each of the IT managers in the target population by telephone in an effort to encourage participation and receive a verbal commitment from them to complete the survey. After the initial telephone contact, an e-mail invitation letter was sent to the potential respondents. The survey link was appended to the bottom of the e-mail cover letter and upon clicking the survey link, the participant was directed to the online survey (Appendix A).

Descriptive statistics, such as frequency distributions, percentages, standard deviations, confidence intervals, Chi-square and Fisher's tests were computed in order to analyze the survey results. Moreover, to ensure better reporting and complete description of our Web-based survey

results, we applied a checklist of recommendations from the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) (Eysenbach, 2004) (Appendix B).

3.3 Interviews

The interview population consisted of the subset of survey respondents who responded positively to a survey item that specifically asked if they were willing to share their thoughts and experiences in an interview. A total of 11 survey respondents initially agreed to be interviewed. All such respondents were sent an e-mail letter introducing the objectives of the interview and asking to schedule a meeting. By the end of this process, only five IT hospital managers ultimately agreed to be interviewed. The other six managers, for reasons unknown, chose not to respond to the many invitations by email and telephone to participate and were unreachable to be interviewed. Each interview lasted 30-60 minutes, and were conducted between January and May 2007. The interviews focused on the organizational, technological, and environmental factors that facilitated or inhibited the adoption of OSS at their hospitals (Appendix C). Before conducting each interview, the participant was briefed on the nature and purpose of the study. All the participants were asked for their authorization to be recorded during the interview and were asked to sign an informed consent.

The interviews were coded and analyzed employing grounded theory consistent with the systematic procedures recommended by Strauss and Corbin (1998), namely open coding, axial coding and selective coding. Coding is the process that dissects, differentiates, combines, and discovers concepts and relevant features from the data (Seaman, 1999). We developed concepts and categories emerging from the data using the line-by-line analysis as described by Straus and Corbin (1998) and Glaser and Straus (1967). The concepts and categories were generated by our analysis of the data and validated applying the constant comparative method. Each interview was

treated as an individual case. NVivo® was used to assist the qualitative analysis process, to manage data, to store the interview transcripts, and to help in coding text (Bazeley & Richards, 2000).

4. Results

4.1 Survey results

This research finds that 23% (n=7) of the hospitals within the survey sample have adopted OSS. Conversely, 76% (n=23) of the hospitals indicated that they have not adopted any type of OSS. All of the hospital adopters of OSS reported having general-purpose products. Among them only 57% (n=4) reported having adopted domain-specific products. Table 2 presents descriptive statistics profiling the hospitals in our survey sample.

Table 2: Descriptive statistics of surveyed hospitals

	Frequency (n =30)	Percent %
Hospital type		
Health care system hospital	12	40.0
Hospital as a part of a multi-system network	11	36.7
Stand-alone hospital	5	16.7
Ambulatory care facility	1	3.3
Other	1	3.3
Number of beds in the hospital		
<50 beds	1	3.3
101-200 Beds	2	6.7
201-300 Beds	6	20.0
301-400 Beds	4	13.3
401-500 Beds	2	6.7
>501	11	36.7
Not classified by beds	4	13.3
Hospital's annual gross revenue		
<$ 5M	1	3.3
$5M-$25M	3	10.0
$26M-$50M	3	10.0
$51M-$200M	2	6.7
$201M- $350M	8	26.7
$351M-$500M	2	6.7
> $501M	11	36.7
Annual IT operating budget		
<2%	5	16.7
2.1-3.0%	15	50.0
3.1-4.0%	1	3.3
4.1-5.0%	5	16.7

5.1-6.0%	1	3.3
>8%	3	10.0
Type of IT personnel		
In-house	27	90.0
Outsourced	3	10.0
Number of In-house IT staff employed full time		
≤10	5	16.7
10-30	10	33.3
31-60	7	23.3
≥91	8	26.7
Years of experience of in-house IT staff		
≤2 years	1	3.3
2-5 years	6	20.0
5-10 years	15	50.0
≥10 years	8	26.7

Key findings from this research indicate that hospitals are adopters of both general-purpose and domain-specific products, but they have adopted general-purpose products to a greater extent than domain-specific products. General-purpose OSS adoption in hospitals clusters mainly in databases, desktop software, programming languages, and operating systems, as well as Web development tools and Server products. Well-known OSS products such as MySQL, Linux, Apache, Firefox, PHP and Perl were the leading software products that hospitals selected to adopt. The scale used in the survey to indicate extent of adoption was adapted following Fichman and Kemerer (1997) and it ranges from unawareness (no knowledge of OSS), to awareness, interest (actively learning), evaluation/trial (acquisition and initiation of an evaluation or trial version), commitment (use for one or more deployment projects), limited deployment (regular, but still limited, deployment and use), and general deployment stages (a stable and regular part of the IT infrastructure). The survey results show that the vast majority of general-purpose products are positioned from the evaluation/trial stages to the limited deployment stages. Well-known OSS products, for example, MySQL, Linux, Apache, and Perl are in the limited deployment stages, whereas OSS desktop software applications, such as Firefox and Mozilla, are in the evaluation/trial stages. The extent of adoption of domain-specific products is lower than

that of general-purpose products. The predominant adoption stages for all the domain-specific OSS products are awareness to interest. Domain-specific adoption occurs mainly in the Telemedicine, Electronic Medical Records, Radiology, Laboratory and Pharmacy information systems products.

Furthermore, the results of the survey provide information about relevant contextual and structural characteristics of the hospitals that tend to adopt OSS. These characteristics may have a determinant effect on the adoption of OSS. First, the majority of the adopting hospitals are very large hospitals, with 500 beds or more. Second, these hospitals tend to have high annual revenue, more than $500 million. Third, hospital adopters of OSS have a propensity to have a large number of IT support staff. Finally, hospitals that have adopted OSS also tend to have IT budgets that are less than 3% of the hospital's total budget.

4.2 Interview results

This study also identifies, through the interview data, key categories that facilitate and inhibit the adoption of OSS in the hospitals within the sample. The interview data reveal that hospital software vendors are the most critical factor influencing the adoption of OSS in hospitals. Further, hospitals rely heavily on software vendors for all of their IT solutions. The results also show that hospital software vendors enlarge their product lines and the services they provide to hospitals to include general-purpose and domain-specific OSS products. In addition, IT managers have a positive satisfaction level, in general, with the software vendor services and products, and, overall, have a good relationship with them. Table 3 presents a concise summary of the results of the interviews.

The majority of the hospital IT managers reported that lack of in-house development, and a perceived lack of security, quality, and accountability of OSS products were the most

significant factors that inhibit the adoption of OSS in hospitals. IT managers also identified the lack of medical informaticians, patient-privacy protection and privacy legislation as major inhibitors to adopt OSS, particularly domain-specific products.

Table 3: Emerging code categories and subcategories of the adoption of OSS in hospitals

Core Categories	Subcategories
1. Hospital IT human resources	▪ In-house software development ▪ IT personnel ▪ Medical informaticians
2. Hospital regulatory landscape	▪ Patient-privacy protection and privacy legislation ▪ Lack of liability/accountability provided by OSS
3. Hospital software vendors	▪ Software vendor providers of OSS ▪ Satisfaction level with software vendors ▪ New software business models
4. Hospital organizational factors	▪ Hospital organizational culture ▪ Hospital organizational structure
5. Hospital technological factors	▪ Perceived lack of quality ▪ Perceived lack of security
6. International development of OSS	▪ Labor cost and qualified programmers ▪ Type of health care systems

Based upon our findings (from both the survey and interviews), the following section presents an empirical model describing the factors facilitating and inhibiting the adoption of OSS in hospitals and the relationships between them.

5. Adoption of OSS in Hospitals: An Empirical Model

We have used Strauss and Corbin's (1998) paradigm to develop an empirical model describing the adoption of OSS in hospitals, based on our data. This empirical model helps us to develop and propose connections between the factors that emerged from our findings. Figure 1 presents the empirical model that lays out the analysis of the factors that emerged from our results and the relationships between them.

The empirical model identifies temporal and inferential, rather than causal, relationships between the factors relevant to the adoption of OSS in hospitals. For example, the mix of causal conditions in a particular hospital at a particular point in time (as defined by the level of in-house

development, the number of IT personnel, etc.) sets the stage and shapes what happens when an event occurs related to the core category (e.g. when a software vendor offers an open source solution to the hospital). This core category then directly influences the strategic actions (i.e. adoption or non-adoption of OSS) that lead to the consequences. The contextual factors and intervening conditions moderate and mediate the strategic actions that are employed to bring about certain consequences (Creswell, 2005; Strauss & Corbin, 1998). So, in terms of the symbology in Figure 1, an arrow from one construct to another cannot be interpreted to mean that the first construct in any way causes the second, but that the mix of factors and actions described by the first construct influence the mix of factors and actions described by the second construct in any particular instance. The constructs of the model are described in more detail below.

Figure 1: Empirical model for the adoption of OSS in hospitals
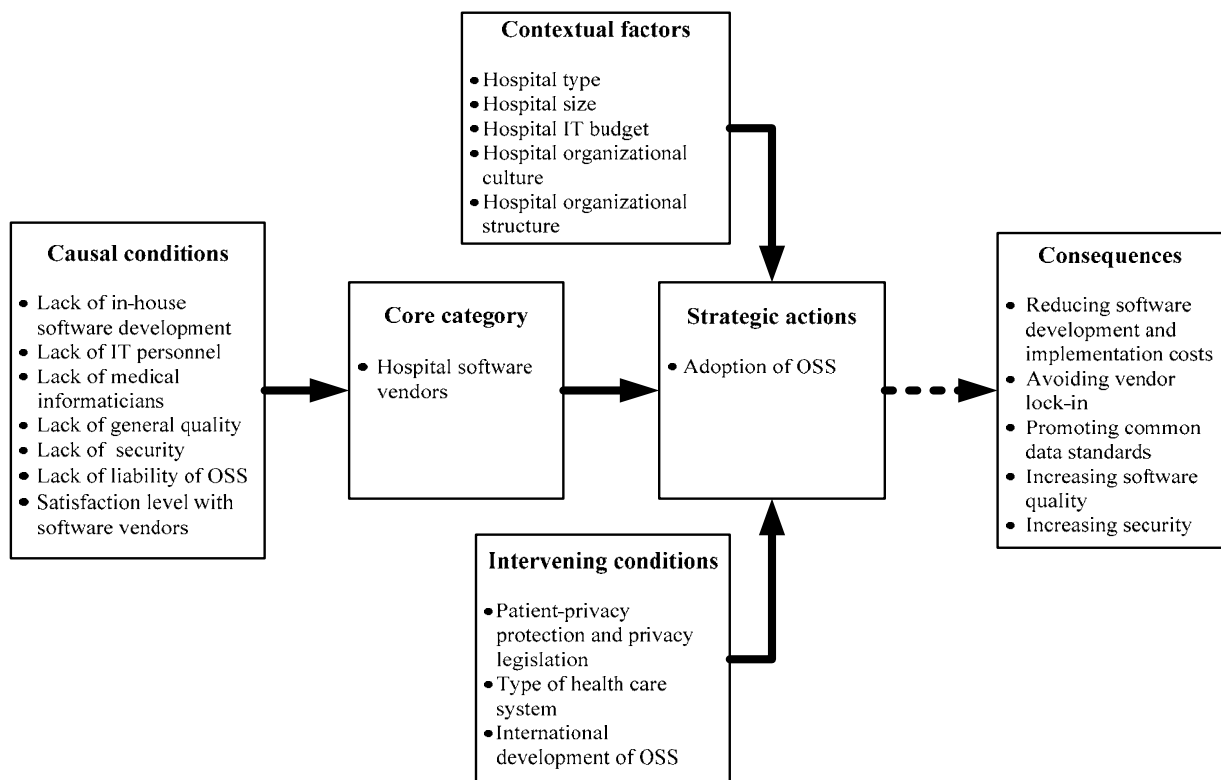
5.1 Causal Conditions

Causal conditions, as the term is being used in our empirical model, are factors that are identified as influencing the core category. There is evidence from our findings that all these causal conditions have an influence on whether or not a hospital is open to an offer of OSS by a software vendor.

The subject of technical personnel in hospitals came up often in our interview data (see section 4.2 and Table 3). Hospital IT managers report that the lack of in-house development is the rule rather than the exception; hospitals do not develop their own software systems, and thus they depend on software vendors for all their IT operations and software needs. Managers also mentioned that much of their IT staff personnel are exclusively devoted to the on-site support of IT systems provided by vendors. The degree to which a hospital lacks in-house development activity, and IT personnel with technical development skills influences how dependent they are on their software vendors, and thus influences how they would react to the offerings of their vendors. Such a dependence would make a hospital more likely to accept a technology solution from a vendor that included OSS. A related causal condition is the lack of personnel who possess an amalgamation of medicine and information systems expertise and thus who would be able to develop and maintain software systems tailored to hospitals and health care organizations.

The perceived lack of general quality and perceived lack of security of OSS products are persistent themes that emerged from our data analysis (these are described under the core category "Hospital technological factors" in Table 3). As one manager commented "OSS is not going to have the same level of quality and not nearly the same level of documentation and rigor you can get from a corporate environment." Another IT manager opined that "the majority of the

OSS are probably of inferior quality because they are just gifts that any research lab puts together and hands out from a couple graduate students." Managers also perceive OSS as a high risk product when it concerns security. As one manager commented, "It is not the fact that the OSS won't be able to provide the functionality that we need in the hospital. The major concern is going to be how secure OSS is." Managers perceive OSS to be highly vulnerable to attacks from hackers or other parties, which may inhibit them from adopting OSS, even from a vendor. These quality and security factors will color a hospital's openness to a vendor's offer of an open source solution.

The lack of accountability of OSS providers is also a concern for the hospital IT managers we interviewed. Having a vendor that can be held liable or accountable if there is inadequate or insufficient quality or security of the software product strongly influences the decision to adopt products from software vendors. As one IT manager expressed: "the factor that caused us not to adopt OSS is the support and accountability that comes with writing a check to a commercial software vendor." The negative perceptions of quality, security and lack of liability reinforce the hospitals' dependence on software vendors.

Finally, our findings report that IT managers have a positive satisfaction level, in general, towards the products, support and services that software vendors provide in their hospitals, as noted in section 4.2. This further reinforces the hospitals' dependence on software vendors.

In summary, these causal conditions all shape and impact the core category, i.e. they influence what happens when and if a vendor offers a hospital a solution that includes OSS.

5.2 Core Category

The mix of causal conditions in a particular hospital setting sets the stage for the "core category," i.e. the hospital software vendors. While our survey did not address the issue of

software vendors, there was unanimous consensus amongst all the hospital IT managers interviewed that hospital software vendors play a pivotal role in the adoption process of OSS in hospitals, as discussed in section 4.2. IT managers identify hospital software vendors who supply OSS products and services as the key facilitators for the adoption of both general-purpose and domain-specific OSS products. In terms of the empirical model presented in Figure 1, the actions of the software vendors is the trigger, or the gateway, that creates the situation where a hospital must decide to adopt or not adopt OSS. Such a decision does not even arise except through the actions of a software vendor, according to the findings of this study. As one manager commented, "hospitals are so dependent on vendors of hospital IT products that we are not in the position to kind of 'buck the rules' and go it alone for the adoption of OSS."

However, sometimes this decision is not even explicit. As one IT manager adopter of OSS expressed, "we don't have a conscious decision to adopt OSS because our hospital outsources a lot of our technical knowledge to vendors, so the adoption of OSS is coming throughout the vendor's decisions for the most part."

The hospitals' decision to adopt OSS from software vendors is linked to their belief that the OSS offered this way has "a professional level of quality control" that is greater than the OSS available from other sources, such as the Internet. As one IT manager who adopted vendor-supported OSS stated, "I am very happy using OSS because, for me, the best of two worlds is when vendors support an OSS solution. I am willing to pay for OSS, because I feel I have professional quality and control over the software."

5.3 Contextual Factors

Contextual factors are the "specific set of conditions (patterns of conditions) that intersect dimensionally at this time and place to create a set of circumstances or problems to which

persons respond through actions/interactions" (Strauss & Corbin, 1998, p. 132). Our data, especially the survey data presented in section 4.1, reveal that several contextual factors are expected to moderate the adoption of OSS in hospitals. The combined qualitative and quantitative results of this study provide evidence that the following contextual factors may facilitate or inhibit the adoption of OSS in hospitals: 1) hospital type, 2) hospital size, 3) hospital IT budget, 4) hospital organizational culture, and finally 5) hospital organizational structure. These factors are different from the causal conditions listed earlier, in that they are more general, static factors that apply to the hospital as a whole and do not specifically form the hospital's attitude towards OSS, or towards the software vendor.

Depending on the hospital type (such as a stand-alone hospital versus a multi-hospital network, or a university hospital versus a private hospital, and so on), the importance of IT adoption within the hospital may differ. Different types of hospitals seem to have different requirements to adopt software. For example, a university hospital may allow experimentation with new software products while a private hospital in a multi-hospital network may not allow any type of experimentation. Such factors may have an affect on the adoption of OSS by hospitals. Hospital size is likely to be related to organizational characteristics such as slack in resources or a large professional workforce that can also have a positive effect on the adoption of OSS in hospitals. Hospital IT budget is another contextual factor that emerged in our study as a meaningful factor since hospitals with smaller relative IT budgets (with 3% or less of the total hospital budget) have a propensity to adopt OSS.

Other contextual factors within the hospital such as organizational culture and organizational structure can also have an effect on the adoption of OSS. As one manager commented, "the organizational design of the hospitals has a major influence on the adoption of

software within the hospital, I don't want to use the word power structure, but it is almost the political landscape of the organization that influences the way we adopt any technology."

Our findings support the effect that all the aforementioned factors have on the strategic actions (i.e. adoption or non-adoption) as depicted in Figure 1 with regards to OSS adoption within hospitals.

5.4 Intervening Conditions

Intervening conditions are those conditions that "mitigate or otherwise impact causal conditions" (Strauss & Corbin, 1998, p. 131). The intervening conditions identified in this study included: 1) patient-privacy protection and privacy legislation, 2) type of health care system, and 3) international development of OSS. These intervening conditions are factors, external to the immediate hospital setting, that may inhibit the adoption of OSS in hospitals. IT managers we interviewed (see Table 3) report that factors such as patient-privacy protection and privacy legislation may act as deterrents for the adoption of OSS in general, especially with regards to the domain-specific OSS products. For example, hospital IT managers were reluctant to adopt domain-specific OSS products because they perceived OSS as posing a threat to patient's privacy and confidentiality as well as to HIPAA compliance mandates. Consequently, we conclude that the aforementioned three intervening conditions also mediate the adoption of OSS in hospitals.

5.5 Strategic Actions

Strategic actions are "purposeful or deliberated acts that are taken to resolve a specific problem" (Strauss & Corbin, 1998, p. 133). The interaction outcome of the core category (hospital software vendors) with the contextual factors and the intervening conditions may result

in a decision by hospitals to make full use of a technology—in this case OSS—as a plausible or implausible alternative to proprietary (closed source) or commercial software products.

5.6 Consequences

Consequences are the outcomes of the interaction of the core category with the contextual factors, intervening conditions and the strategic actions. The outcomes of this empirical model are closely aligned with the potential benefits of OSS claimed in the literature reviewed in literature section of this paper. However, we can only speculate about the actual consequences, as that part of the model is beyond the scope and objectives of this research. However, investigating the consequences of OSS adoption in hospitals is a vital area for future research.

6. Implications

6.1 Implications for the Literature

OSS has created a stir of interest in many disciplines ranging from computer science to sociology, and a growing body of literature has emerged to explain many aspects of OSS. However, no work has investigated the adoption of OSS in hospitals. The research presented here addresses this gap.

A number of respondents from the interviews noted that the lack of IT personnel and the lack of medical informaticians are inhibiting factors for adoption of OSS by hospitals. This is consistent with previous authors (Fitzgerald & Kenny, 2004; Hogarth & Turner, 2005; MacDonald et al., 2003; Waring & Maddocks, 2005; Yackel 2001) who have noted the importance of IT personnel with high levels of technical expertise required in order to deal with OSS applications and the technological complexity in the medical domain that needs personnel that understand both medicine and information systems.

In contrast to other studies claiming that the reduction of ownership and development cost is one of the main advantages of adopting OSS in health care (Fitzgerald & Kenny, 2004; Glynn et al., 2005; Hogarth & Turner, 2005; Holck, Larsen, & Pedersen, 2005; Kantor et al., 2003; Yackel, 2001), the findings from this research indicated that cost factors are not a core, important category for hospital IT managers when deciding to adopt OSS. The IT managers in our study were found to be more concerned about the quality, security and liability issues surrounding OSS than about the potential cost-benefit factors associated with the adoption and use of OSS. This finding also compares with a prior study by Goode (2005), which also noted that managers see software with high cost as an indicator of quality.

Prior research (Fitzgerald and Kenny, 2004; Glynn et al. 2005; Holck et al. 2005; Waring & Maddocks, 2005) has noted the importance of top management support for the successful adoption of technology within organizations. Our findings, by contrast, show that not only top management support is important to the adoption of OSS by hospitals, but clinical personnel within hospitals (e.g., physicians, nurses, etc,) also exert a significant influence on the decision to adopt not only OSS but any technology. Many IT managers recognized the political influence of these groups as a critical factor in how OSS would be used in the future, even before getting to the technology portion of the adoption of OSS by hospitals.

This study also shows that the hospital industry is a very conservative industry when it concerns adopting new technologies. Managers repeatedly indicated the "conservative aspects and risk adverse" behavior of the hospital industry to adopt not only OSS but also any new technology. This finding is consistent with MacDonald, et. al (2003) and Glynn (2005) who also pointed out hospitals' risk averse behavior when adopting IT.

Finally, our core finding about the central role of software vendors in the adoption decision in hospitals has some relationship to prior literature. Some existing studies have indicated that avoiding vendor lock-in is perceived to be an advantage of adopting open source (Carr, 2003, 2004; Fink, 2003; Fitzgerald, 2004; Goldman & Gabriel, 2005; Goode, 2005; Kantor et al., 2003). In contrast, in our study, the role of vendors emerged quite differently. The role of vendors as OSS adopters, who then transfer their adoption decisions on to their client hospitals, has not previously been described in the literature. This finding describes vendors as innovating the way they develop, distribute, support and maintain software systems within hospitals. Prior studies have not shown software vendors to be such key enablers of OSS in the hospital industry.

6.2 Implications for Future Research

This research is unique within the field of OSS and health care. That is, there is no study that has been published to date presenting an empirical model for the adoption of OSS in hospitals. This model, grounded in empirical data collected from surveys and interviews, identifies the factors and relationships facilitating and inhibiting the adoption of OSS in hospitals. This model provides the basis for future testing of the interactions among the key concepts proposed in this study. Furthermore, there are numerous significant issues for researchers, ourselves included. Our findings, while not highly generalizable due to the limitations of the study, provide sufficient grounding for future confirmatory studies.

In particular, a number of very interesting propositions or hypotheses are suggested by our empirical model, and by the survey and interview data. Future research aimed at validating these hypotheses would be a significant contribution to the field. Examples of such propositions include:

- **Proposition**: Adoption of OSS is more likely to be found in hospitals that have in-house technical staff with experience in software development, OSS, and/or with medical informatics.

- **Proposition**: Hospitals with an existing relationship with a software vendor who offers OSS solutions are more likely to adopt OSS. The likelihood increases with the degree of dependence on the vendor and the degree of satisfaction with the vendor.

- **Proposition:** The adoption of OSS in a hospital is more likely when there is a centralized IT strategy within the hospital.

- **Proposition:** The likelihood of a hospital's adoption of OSS is negatively correlated with the IT manager's perception of the general quality and security of OSS products.

To further validate propositions such as those above, as well as the whole empirical framework derived from this study, the following future research is planned:

1) Validation of the model by collecting data from a large sample of hospitals, either in the U.S. and/or internationally, would allow for further conclusions about the causal relationships and interactions suggested by our empirical model.

2) A case study in a hospital setting to analyze the consequences of the adoption and implementation of OSS.

3) Further empirical investigation into the relationship between hospital software vendors and adoption of OSS.

6.3 Implications for Practice

The present research provides a better understanding to hospital IT managers and practitioners about the extent of OSS adoption in hospitals in conjunction with the factors facilitating or inhibiting this adoption process. Hospitals and health care organizations that are

considering the adoption and implementation of OSS technologies need to understand how technological, environmental and organizational factors affect the adoption process. This way IT hospital practitioners can prepare against the expected barriers and can utilize the facilitators for successful OSS technology adoption.

The first implication for practitioners is that, contrary to theoretical and anecdotal expectations about the cost-benefit advantages of OSS vs. proprietary or commercial-based software, the findings from this research indicated that financial factors are not deemed to be a core concern for IT managers when deciding to adopt OSS. The IT managers in our study were found to be more concerned about the quality, security and liability issues surrounding OSS. This implies that, when building a business case, or justification, for the adoption of OSS, the analysis must take into account issues related to quality, security, and accountability with at least as much prominence as cost-benefit issues.

The second implication for hospital IT practitioners would be to involve all the stakeholders within the hospital in the adoption decision-making; for this particular point, our finding indicated that physicians, nurses, and other clinical personnel are key stakeholders to address in the adoption process of not only OSS but any type of technology introduced to a hospital. Thus the receptivity to the idea and philosophy of OSS must be assessed with these stakeholders, and any ideas and concerns that might surface during the assessment must be documented and taken into account.

The third recommendation for hospitals that are considering OSS is that they can start adopting OSS with a small pilot project in order to test and experiment with the quality issues of interest, as well as the costs and benefits, of OSS to the hospital. In addition, it is very important to collect data and metrics from the pilot project and communicate the results to all the

stakeholders, including vendors, within the hospital. It is important to mention that OSS is not "free," and never will be without a cost.

Another implication for practitioners who want to promote the use of OSS within the hospital and health care industry is for them to liaise with hospital software vendors and the OSS community. Coordinating with hospital IT vendors is important because, as our findings reported, any tendency towards adoption of OSS in hospitals is occurring because healthcare IT vendors are embracing, providing, and maintaining OSS products. Under this business model, hospital software vendors are not only offering the software to hospitals but also offering services for installation, customization, and maintenance of OSS applications, either domain-specific or general-purpose. Furthermore, there are good examples of software partnerships amongst IT businesses, open source communities, and researchers such as Eclipse and even Linux (Capek, 2005; Goldman & Gabriel, 2005; Zeller & Krinke, 2005) that can be replicated in the hospital and health care industry. Moreover, the hospital industry is probably the most influential and powerful industry operating today in the health care area. If this industry sees the benefits from OSS, then partnerships between IT businesses, OSS communities, and universities could result in research, development and promotion of OSS hospital products and policies that further the evolution of the OSS movement, as well as provide substantial benefits to the hospital industry. Therefore, such partnerships could be a potentially transforming development in promoting and adopting OSS in hospitals.

7. Limitations of the Study

Notwithstanding the important contributions of the current study, it has its own shortcomings. For example, our findings may not apply to the full spectrum of U.S. hospitals. This research is exploratory in nature, so that the design, data collection methods, and analysis

were broad by design, and not intended for confirmation. This research also examined the adoption or non-adoption of OSS in a limited geographical area and over a particular time period, which makes any attempts to generalize the results across hospitals in the U.S. difficult without further empirical analysis and investigation.

Another limitation was the modest sample size of response in the survey (n=30) and interviews (n=5). Through the evolution of this study, it became clear that IT managers in the hospital industry in the BWNV area were less than enthusiastic about discussing and sharing information about open source adoption within their hospitals. Many attempts to influence a higher rate of response and interview participation were made, including initial contacts, follow-up contacts, reminders, and even financial incentives. While the small sample size affects the ability to generalize results, it does not affect what was the intent of the study, to explore and identify relevant issues and factors for further study. However, it is important to mention that these are important limitations for any future similar study because of the unwillingness of the managers and executives to share their views on issues concerning IT adoption.

Finally another limitation of this research is that the data appears not to represent all types of OSS products. While it was not the intent of the study, it is clear from the responses (in particular the types of OSS that survey respondents report adopting) that our respondents were referring primarily to large, enterprise-level OSS applications (e.g. database servers, web servers, operating systems, etc.). This limits our ability to extend our findings to the entire spectrum of OSS products available to hospitals. It also limits our ability to compare the results of this study to prior research, which mostly addresses the adoption of smaller, stand-alone, download-and-install types of OSS applications.

8. Conclusions

This research identifies the factors that could lead to more effective adoption of OSS by hospitals. In addition, this research sheds light and broadens the understanding of OSS adoption within hospitals by offering to IT practitioners information on the extent of that adoption currently.

Finally, the insight gained from this dissertation serves as a guide and foundation for future work to investigate more determinants of OSS adoption in hospitals and health care organizations. It is also the researcher's hope that this study will be the seminal stone to pave the way for future studies on OSS adoption and implementation in organizations both public and private, national and international.

Appendices:

Appendix A: Survey instrument
Appendix B: CHERRIES
Appendix C: Interview guide protocol

References

Armstrong, J. S., & Overton, T. S. (1977). Estimating Nonresponse Bias in Mail Surveys. *Journal of Marketing Research, 14*(3), 396-402.

Bazeley, P., & Richards, L. (2000). *The NVivo qualitative project book*. London ; Thousand Oaks, Calif.: SAGE Publications.

Brown, S. H., Lincoln, M. J., Groen, P. J., & Kolodner, R. M. (2003). VistA--U.S. Department of Veterans Affairs national-scale HIS. *International Journal of Medical Informatics, 69*(2-3), 135-156.

Capek, P. G., Frank, S. P., Gerdt, S., and Shields. D. (2005). A history of IBM's open-source involvement and strategy. *IBM Systems Journal 44*(2), 249-248.

Carnall, D. (2000). Medical software's free future. *BMJ, 321*(7267), 976-.

Carr, N. G. (2003). IT Doesn't Matter. *Harvard Business Review, 81*(5), 41-49.

Carr, N. G. (2004). *Does IT matter? : information technology and the corrosion of competitive advantage*. Boston: Harvard Business School Press.

Charmaz, K. (2006). *Constructing grounded theory*. London ; Thousand Oaks, Calif.: Sage Publications.

Chau, P. Y. K., & Tam, K. Y. (1997). Factors affecting the adoption of open systems: An exploratory study. *MIS Quarterly: Management Information Systems, 21*(1), 1-20.

Creswell, J. W. (1994). *Research design : qualitative & quantitative approaches*. Thousand Oaks, Calif.: Sage Publications.

Creswell, J. W. (2005). *Educational research : planning, conducting, and evaluating quantitative and qualitative research* (2nd ed.). Upper Saddle River, N.J.: Merrill.

Dedrick, J., & West, J. (2003). *Why Firms Adopt Open Source Platforms: A Grounded Theory of Innovation and Standards Adoption.* Paper presented at the Proceedings of the Workshop on Standard Making: A Critical Research Frontier for Information Systems, Seattle, Washington.

Dedrick, J., & West, J. (2004). *An Exploratory Study into Open Source Platform Adoption.* Paper presented at the Proceedings of the 37th Hawaii International Conference on System Sciences.

DeLano, W. L. (2005). The case for open-source software in drug discovery. *Drug Discovery Today, 10*(3).

Erickson, B. J., Langer, S., & Nagy, P. (2005). The Role of Open-Source Software in Innovation and Standardization in Radiology. *Journal of the American College of Radiology, 2*(11), 927-931.

Eyler, A. A., Mayer, J., Rafii, R., Housemann, R., Brownson, R. C., & King, A. C. (1999). Key informant surveys as a tool to implement and evaluate physical activity interventions in the community. *Health Educ. Res., 14*(2), 289-298.

Eysenbach, G. (2004). Improving the Quality of Web Surveys: The Checklist for Reporting Results of Internet E-Surveys (CHERRIES). *J Med Internet Res, 6*(3), e34.

Fichman, R. G., & Kemerer, C. F. (1997). Object technology and reuse: lessons from early adopters. *Computer, 30*(10), 47-59.

Fink, M. (2003). *The business and economics of Linux and open source*. Upper Saddle River, NJ: Prentice Hall PTR.

Fitzgerald. (2004). A critical look at open source. *Computer, 37*(7), 92-94.

Fitzgerald, & Kenny. (2004). Developing an information systems infrastructure with open source software. *Software, IEEE, 21*(1), 50-55.

Gatignon, H., & Robertson, T. S. (1989). Technology Diffusion: An Empirical Test of Competitive Effects. *Journal of Marketing, 53*(1), 35-49.

Glaser, B. G. (1978). *Theoretical sensitivity : advances in the methodology of grounded theory*. Mill Valley, Calif.: Sociology Press.

Glaser, B. G. (1999). The Future of Grounded Theory. *Qualitative Health Research, 9*(6), 836-845.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory; strategies for qualitative research*. Chicago,: Aldine Pub. Co.

Glynn, E., Fitzgerald, B., & Exton, C. (2005). *Commercial Adoption of Open Source Software: An Empirical Study.* Paper presented at the Proceedings of the 2005 International Symposium on Empirical Software Engineering (ISESE'05), Noosa Heads, QLD, Australia.

Goldman, R., & Gabriel, R. P. (2005). *Innovation happens elsewhere : open source as business strategy*. Amsterdam ; Boston: Morgan Kaufmann.

Goode, S. (2005). Something for Nothing: Management Rejection of Open Source Software in Australia's Top Firms. *Information and Management, 42*(5), 669-681.

HIMSS. (2006). HIMSS Bylaws.   Retrieved June 1, 2006, from http://www.himss.org/content/files/himss_bylaws.pdf

Hogarth, M., & Turner, S. (2005). *A Study of Clinical Related Open Source Software Projects.* Paper presented at the American Medical Informatics Association Conference (AMIA) Washington, DC.

Holck, J., Larsen, M. H., & Pedersen, M. K. (2005). *Managerial and Technical Barriers to the Adoption of Open Source Software*: Springer Berlin-Heidelberg.

Huff, S. L., & Munro, M. C. (1985). Information technology assessment and adoption: a field study. *MIS Quarterly*(December), 327-338.

Kantor, G. S., Wilson, W. D., & Midgley, A. (2003). Open-source Software and the Primary Care EMR. *J Am Med Inform Assoc, 10*(6), 616-.

Lindner, J. R., Murphy, T. H., & Briers, G. E. (2001). Handling Nonresponse In Social Science Research. *Journal of Agricultural Education, 42*(4), 43-53.

Longman, P. (2007). *Best care anywhere : how America's most socialized healthcare system became its finest : what the VA miracle means for you and your country*. Sausalito, CA: PoliPointPress.

McDonald, C. J., Schadow, G., Barnes, M., Dexter, P., Overhage, J. M., Mamlin, B., et al. (2003). Open Source software in medical informatics--why, how and what. *International Journal of Medical Informatics, 69*(2-3), 175-184.

Nagy, P. (2007). Open Source in Imaging Informatics. *Journal of Digital Imaging, 20*(0), 1-10.

Norris, J. S. (2004). Mission-critical development with open source software: lessons learned. *Software, IEEE, 21*(1), 42-49.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3 ed.). Thousand Oaks, Calif.: Sage Publications.

Raghupathi, W., & Gao, W. (2007). An Eclipse-based development approach to health information technology. *International Journal of Electronic Healthcare, 3*(4), 433-452.

Scarsbrook, A. F. (2007). Open-source software for radiologists: a primer. *Clinical Radiology, 62*(2), 120-130.

Strauss, A. L., & Corbin, J. M. (1998). *Basics of qualitative research : techniques and procedures for developing grounded theory* (2nd ed.). Thousand Oaks: Sage Publications.

Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology : combining qualitative and quantitative approaches*. Thousand Oaks, Calif.: Sage.

Valdes, I., Kibbe, D. C., Tolleson, G., Kunik, M. E., & Petersen, L. A. (2004). Barriers to proliferation of electronic medical records. *Informatics in Primary Care, 12*(1), 3-9.

Van Latum, F., Van Solingen, R., Oivo, M., Hoisl, B., Rombach, D., & Ruhe, G. (1998). Adopting GQM based measurement in an industrial environment. *Software, IEEE, 15*(1), 78-86.

Waring, T., & Maddocks, P. (2005). Open Source Software implementation in the UK public sector: Evidence from the field and implications for the future. *International Journal of Information Management, 25*(5), 411-428.

Yackel, T. (2001). How the open-source development model can improve medical software. *Medinfo, 10*, 68-72.

Zeller, A., & Krinke, J. (2005). *Essential open source toolset : programming with Eclipse, JUnit, CVS, Bugzilla, Ant, Tcl/Tk and more*. Chichester, England: John Wiley & Sons.