

Grant Final Report

Grant ID: R01HS014891

**Value of Imaging-Related Information
Technology (VIRIT)**

Inclusive Dates: 09/07/04 - 08/31/2008

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Submitted to:

The Agency for Healthcare Research and Quality (AHRQ)

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Abstract

Purpose: To assess the impact of Medical Imaging Informatics (MII) on healthcare costs and quality. Our goal was to develop a "business case for quality" related to MII implementation.

Scope: MII systems have the potential to improve the safety and quality of healthcare by enhancing effectiveness, timeliness and efficiency, yet only a minority of radiology departments has fully implemented them. This presents an opportunity to improve quality and safety. A better understanding of the financial and operational value of MII systems will facilitate decision making regarding deployment.

Methods: We evaluated MII deployment and use at two large academic medical centers that underwent the process almost a decade apart. We identified the financial implications of MII deployment, including costs and savings attributable to their use. We determined the effect of MII on quality and safety by examining process times, efficiency of provider and capital utilization, throughput and other metrics.

Results: We found that implementation of MII systems improves quality and financial metrics, and demonstrated a strong business case for investing in these systems. The financial case for investing is driven by increased throughput - film and other cost savings are secondary contributors to MII's business success.

Key Words: radiology, medical informatics, health information technology, picture archiving and communications systems (PACS)

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Final Report

Purpose

Research conducted over the past several decades has clearly demonstrated that Information Technology (IT) can improve the quality and safety of healthcare, yet it is widely acknowledged that the IT infrastructure in healthcare lags behind other industries. Managing information is particularly challenging in Radiology because of dramatic increases in the number, size and complexity of imaging studies. Medical Imaging Informatics (MII) systems, generally comprised of digital imaging systems, radiology information systems, picture archiving and communication systems (PACS), and voice recognition technology can help address this challenge. MII systems have the potential to improve the quality and safety of care by enhancing effectiveness, timeliness and efficiency, yet only a minority of hospital Radiology departments has fully implemented them. The low percentage of Radiology departments with fully implemented MII systems represents an opportunity to improve the quality and safety of patient care. However, the decision to deploy a comprehensive MII system is often based on financial considerations, rather than the potential to improve quality and safety. A better understanding of the financial and operational value of MII systems will facilitate decision making regarding MII deployment and result in substantial improvements in healthcare quality and safety. In this study, we assessed the impact of Medical Imaging Informatics (MII) on healthcare costs and quality. Our overall goal was to develop a "business case for quality" related to MII utilization. We plan to widely disseminate the findings of our study via publication and presentation. This information will help translate existing research into practice and further the AHRQ's goals in the area of quality and safety.

Deployment of a comprehensive MII system at Massachusetts General Hospital (MGH) began in 1995. The potential for cost savings was a deciding factor in the decision to proceed. Preliminary analysis suggested there was a substantial return on investment for these technologies. Wide scale MII deployment at New York University (NYU) Medical Center began just prior to the start of our data collection. The research evaluated MII deployment at MGH and NYU. The opportunity to study MII deployment at two large academic medical centers that went through the process almost a decade apart presented a unique opportunity to better understand the value of MII and to isolate the effects of MII from other secular trends in healthcare. Our analysis identified the financial implications of deploying MII systems, including the costs and savings attributable to their use. We also determined the effect of MII on healthcare quality and safety, by examining outcomes such as process times, provider and capital utilization efficiency, throughput and other metrics. Finally, we began to develop models to predict the value of MII in different settings.

The research has added to our knowledge and understanding of the value of MII and provided data that should facilitate rational decision making concerning the implementation of MII in a variety of health care settings. The research addressed the following Specific Aims:

Aim 1. Determine the financial impact of the deployment of a comprehensive MII system in two large academic Radiology departments.

- 1.1: Determine the financial costs associated with MII deployment at MGH and NYU.
- 1.2: Calculate cost savings and increased revenue attributable to MII deployment at MGH/NYU.
- 1.3: Determine the rate of return earned and payback period for MII deployment at MGH/NYU.

Aim 2. Determine the impact of MII on healthcare quality, focusing on the dimensions of quality as defined by the Institute of Medicine.

- 2.1: Analyze trends in process times, undictated studies, duplicate studies, and the efficiency of provider and capital utilization before and after MII deployment at MGH and NYU.

Scope

Importance of Information Technology in Healthcare

Modern healthcare is one of the most information-intensive enterprises in the United States, yet it remains decades behind other relatively information-intensive industries in its use of electronic information technology (IT). To care for patients, physicians and other healthcare professionals must collect, manage, analyze and act on a massive amount of complex information. In the past, healthcare providers relied on ad-hoc processes to support information collection, processing and management. However, the volume and complexity of information that must be managed now routinely exceeds the bounds of unaided human cognition.

The Committee on the Quality of Healthcare in America was formed by the Institute of Medicine in 1998, and charged with developing a strategy that would result in substantial improvements in the quality of healthcare over the next 10 years. In its 2001 publication *Crossing the Quality Chasm*, the Committee defined six specific aims for quality improvement, namely that healthcare should be *safe, effective, timely, patient-centered, efficient and equitable*. The Committee concluded that information technology (IT) has the potential to improve healthcare quality with regard to all six of the aims. At the same time, however, the Committee recognized that the capital requirements and logistical challenges associated with applying IT to healthcare are substantial, and should not be underestimated.

Despite the potential benefits, physicians, hospitals and other healthcare facilities have lagged behind most industries in the adoption of IT systems. Only a minority of healthcare

facilities in the United States has comprehensive IT systems in place and uses them to support the process of providing clinical care. A number of factors may help explain the relative under investment in healthcare IT. These include: the lack of uniform standards for health information exchange, system interoperability and data sharing; the challenges associated with integrating IT systems into existing legacy systems; the relatively high cost of investing in IT systems; the paucity of commercially developed "plug and play" systems; and cultural barriers to change. Physicians and other institutional decision makers may not have the knowledge or analytic skills to make decisions concerning the purchase and deployment of increasingly complex IT systems. Furthermore, though the *potential* benefits of IT are certainly compelling, hard data concerning the impact of these systems on the cost or quality of healthcare are lacking. In the absence of these data, purchasers of healthcare (e.g., insurers, employers) have been somewhat reluctant to provide the large amount of initial capital funding required for IT acquisition without additional information concerning the expected return on their potential investment. The absence of a comprehensive IT infrastructure to support coherent, patient-centered healthcare undermines the quality of care and makes improvements in efficiency extremely difficult.

Providers in rural, small, and other underserved communities face even greater barriers to implementing IT. In general, healthcare facilities in these communities have relatively less well developed IT infrastructures, less capital available for investment in new systems, and are less likely to have the personnel to support the integration of complex IT systems into the healthcare delivery process.

Information Technology in Radiology

Medical Imaging Informatics (MII) is responsible for a substantial portion of the total healthcare budget allocated to Information Technology. MII systems, usually comprising a combination of digital imaging systems, picture archiving and communication systems (PACS), radiology information systems and voice recognition transcription technology, are now available from a number of commercial vendors. The commercial availability of MII systems makes IT in Radiology somewhat unique compared with IT in most other sectors of healthcare. Nevertheless, a minority of Radiology departments in U.S. hospitals have deployed comprehensive MII systems.

MII systems have the potential to improve healthcare quality in at least four of the six focus areas described by the Institute of Medicine. In the area of *safety*, MII systems can provide consistent access to subspecialty radiology experts, support the ability of a multidisciplinary care team to perform as a unified whole, minimize lost studies, and may help reduce management errors. In the area of *effectiveness*, there is growing evidence that MII systems may improve interpretation accuracy, facilitate communication with referring physicians and help to coordinate care across clinicians and settings. In the area of *efficiency*, MII systems may improve the efficiency of technologists, radiologists, and referring physicians; may lead to overall improvements in workflow efficiency; and may lead to enhanced revenue from Radiology operations. In the area of *timeliness*, MII systems can provide more immediate access to clinical information by shortening study and report turn-around times. Finally, MII has the potential to play a central role in any effort to redesign the care processes surrounding Radiology operations and may thereby lead to substantial improvements in quality.

Barriers to MII Diffusion

Despite the potential benefits of MII, there are many reasons why broad acceptance of these systems has taken more than 20 years. These reasons may also explain why some institutions have elected to defer implementation. The issues can logically be divided into those related to the development of industry-wide standards (and therefore to the availability of commercially developed systems), integration of PACS with other radiology and hospital information systems, limitations of PACS technology per se, cultural acceptance of PACS by radiologists and other physicians, legal and security issues, and perhaps most importantly, cost. One by one, these impediments have become less substantial, until there are few legitimate technical or non-technical barriers to the implementation of an integrated MII system. Nevertheless, uncertainty about the likely effects of these systems on departmental and hospital finances, as well as the quality and safety of care in a particular hospital setting, may still be slowing diffusion of the technology.

The development of a robust image communications standard - the Digital Imaging and COmmunications in Medicine (DICOM) standard - was a seminal enabling event that allowed vendors to pursue PACS development on a common basis. DICOM permits imaging systems and PACS components from different vendors to function together. With the Food and Drug Administration's approval of digital mammography systems, all imaging modalities can now be linked to PACS. Likewise, the Health Level 7 (HL-7) standard permits PACS to interface and even integrate with radiology and hospital information systems (RIS and HIS). More improvements in PACS-RIS/HIS integration can be expected in the future.

From a technical standpoint, huge improvements in computer technology have benefited PACS development. Concerns about system response time, display resolution, archive capacity, workstation functionality and overall scalability have largely evaporated. High bandwidth networks with different architectures are readily available. Many hospitals have already upgraded their networks to run a HIS. Even where network bandwidth might be otherwise marginal, a combination of image compression, workflow management with routing and pre-fetching of images, and implementation of sub-networks for high traffic areas can support radiology and institutional work process needs.

Acceptance of "soft-copy" images by radiologists and other physicians was somewhat of an unknown at the beginning of the PACS era. Since then, radiologists have rapidly come to the conclusion that soft-copy presentation of cross-sectional images is far superior to hard copy viewing. The ability to change brightness and contrast, coupled with the added utility of quantitative analysis and three-dimensional display functions, has tipped the scales so strongly in favor of PACS that it is hard to imagine going back to hard-copy film. In addition, with a web server running on the hospital intranet, images are far more available than they were in the hard-copy era. Physicians can now tap into the radiology archive from home. This has proved popular with both radiologists and referring physicians, as it often saves them a trip to the hospital.

Legal and security issues have proved more theoretical than real. Electronic management and storage of data have become pervasive in and outside of healthcare and are no longer points of special concern in relation to PACS. Secure login protects patient confidentiality.

Perhaps the one issue that has most delayed the adoption of PACS and other components of a comprehensive MII system in many institutions is concern about cost: both the cost of initial deployment, as well as the cost (and potential for cost savings) associated with MII utilization.

Many Radiology departments have been challenged by their institutions to demonstrate positive financial returns on investments in MII. These institutions may even look on MII as yet another imaging modality (such as CT or MRI) that should have a positive return on investment (ROI), rather than as an essential information system that should be treated as a necessity for staying in business in an increasingly competitive healthcare marketplace. Fortunately, two unrelated trends have improved the financial picture related to MII. First, the cost of buying, processing and handling hard-copy film has continued to increase, while the cost of workstations, networks and data archives has fallen precipitously. Second, increasing expectations of patients and referring physicians, consolidations of hospitals into regional delivery systems, and the increasing interdependency of information systems in the care process have prompted more institutions to view MII as a necessary component of the hospital or enterprise-wide patient care information system. A better understanding of the value proposition for MII deployment should help to facilitate more widespread diffusion of MII systems.

The Business Case for Medical Imaging Informatics

The body of evidence attesting to the *potential* of MII systems to improve healthcare quality and safety is increasingly compelling. The availability of "plug and play" systems from a number of commercial vendors has lowered the barrier to entry for many institutions that do not have the resources to develop their own systems. However, as these barriers to MII implementation have been gradually eliminated, uncertainty regarding the costs and potential cost savings attributable to MII deployment remains. Thus the critical issue is rapidly becoming not simply whether or not to deploy, but when, which components to choose, how best to integrate the components with existing hospital information systems, what will it cost, and - perhaps most importantly - what is the business case for investing. There are several reasons for the shift in focus to cost and potential financial returns. The market may eventually require a well integrated MII system in any institution that wishes to remain competitive. Patients and physicians may demand the convenience and efficiency that these systems can offer. Hospital administrators may require that images and study reports be available for the electronic medical record. Competitors may deploy MII systems in order to increase their market share. Nevertheless, it is unlikely that the necessary investments will be made without a better enumeration of the business case for investment.

Declining margins, increased competition, increased costs, and limited access to capital have challenged hospital leaders to make more informed decisions when investing a large amount of resources in capital assets, especially given the industry focus on patient safety and quality which requires large investments in technology. More often than not, hospitals are requiring that the "business case" be justified or at least evaluated before embarking on large IT expenditures that will return benefits to hospitals, but not necessarily in the year the expenditure was made. As a result, in an attempt to create a business case, return on investment (ROI) and other financial modeling tools, while all having some limitations, are being used more frequently in the healthcare setting to assess the strategic soundness of capital investments.

In the current study, we determined the economic and quality implications of MII deployment and utilization. Our analysis included a careful assessment of the capital costs associated with MII deployment, as well as the operating costs and potential savings attributable to MII use. We also determined the effect of these systems on healthcare quality, focusing on four of the six dimensions of quality as defined by the Institute of Medicine: *timeliness*,

efficiency, effectiveness and safety. By conducting a comprehensive analysis of the financial and quality implications of MII, we developed a business case for quality related to MII deployment and utilization. In addition, we began to develop a model to predict the value of MII in different settings. Data derived from our study will be made widely available to key stakeholders who must make decisions about whether, or when, to implement MII systems in their institutions. Our findings will thus help translate existing research into practice and further the goals of the AHRQ in the area of quality and safety.

Rationale for the Study

The low percentage of hospitals with fully implemented MII systems represents an opportunity to improve the quality and safety of patient care through the implementation of proven systems with a strong evidence base. However, the decision to deploy a comprehensive MII system is often made based on financial considerations, rather than the potential to improve quality and safety. A better understanding of the financial and operational value of MII systems, specifically the business case for investing in them, will facilitate decision making regarding MII deployment and result in substantial improvement in healthcare quality and safety.

We hypothesized that MII can result in substantial cost savings while at the same time improving the quality of care. To better understand the economic and quality implications of MII, we evaluated the deployment and use of MII at Massachusetts General Hospital (MGH) and New York University (NYU) Medical Center. Both can be considered "early adopters" of MII; MGH was one of the first to embrace the technology, and NYU has just completed a wide scale rollout. Studying these early adopters made it possible to understand the barriers to, and benefits of, MII deployment.

For our analysis, each institution served as a control site for the other. The deployment of the MII systems at the two institutions occurred almost a decade apart. Our evaluation thus controlled for the effects of other, superimposed trends in healthcare on the costs and outcomes associated with MII deployment. Our analysis was more comprehensive than prior studies. We developed a rigorous approach to data collection and analysis that can be used by others in the future. We also intend to make the results widely available so that key stakeholders in other institutions can use them to better inform their decisions regarding the deployment and use of MII.

Methods

There were two principal components to the research, corresponding to the project's two Specific Aims. Though much of the data collection served both components of the project, we describe the methods and results separately, by Specific Aim.

Aim 1: Determine the Financial Impact of the Deployment of a Comprehensive MII system in Two Large Academic Radiology Departments

- 1.1: Determine the financial costs associated with MII deployment at MGH and NYU.
- 1.2: Calculate cost savings and increased revenue attributable to MII deployment at MGH/NYU.
- 1.3: Determine the rate of return earned and payback period for MII deployment at MGH/NYU.

The study used a combination of financial analysis and traditional statistical tools to establish the business case for investing in MII systems. While the implementation of MII systems was assumed to increase the efficiency of radiologists, which results in an increase in exam throughput, other secular changes such as clinical technological improvements and growth in the market, might also have contributed to the rising number of radiology procedures being performed each year. Being able to attribute and distinguish the increased volume resulting from MII implementation versus the result of other secular trends was of paramount importance to the study. Predictive statistical models were used to distinguish this throughput – to be referred to as MII volume. Financial analysis tools were used to evaluate the combined financial effect of the costs, savings, and the net revenue generated from the MII volume to determine if there is a business case for investing in these systems.

Predictive Models. A key assumption is that the two Academic Medical Centers (AMCs) being studied have similar structural, environmental, and market characteristics that can justify one AMC being used as a control for the other when evaluating trends in their financial and productivity data. Both AMCs are large, urban, tertiary care, teaching hospitals with similar American Hospital Association survey profiles as well as similar imaging systems and similar economic and patient population constraints. It is assumed that without the implementation of a MII system, both AMC radiology departments would have experienced similar trends in costs and volume and would have been affected similarly by clinical and technological secular changes. Any deviations from the trends observed may be attributed to the implementation of the MII systems.

Predictive models were developed to identify the MII volume, the portion of the increased throughput that is attributable to the implementation of the MII system, as opposed to any increased volume that is due to secular changes and growth in the market. Multiple linear regression models were used to control for differences between the two AMCs' monthly throughputs during the 10 year study. The relationship between the growth in volume (converted to RVUs) over time to the increased use of both PACS and SR (primary components of MII system) was modeled. The model included a monthly rate of implementation that reflected the percent of cases processed with the MII system at each institution as well as a ratio of AMC1's RVUs to AMC2's RVUs. The model allows us to limit our attribution of the growth in volume and productivity that occurred over the 10-year period of the study to growth that was synchronous with the growth in the use of MII. Further, to eliminate any growth that might be

due to changes in imaging technology, to changes in the role of imaging in medicine, or to changes in disease or population demographics, we used the ratio of the values of the throughput, measured in RVUs, at the two AMCs as our dependent variable. Any changes in imaging technology or the role of imaging in medicine, or changes in disease and population demographics would similarly affect both institutions simultaneously and would not alter the ratio.

In contrast, changes attributable to MII implementation would only affect the institution doing the implementing at the time and, therefore, would appear as changes in the ratio. Stepwise linear regression modeled throughput as a function of the rate of implementation of MII at both institutions. To control for simultaneous secular trends, throughput was expressed as the ratio of the AMC1 value to the AMC2 value for each of the work (W), technical (T) and work + technical (W+T) RVUs. Incremental revenue and incremental costs for the MII volume were calculated by multiplying the MII volume by the annual Medicare conversion factor, and by the cost per procedure, respectively.

Establishing the Business Case. Although there are no established rules for evaluating the “business case” of hospital capital investments, earlier studies discussing the business case for quality suggested that asset costs be justified, cost savings and financial returns be evaluated, and a positive indirect, sustainable effect on organizational function accrue within a reasonable time frame. The business case for AMC1’s investment in MII is determined by calculating both a payback period and an internal rate of return (IRR). The payback period and IRR provide useful data for the overall evaluation of the investment quality and can be compared to alternative investment options when evaluating and determining the best use of the institutions’ limited capital resources. These calculations include the capital cost (purchase price) of the MII system and the film cost savings as well as the increased marginal costs and increased net revenue of the MII volume of AMC1’s investment.

While many costs are eliminated or significantly reduced as a result of the deployment of MII, the largest among these was expected to be film savings. Film savings were calculated at each AMC by identifying the filming protocol of the AMC and applying it to the volume of studies generated by each modality subsequent to the MII deployment. The estimated film costs were compared to actual film costs reported in the general ledger to determine savings. Sensitivity analyses using more conservative filming protocols (e.g., assuming that not all images acquired would be filmed) to estimate film savings were also performed. Changes in other operating costs exclusive of physician labor costs were captured in the incremental operating cost calculations. Transcription costs, storage, library, and other miscellaneous operating costs decline as a digital system replaces a film system but these were judged to be insignificant in value as compared to film savings and were not included individually in our analysis but are captured through their inclusion in the incremental cost of the increased throughput.

Data. Cost and revenue data collected from each institution’s internal accounting and information systems for the ten year (fiscal years 1995 to 2005) study period of this analysis include capital costs, annual and monthly general ledger line item operating costs for the department of radiology at each institution, radiology exam volume, monthly technical relative value units (RVUs), the work component of monthly professional RVUs, and the annual Medicare conversion factors. For the sake of simplicity all services were conservatively valued

at the Medicare rates, rather than specific payer reimbursement rates, at the time they were performed. RVUs are used both as a measure of throughput and a proxy for volume.

Aim 2: Determine the Impact of MII on Healthcare Quality, Focusing on the Dimensions of Quality as Defined by the Institute of Medicine.

- 2.1: Analyze trends in process times, undictated studies, duplicate studies, and the efficiency of provider and capital utilization before and after MII deployment at MGH and NYU.

Data. The sources for the clinical data were the RIS and PACS data bases at AMC1 and AMC2. The RIS systems are written in MUMPS (Massachusetts General Hospital Utility Multi-Programming System) and the structure of its database is hierarchical. A third party vendor, Knowledge Based Systems, provides a tool, KB SQL (Structured Query Language), that is an ODBC driver that essentially gives a relational view into the hierarchical database. We used KB SQL to pull data out of the RIS into Microsoft SQL Server using SQL Server's DTS (Data Transformation Services) tools. SQL Server is the database that was used to store clinical data for the project. Both the AMC1 and the AMC2 groups agreed to capture the same fields in the same RIS tables to maintain consistency.

The PACS uses a commonly used relational database which supports SQL queries. The data from the PACS was generated using queries which generated flat ASCII files which were analyzed using Microsoft Access. The PACS data was compared with the data in RIS to determine how many (what percent) of the exams were read in PACS each month.

Monthly RVU figures were obtained using the CMS conversion tables for each year. The work total was the sum of the professional and practice components. (That is, the mal-practice component was not included.) At AMC2 due to data limitations, RVUs could only be determined for one of the business components of the center from the initiation of the study through May, 1999. Those values were scaled up to reflect the entire department. Clinical FTEs were derived from financial records at each institution.

We also calculated the times from exam completion to preliminary and to final reports (C-P and C-F times, respectively). As the implementation data were on a monthly basis, we reduced the time data to a monthly summary as well. We then determined the mean C-P and C-F times by month. We investigated the distributions of these times. As they were highly skewed (being distorted by some truly exceptional times, in some cases exceeding a year), we decided that a model of the mean times for all procedures by month would largely reflect only the fraction and times of procedures with very long times from completion to report. Instead of modeling the monthly mean times, for each month, we modeled both (1) the fraction of all reportable procedures with times in excess of an arbitrary cutoff and (2) the mean time for all with times under that cutoff. We used cutoffs of $\frac{1}{2}$, 1, 2, 3, and 7 days. Though we report only the results for three days, the results (in terms of which independent variables showed a significant relationship to the representation of time being modeled) were similar for all cutoffs studied.

Statistical Methods. We modeled the extent of implementation of each of PACS and SR at the two institutions to derive smoothed curves that only increased over time while simultaneously reducing the noise. The models were based upon the monthly fraction of procedures that were performed using PACS and SR. Logistic models with the calendar date as

the independent variable were fit to the data from the date of initial implementation. (The predicted extent was set to zero before that date.)

To study productivity, we represented the monthly productivity by the ratio of the AMC1 and AMC2 values of each measure (work and technical RVUs, work RVUs per clinical FTE and technical RVUs per clinical FTE.) We performed stepwise linear regressions using the smoothed extent of implementation of PACS at AMC1 and AMC2 and of SR at AMC1 as the independent variables. In these models, the intercept became the estimated ratio of productivity if there had been no PACS at either place or SR at AMC1. The slope for each term reflected the change in the ratio associated with complete implementation. We hypothesized that the AMC1 terms would correspond to increases in the ratio while the AMC2 PACS term would indicate a decrease in the ratio counterbalancing the increase due to PACS at AMC1. Only terms with p-values of 0.05 or less were used in the models.

To quantify the productivity gains associated with the implementation of HIT, we adjusted for the difference in size of the institutions by dividing all terms in our models by the estimated intercept (the estimate of what would have been the ratio of the productivity measure had there been no HIT). Further, as our data showed that 100% implementation was not achieved at either institution, we estimated the total potential gain as the gain that would be achieved at 90% implementation rather than at 100% (that is, by 90% of the adjusted slope).

To study timeliness, we performed stepwise linear regressions using the smoothed extents of implementation of PACS at AMC1 and AMC2 and of SR at AMC1 as the independent variables. In each model, we tested for the incremental effect of the PACS and SR variables using the value at the other institution as a (forced) covariate. Only terms with p-values of 0.05 or less were used in the models. All modeling was performed using SAS, version 9.1 (Cary, NC.)

Results

Aim 1

The payback period for the MII system deployed by AMC1 in 1995 was 48.8 months and the IRR in the year of payback was 56%. While the film savings realized by AMC1's deployment of the MII system positively contributed to the financial return, the payback period of the initial capital investment is not realized until the fifth year of operations (64.5 months) yielding an 18% internal rate of return. Alternatively, the net profitability of the MII volume, considered alone, yields a 16% internal rate of return in just the fourth year of operations (54.2 months).

While both film savings and profitability of MII volume are positive contributors to the financial justification of the MII investment, financial yield of the MII volume is the primary driver of the business case in the first four years. In the year of payback, the cumulative profitability of the MII volume contributed 124% of the cumulative MII capital investment while the cumulative film savings contributed only 79% of the MII capital cost. The cumulative net profits from the MII volume were also slightly more than 1.5 times the film savings at the time of payback.

The payback period for the MII system deployed by AMC2 in 2003, predictably, had not been realized by the end of the study period, 2005.

Aim 2

The linear regression models of each of the four measures of productivity demonstrated a significant ($p < 0.0001$) relationship to the modeled extent of penetration of PACS at AMC1. No other terms were significant. However, backwards modeling of the work RVUs per clinical FTE also found significant effects associated with SR at AMC1 and PACS at AMC2.

The introduction of PACS at AMC1 is associated with approximately a 30% increase in work RVUs and almost a 70% increase in technical RVUs. These estimates are derived from the models using AMC1 PACS alone. The relative effect was based on the ratio of the estimated slope to the intercept. For instance, the model estimates that in the absence of PACS, AMC1 work RVUs would be 1.78 times those at AMC2. At full (100%) implementation, the model estimates that the ratio would be 2.24, an increase of 31.5%. At a more realistic 90% maximum implementation, the estimated increase would be 28.3%.

The measure of timeliness at the institution was not significantly related to the corresponding measure at the other institution. The fraction of AMC1 exams with the report finalized within three days of the completion of the exam was significantly related ($p < 0.0001$) to the estimated fraction of its exams that were processed via the PACS system. The modeled percentage over three days dropped by more than half from more than 40% to under 20%. The expected change at 90% implementation is estimated to be $27\% \pm 2\%$.

The fraction of AMC1 exams with the preliminary report within three days of exam completion was also significantly related ($p < 0.0001$) to the extent of PACS use at AMC1. The modeled percentage over three days also dropped from almost 15% to roughly half of that. The expected change at 90% implementation is estimated to be $8\% \pm 1\%$. However, a backwards regression identified an alternative model using terms for the extent of PACS use at both AMCs.

The models for the mean C-F and C-P times for exams with times under three days were significantly related to the estimated extent of implementation of SR at AMC1 (both $p < 0.0001$). Both models projected that a 90% implementation of SR would be associated with a reduction of approximately 16 hours in the time from the completion of the exam to both reports.

None of the models for the mean times nor the fraction of AMC2 exams reported within three days demonstrated any significant relationship to the implementation of PACS at AMC2 or PACS or SR at AMC1.

Overall Conclusions

Our results demonstrate that there is a strong business case for the use of MII systems in radiology departments and hospitals, and that the implementation and use of these systems is associated with measurable quality and efficiency improvements. These results should encourage institutions that have yet to implement these systems to do so, sooner rather than later.

List of Publications and Products

Currently, three manuscripts are under review for possible publication. These include:

1. Making the Business Case for Radiology Medical Imaging Informatics. (submitted to *JAMA*)
2. Impact of Health Information Technology on Radiologist Productivity. (submitted to *Radiology*)
3. Impact of Health Information Technology on Timeliness of Radiology Reporting. (submitted to *Radiology*)

Two additional manuscripts are in the final stages of preparations. The first of these focuses on the potential effects of MII deployment on the projected shortages of radiologists and radiologic technologists. The second uses data from smaller U.S. hospitals, as well as data from other health systems (U.K., Jamaica) to project possible effects of MII deployment in different settings and healthcare systems.