Health Information Technology and the Transformation of American Medicine

Ruben Amarasingham MD, MBA

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Dr. Ruben Amarasingham is the Director, Center for Knowledge Translation & Clinical Innovation and Associate Chief of Medicine Services at Parkland Health & Hospital System and Assistant Professor of Medicine, Division of General Internal Medicine at UT Southwestern Medical Center at Dallas. Dr. Amarasingham's research themes include the evaluation of health information technology, the application of advanced informatics concepts in healthcare, and the use of innovative care models to reduce disparities, improve quality, and lower costs.

Ruben Amarasingham, MD, MBA
5201 Harry Hines Blvd
Dallas, TX 75235
ramara@parknet.pmh.org

Artwork on cover: *The Doctor* by Sir Luke Fildes, 1891, oil on canvas.

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A Framework for Health Information Technology

The management of information is a central activity of modern medicine. This activity can be broadly divided into three categories: clinical, administrative, and research.[1] It should be obvious that within the clinical domain, the premium of reliable, accurate, and timely information cannot be too high. For most of the past century, clinical information has been recorded and transmitted through paper or film. Advances in the last 30 years have made many of these processes possible in electronic form. Such technologies include electronic medical records (EMR), computerized provider order entry (CPOE), and digital radiology systems, among hundreds of others. These new technologies have many names; for our purposes, we shall refer to them collectively as health information technologies (HIT). HIT can be divided into different information

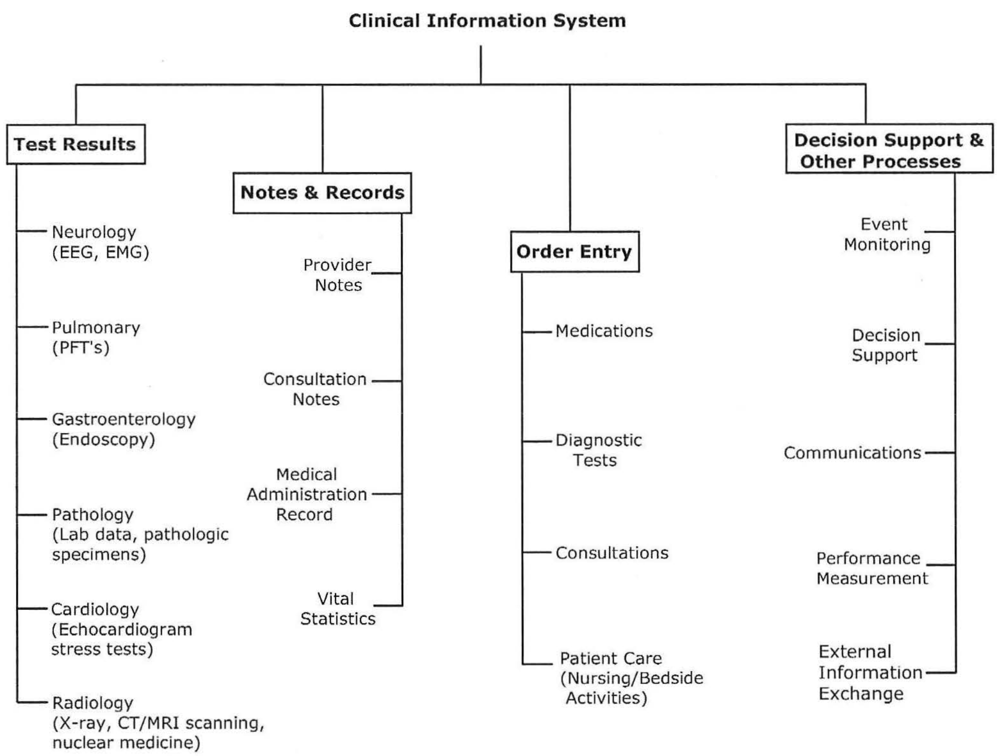


Figure 1. Four major domains and associated clinical sub-domains of HIT. Each of the boxes represent domains of clinical information that can be potentially computerized. *From Amarasingham, R Medical Care, 2006.*

system areas or domains. Myself and a team of colleagues proposed the following typology of domains as a basis for clinical information systems evaluation in 2006: automation of test results, automation of notes and records, automation of order entry and automation of decision aupport and other processes (Figure 1). Within each domain are multiple clinical sub-domains. For example, order entry can involve medications, diagnostic tests, patient care and consultations.

Adoption of Health Information Technology in the United States

Literature examining the prevalence of HIT is sparse but growing. Studies have several limitations, including information and selection biases, lack of internal validity, lack of external validity, and limited comprehensiveness. Only two studies based their conclusions on clinical end-users and they lack detail on specific components.[2, 3] Few studies describe the HIT capabilities of safety net hospitals. In general, systematic consideration of selection bias is not made and the baseline characteristics of responders and non-responders are not reported. Few studies are longitudinal in nature. As a whole, little effort was made at piloting, inter- and intra-reliability testing, validation and other critical aspects of survey development. On the basis of this literature, precise estimates about the quality, depth, and functionality of HIT in the United States are difficult to make.

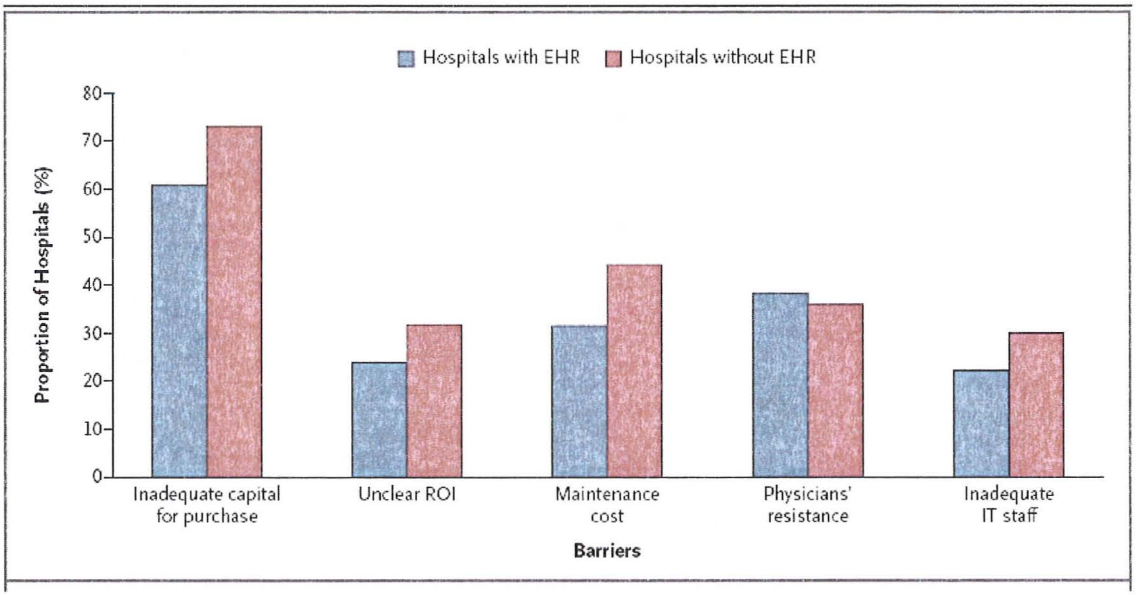


Figure 2. Major perceived barriers to adoption of Electronic Health Records. From Jha et al, NEJM, 2009.

However this year, Jha and colleagues documented the state of hospital IT adoption in a seminal study published in the New England Journal of Medicine.[4] The paper overcame many of the methodologic problems of prior work; however they did not use a validated survey instrument. They found that only 1.5% of U.S. hospitals have adopted a comprehensive EHR system. Not withstanding the projected growth rate of HIT, multiple authors have commented that without clinical and financial benefits, hospitals may be unwilling to make the changes currently advocated by various opinion leaders.[5, 6] As shown in figure 2 a significant percentage of hospitals do not believe that there is a clear return on investment, express physician resistance, and worry about adequate capital for IT investments.

Studies Examining the Benefits of Clinical Information Technology

Few professionals deny the potential benefits of HIT.[7] These technologies hold promise across all facets of inpatient care, including clinical decision making, prescribing, performance measurement, information retrieval, and communications.[8] Given rising health care costs and the increased attention on medical errors, significant enthusiasm has erupted for HIT. It is believed that HIT will significantly reduce costs through efficiency gains, more appropriate utilization, and less duplication of services.[5] Reports hypothesize that HIT can circumvent personnel shortages by improving the productivity of remaining individuals.[7, 8] However few studies demonstrate unequivocal improvements in financial and clinical endpoints. These primary outcomes may include length of stay, inpatient mortality, costs realized per admission, and total return on investment.

The informatics literature does suggest that intermediate outcomes may be realized through HIT (Figure 3), particularly in the area of patient safety. Studies have demonstrated that HIT can increase adherence to preventive measures in the hospital.[9-12] reduce unnecessary laboratory tests,[13-15] reduce medication errors,[16, 17] and improve monitoring.[18] There is less evidence for decreasing the time to effective treatment, and little research has been done on the effectiveness of automated performance measurement, which is the ability to capture process and outcome measures electronically in real-time. In contrast to proximate intermediate outcomes, distal clinical and financial outcomes, as described in figure 3 are poorly demonstrated.

For example, a few studies have examined length of stay and the results are equivocal.[19-21] Only a handful of studies examine HIT and overall inpatient mortality. Although one study has shown decreased costs in a very specific setting,[21] return on HIT investment is notoriously difficult to prove.[22] The costs of

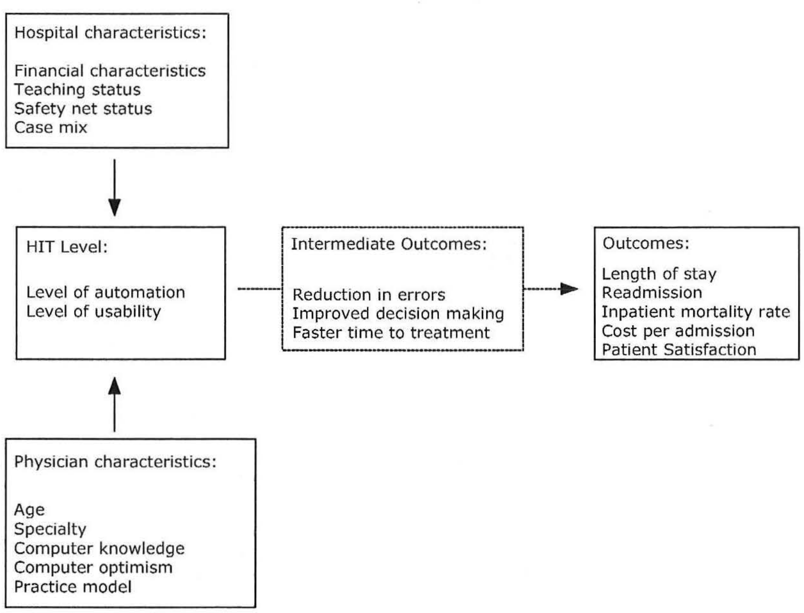


Figure 3. A First-Order Conceptual Model of HIT and Outcomes.

specific processes, for example, are poorly defined and savings may not be measured in certain areas. In addition, projects examining the benefits of HIT are almost exclusively conducted in the context of single institutions, usually academic medical centers.[9-21] Therefore, positive findings may not be generalizable to other hospital types. Indeed, the costs of training a staff naïve to the use of advanced IT may be significantly greater for non-academic, community hospitals. This may be especially true for rural or safety net hospitals. Finally, in some cases, study authors were involved with implementing the very technology they sought to evaluate, thus raising the possibility of an inadvertent information bias. A systematic review performed by Chaudhry and colleagues in 2006 reported that 25% of all critical studies on this subject were from the same 4 academic institutions, many of which implemented internally developed systems.[23] Data on outcomes were mixed.

Development of the Clinical Information Technology Assessment Tool (CITAT): A Structural Measure of Hospital Information System Performance

In 2005, my colleagues and I developed a clinical information technology assessment tool (CITAT) in eight steps according to established methods of survey design to help examine the impact of HIT and outcomes.[24] The steps for survey development included: development of a conceptual model, literature review, content identification, item construction, pre-testing, item selection and re-classification, and pilot testing. We constructed a model for measurement based on a hospital information system's *automation* and *usability,* two domains used to characterize information systems.[25-27] For the purposes of this model, we interpret the standard definition of *automation* in a clinical context: namely, as the degree to which clinical information processes in the hospital are fully computerized.[27] We further categorize automation into four sub-domains (test results, notes & records, order entry, and other processes) based on the previous work of others.[28] The clinical effectiveness of a hospital's information system also depends on its usability characteristics.[29-31] If a system is highly automated, but extremely difficult to use, physicians may be less capable of providing the best care.[32] We proposed that usability be measured in parallel to a system's automation, as a twin construct. We define *usability* as the degree to which the clinical information system is effective, easy to use, and well supported.[26, 33] The state of a hospital's information system can thus be represented as a function of two domain categories (automation and usability) and seven sub-domains (Table 1).

At least one automation item was developed for each unique aspect of the hospital information system within each of the automation sub-domains. Certain components tended to have more unique aspects, and therefore had a higher representation of questions. For example, the instrument contains more items devoted to decision support than lab results reporting, because the range and subtlety of the first component is more difficult to capture. Two response formats were employed for automation items: a visual analog scale (most items), and dichotomous yes/no questions. For item responses using a visual analog scale, a low value indicates that the respondent routinely completes a given process without the use of a hospital computer (e.g. through paper or verbal communication). The highest value on the scale indicates that the respondent completes the entire process through the hospital computer system interface. If a respondent indicates the highest value on the scale for a given process, three conditions are assumed of the hospital information system for that process: 1) the process is fully computerized 2) the physician knows how to activate the computerized process; and 3) the physician chooses to use the computerized process over other alternatives (if present). Therefore each visual analog response represents the degree to which a given process is functionally computerized, since a high score requires that the process is not only available by computer, but routinely performed by computer.

We developed usability items according to the three sub-domains that define usability in our model: *effectiveness*, *ease* and *support* (Table 1). As with automation, we examined the cognitive science and medical informatics literature to identify content and develop items relevant to the three usability sub-domains.[26, 29, 31, 33-39] Two response formats were used: a 5 point Likert scale which asks respondents to agree or disagree with a particular statement, and dichotomous yes/no questions. It is possible that certain hospitals employ paper-based processes that achieve a high level of usability without significant automation. We therefore designed each usability item so that respondents could answer the questions regardless of the technology employed at their institution.

Table 1. Clinical Information Technology Assessment Tool Structure

Domain	Sub-domain	Construct
Automation	Test results	Degree to which test results are reported and retrieved electronically
	Notes and Records	Degree to which notes & records are reviewed and generated electronically
	Order entry	Degree to which physician orders are electronically generated
	Other processes	Degree to which certain processes (decision support, event monitoring, internal and external data sharing, and performance measurement) are electronic
Usability	Effectiveness	Physician's perception of how effectively the information system carries out a particular function
	Ease	Physician's perception of how easy it is to carry out a particular function using the information system
	Support	Physician's perception of the response speed of user-support for the information system

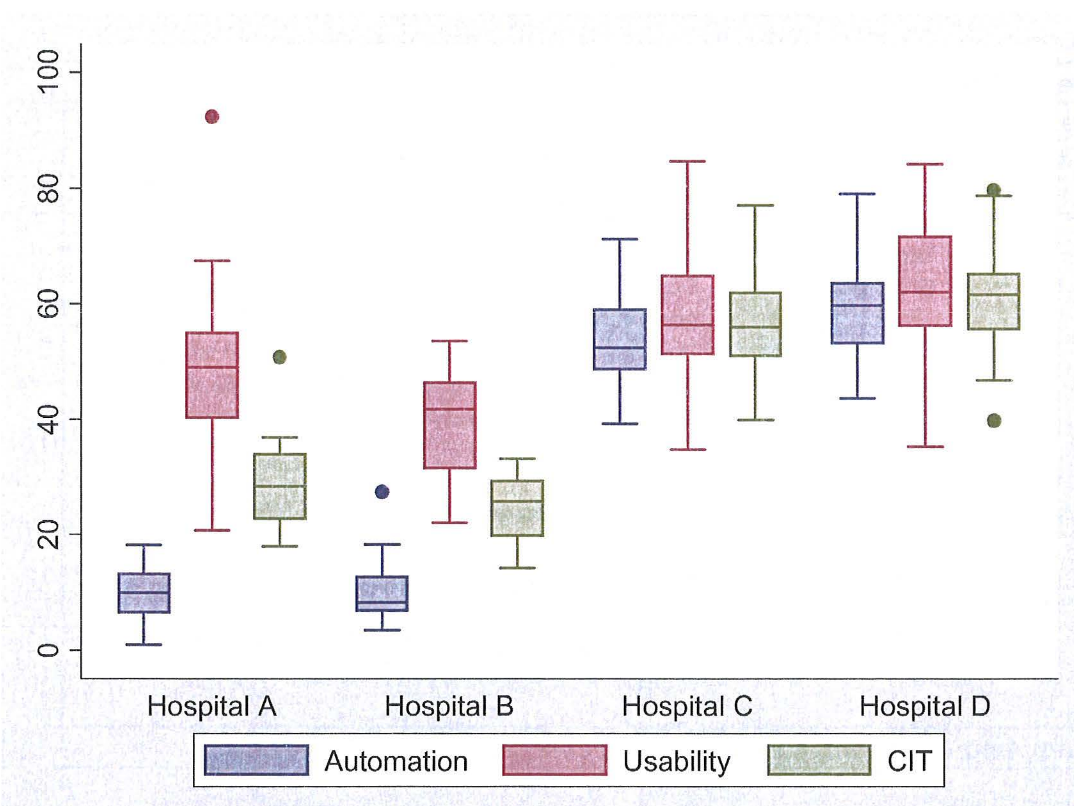
From Amarasingham, R et al., Medical Care, 2006

The initial instrument of 131 usability and automation items went through extensive cognitive response testing among a group of eleven clinicians having no formal informatics training. Items identified as improperly conveyed were re-constructed and re-tested until clarity was achieved. Finally, in order to determine whether each question was assigned to the correct content area, study investigators independently re-assigned each question to a domain and sub-domain. The investigators had overall agreement of 92.3% (kappa=.82) on the domain classification. Overall agreement on the sub-domain classification was 85% (kappa=.76). Items for which there was disagreement received classification through consensus by the two investigators; non-unique (i.e. redundant) items within a sub-domain were eliminated.

Assessing the Validity of the CITAT

We administered the assessment tool to convenience samples of physicians at four hospitals in the United States.[24] Hospitals A and B were part of a large private, not-for-profit community hospital system; they share the same information system but possess otherwise different missions and orientations. Hospital A was a tertiary-level community hospital that provides residency training for a large number of specialties. It has nearly three times the number of beds as hospital B. In addition, Hospital A supported services that require sophisticated levels of medical technology including open heart surgery and

Figure 3. Comparison of CITAT Scores



From Amarasingham, R Medical Care, 2006.

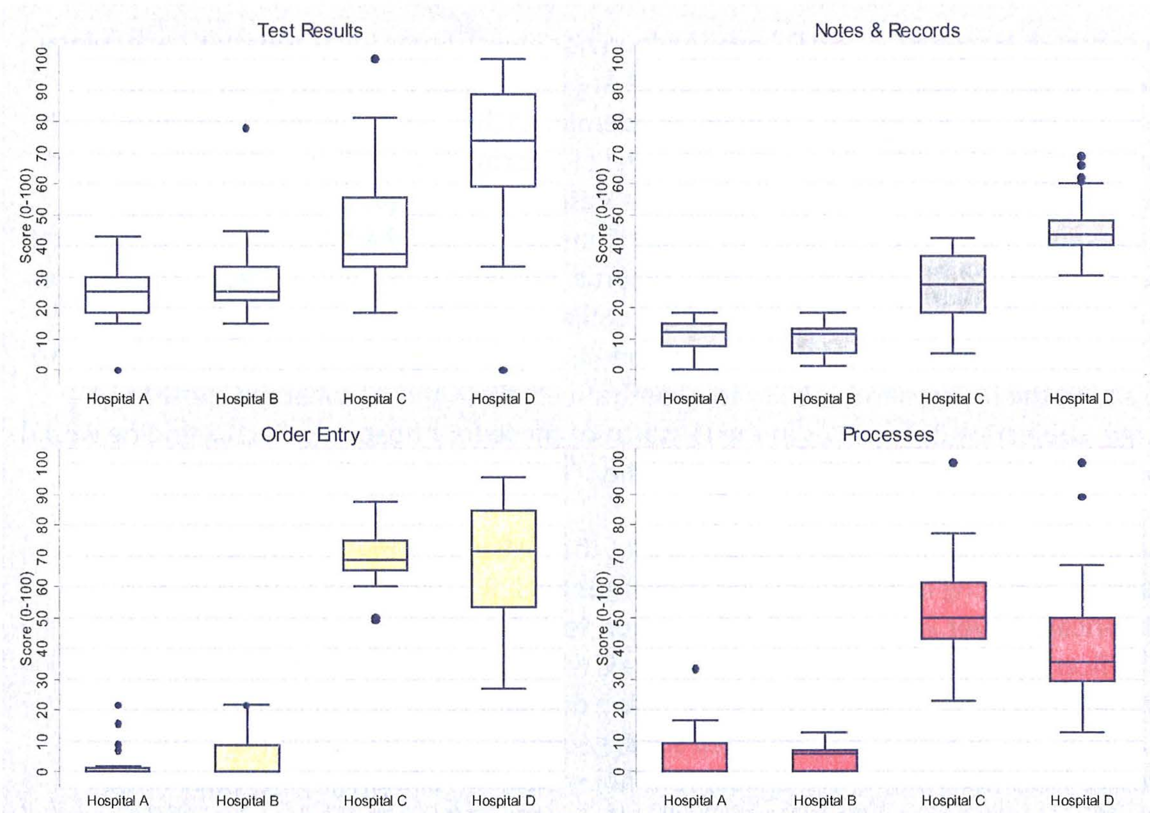
major organ transplantation. Hospital B was a smaller community hospital with fewer services and fewer residency training programs. These hospitals also differ in their geographical context; Hospital A is located in a suburban area whereas Hospital B is located in a lower income, inner-city neighborhood. We included these two hospitals in our pilot study because, though they are outwardly different in scope, their information systems are identical. If the instrument returned a similar assessment of both hospitals' information systems, we might conclude that the measurement instrument is not influenced by other structural characteristics, such as the presence of technologies that support organ transplantation (i.e., discriminant validity).[40] In addition such a result would suggest that the instrument is independent of interactions between the information system and the surrounding environment (e.g., the people, policies, mission, or orientation that constitute the organization). We also chose these hospitals because the information technology investment in these hospitals has been low compared to that of other national leaders. At the time of the pilot study, they had not yet invested in an electronic medical record, computerized provider order entry system, wireless prescribing, or radio-frequency identification (RFID).

In contrast, Hospitals C and D have made major investments in information technology over the last three decades. Both systems are recognized as models of HIT in the hospital setting. Hospital C is a major academic teaching hospital which supports a full complement of residencies and a high level of information and non-information based medical technologies. Hospital D is a large Veterans Affairs (VA) medical center and represents one of the test sites for major IT innovations in the VA system. Both hospitals have sophisticated electronic medical records, provider order entry, electronic decision support systems and some degree of bar coding technology. Hospital D, in addition, employs wireless inpatient prescribing and RFID technology. In this pilot, we wanted to examine the instrument's ability to quantitatively discriminate what we know to be large, subjective differences in the IT status of these four hospitals. Such a finding would indicate initial evidence of construct validity. [40]

Results from the pilot study suggested that the instrument met criteria of construct validity, including discriminant and convergent validity. First, the 2 hospitals with historically lower investment in information technology (Hospitals A and B) scored significantly lower than the pair of hospitals with sophisticated IT systems (Hospitals C and D) in all of the instrument's automation domains (figure 3). Second, although Hospitals A and B have different bed sizes, geographic contexts, hospital staffs, and service lines, they share the same information system technologies. Despite these significant structural differences, results showed no difference in the automation or usability scores between these hospitals. The instrument's capability to accurately distinguish information technologies from other characteristics of the hospital, such as the medical technologies that support open-heart surgery or major organ transplantation, suggests discriminant validity. Finally, we also created a CIO questionnaire based on items taken directly from the automation and usability components of the physician survey. CIO scores were slightly greater than, but paralleled, those of the physicians, with Hospitals C and D scoring highest on all measures than Hospitals A and B. This finding lends evidence of convergent validity. Our results also suggest that the instrument is reliable and precise. The instrument achieves a relatively high degree of precision for a relatively low number of respondents (ranging from 18 to 45 with low standard deviations across measures). We also found that in nearly all circumstances, CIT scores at a given hospital did not vary by the characteristics of the physician, indicating a high level of interobserver reliability. These results suggest that this measurement system is independent of respondent characteristics and may be administered to internists or family practitioners with different computer backgrounds. The instrument appears to be internally consistent, with high values of intraclass correlation on all of its subdomains.

Performance of the CITAT in an ICU quality improvement cohort study

Figure 4. Comparison of Sub-Domain CITAT Scores



From Amarasingham, R et al., Archives of Internal Medicine, 2009.

After the initial study, we subsequently tested the CITAT instrument in 19 Michigan ICUs participating in the Keystone ICU Project, a collaborative research study between the Johns Hopkins University Quality and Safety Research Group and the Michigan

Health & Hospital Association (MHA)-Keystone Center for Patient Safety & Quality.[41] The Keystone Project was designed as a prospective cohort study using ICU-specific historical controls as the baseline comparator to evaluate a multi-faceted, evidence-based intervention to reduce Catheter Related Blood Stream Infections (CRBSI). In the original study, 108 ICUs voluntarily participated in the MHA Keystone ICU project. The results of this study, published in 2006 in the NEJM, were a landmark in the quality improvement and safety literature. For each of these ICUs, CRBSI rates were obtained in four three month intervals: 3 months prior to implementation, 0-3 months (peri-implementation), 3-6 months post-implementation, and 6-9 months post-implementation with widespread and dramatic improvements. During this period each of the physician ICU directors of each of the 19 ICUs completed the clinical information technology assessment tool for intensive care units (CITAT-ICU). We also wanted to examine differences between the physician director and physician staff scores among the ICUs in order to assess the inter-rater reliability of the instrument. We therefore requested each ICU to have at least one of their staff physicians independently complete the CITAT-ICU.

Table 2. Association between IT Scores and Rate of Post-intervention Catheter-related Bloodstream Infections (CRBSI) per 1,000 Central Line Days*

	Adjusted†	
Independent Variable	Change in Post-intervention Rate of CRBSI (95% CI)‡	*P*
IT Scores		
Overall IT	-0.46 (-0.80, -0.10)	0.02
Automation	-0.31 (-0.60, -0.02)	0.04
Usability	-0.42 (-0.79, -0.04)	0.03
Automation sub-domains		
Test results	-0.30 (-0.60, -0.01)	0.04
Notes & Records	-0.14 (-0.48, 0.20)	0.39
Order Entry	-0.12 (-0.27, 0.04)	0.13
Processes	-0.27 (-0.56, 0.01)	0.06
Usability sub-domains		
Effectiveness	-0.37 (-0.78, 0.04)	0.07
Ease	-0.09 (-0.33, 0.14)	0.41
Support	-0.19 (-0.41, 0.03)	0.08
Hospital characteristics		
Bed size	2.8 (-1.1, 6.7)	0.14
Rural location	-4.7 (-30, 21)	0.71
Teaching status	5.2 (-6.8, 17)	0.93

From Amarasingham R et al., Journal of the American Medical Informatics Association, 2007.

*One ICU reported data for one phase of the intervention only. Since a change in CRBSI rate could not be calculated for this ICU over the study intervention, it was removed for this analysis leaving 18 hospitals.

†Multivariate model adjusted for the pre-intervention rate.

‡Change in Post-rate (per 10,000 central line days) after a 1 year exposure to the study.

Our results suggested that higher scores on a multitude of information technology domains are associated with lower post-intervention rates of CRBSI.[42] These results remain significant after accounting for the baseline or pre-intervention rate. According to our findings, an ICU with a 10 point higher IT score is associated with 4.6 fewer central line infections per 1,000 central line days compared to an ICU with a lower IT score that implements the same evidence based intervention. Our research team speculated on several potential explanations exist for these positive findings. Catheter-related blood stream infections are the result of multiple factors including a system's organization and structural environment. Providers equipped with systems that can more easily retrieve test results, provide ubiquitous access to clinical information, and employ order sets that reduce variations in clinical care may be more likely to deliver higher quality of care. Highly automated, carefully designed information systems may allow ICU teams to focus on truly clinical tasks by reducing paperwork, enhancing patient monitoring, and simplifying data extraction. In the case of central line placement, efficiencies created by a powerful information system may allow physicians and nurses to better comply with effective, but potentially time consuming, interventions such as those introduced in this study. Such steps include performing the central line insertion using checklists and enabling more team-members, such as nurses, to participate. An electronic medical record, or complex decision support system, may prompt daily consideration of central line removal. In the future, clinical information systems might incorporate other key data elements about central lines, and provide automatic tracking, with warnings if certain signals appear (e.g. fever and tachycardia in the presence of a catheter that has been in place for an extended period).

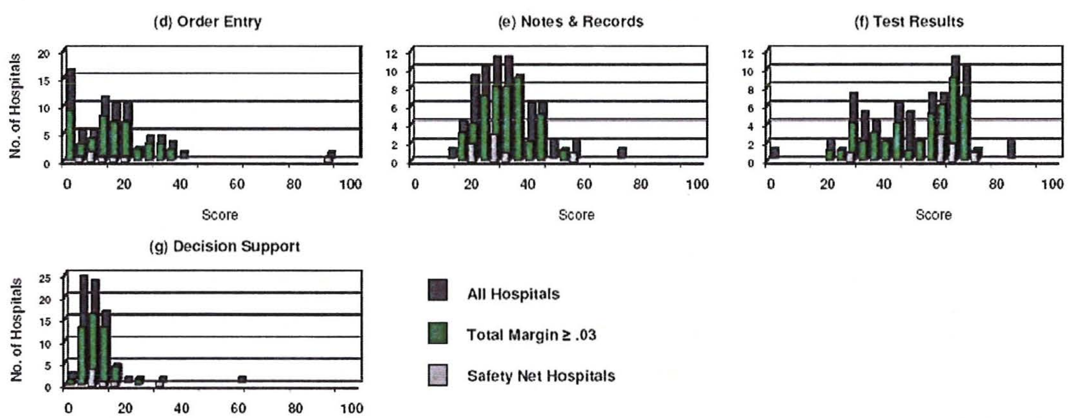
Most quality improvement efforts are data intensive. Interventions need to be accompanied by tenaciously collected baseline and follow-up data. Powerful information systems may reduce the burden of data collection, freeing quality improvement teams to focus on efforts to change provider behavior, re-engineer processes, champion interventions, and sustain gains. Allowing staff to concentrate on the "human" aspects of quality improvement may be a significant benefit of well designed clinical information systems and may explain some of our findings.

A Multi-Hospital Study of Clinical and Financial Outcomes Using the CITAT: The TEXCITE Study

In 2006, we embarked on a comprehensive study to evaluate the relationship between hospital information technology systems and key clinical outcomes.[43, 44] To do this, we conducted a cross-sectional study of urban hospitals in the state of Texas. We sampled from 72 general, acute care hospitals located within 10 geographically dispersed metropolitan statistical areas (MSA) in Texas (Abilene, Austin, Dallas, El Paso, Houston, Laredo, Lubbock, McAllen, San Angelo, and San Antonio). We selected Texas as the site for study because it contains a large and diverse patient population and a wide range of hospitals for which specific clinical outcomes could be obtained. We excluded pediatric, specialty, or long-term care hospitals, hospitals that were in the process of closing or merging with another facility, and hospitals for which we could not obtain discharge data for the targeted Diagnosis Related Groups.

Using the American Medical Association (AMA) master file, we selected a 50% random sample of physicians among those that were indicated 1) to have practice locations in the designated MSAs and; 2) to be practicing internal medicine (including 9 sub-specialties), general surgery (including 10 sub-specialties), or family practice (n = 7,432). We mailed surveys to each of the selected physicians between December 2005 and May 2006. We asked the physician to indicate whether they practiced inpatient medicine, and, if so, to select the hospital in which they provide the majority of their inpatient care. To be eligible, physicians had to actively practice in one of the 72 hospitals selected for this study. In the first phase of the study, we found that the overall level of automation was low across sub-domains (figure 4) and that hospitals with higher IT

Figure 5. Distribution of Sub-Domain Scores in Texas Hospitals



From Amarasingham, R BMC Medical Informatics and Decision Making, 2008

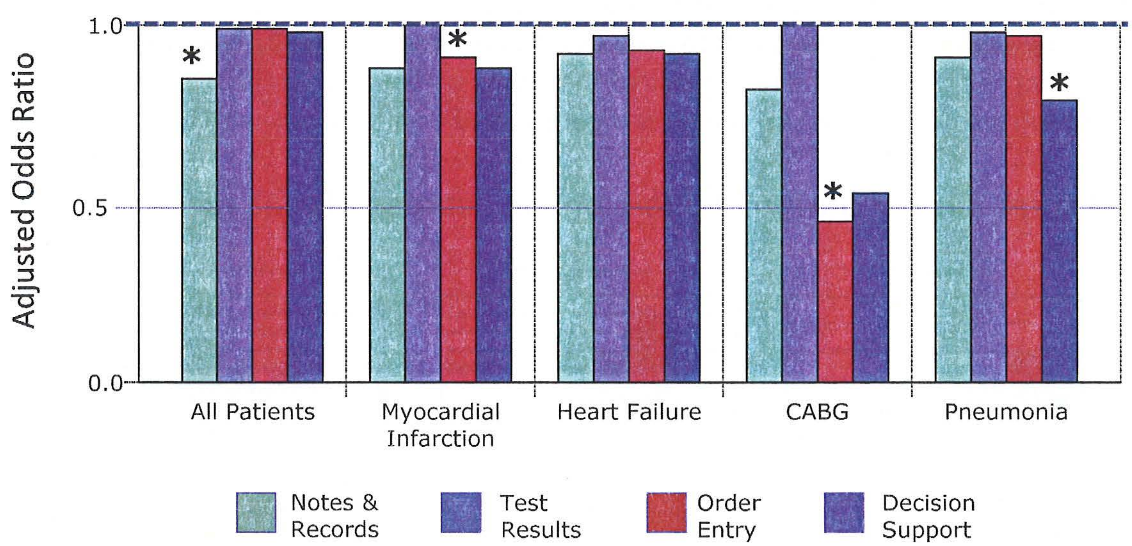
operating expenses (>$1 million annually), IT capital expenses (>$75,000 annually) and hospitals with larger IT staff (> 10 fill-time staff) had higher scores than hospitals that did not meet these criteria.{Amarasingham, 2008 #365} These findings were consistent with other studies on this subject.

In the second phase, we examined inpatient mortality, complications, costs, and LOS among patients older than 50 years who were admitted between December 2005 and May 2006 at any of the 72 study hospitals. Discharge-level data (n=167,233) including information on all four outcomes, were obtained from a hospital claims datafile. For each hospital in our sample, we obtained the ownership status (public, private/non-profit, and private/for-profit), bed size, and total margin. Estimates of the risks of complication and mortality for each hospitalization were obtained from the risk-adjusted complication index (RACI) and risk-adjusted mortality index (RAMI) variables provided in the hospital claims datafile, respectively.

Relationship between Clinical Information Automation and Inpatient Outcomes

Across a variety of clinical conditions, higher CITAT scores were associated with decreased adjusted odds ratios for fatal hospitalizations (figure 5). Higher notes & records scores were associated with a statistically significant decrease in the adjusted odds for inpatient mortality in all-cause hospitalizations (OR=0.85, 95% CI: 0.74, 0.97). Hospitals with higher order entry scores were associated with decreased adjusted odds

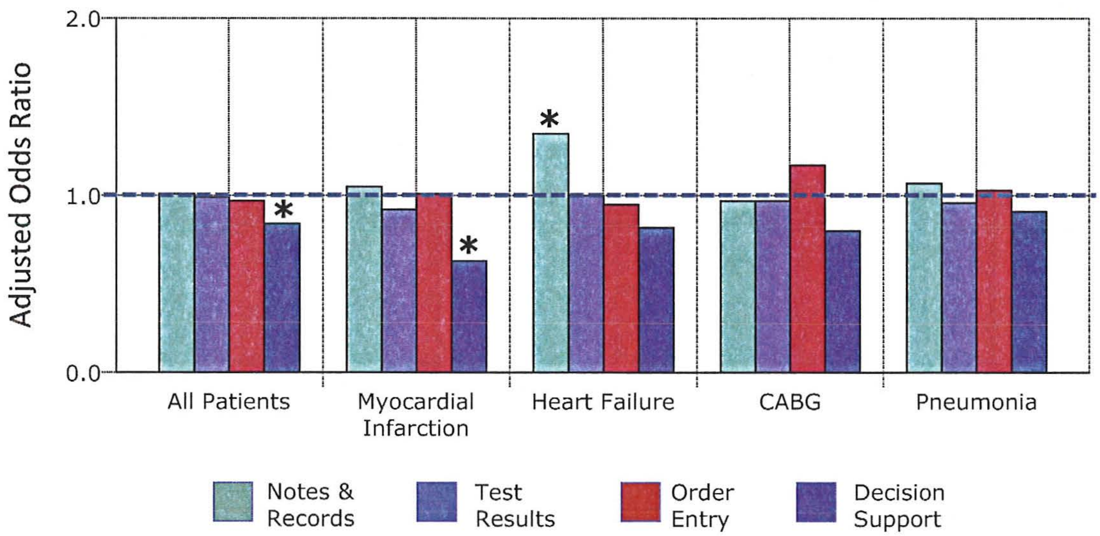
Figure 6. Odds of Inpatient Death and Higher CIT Score



From Amarasingham, R et al., Archives of Internal Medicine, 2009.

for fatal hospitalizations for patients admitted with myocardial infarction (OR=0.91, 95% CI: 0.83, 0.99) and coronary artery bypass graft surgery (OR=0.45, 95% CI: 0.29, 0.68). Higher decision support scores were associated with decreased adjusted odds for mortality due to pneumonia (0.79, 95% CI: 0.63, 1.00). Generally patterns were internally consistent across disease conditions and automation sub-domain regardless of statistical significance. Of the automation sub-domains, a higher decision support score was consistently associated with a decreased adjusted odds for complications (figure 6). These results were statistically significant for all causes (OR=.84, 95% CI: .79-.90) and myocardial infarction (OR=.63, 95% CI: .45-.87). Contrary to this trend, we observed that a higher notes & records score was associated with increased adjusted odds for complications associated with heart failure (OR: 1.35, 95% CI:1.16-1.57). For nearly all clinical conditions, higher scores on decision support, order entry, and test results were associated with lower average hospital costs (figure 7). Higher test results scores were statistically significantly associated with lower adjusted costs for all hospital admissions (- $110, 95% CI: -$181, -$20) and for heart failure (- $207, 95% CI: -$272, -$128). A higher order entry score was associated with statistically significantly lower adjusted costs for all conditions (- $132, 95% CI: -$232, -$13). As with test results and order entry, a higher decision support score was also associated with lower adjusted costs for all conditions (- $538, 95% CI: -$704, -$333) and for CABG (-$1043, 95% CI:-$1729, -$55). No clear pattern emerged in the relationship between CITAT scores and hospital LOS by clinical condition (figure 8). A 10-point increase in score on order entry and decision support was associated with decreased, but not clinically meaningful, lengths of stay for heart failure (OE: -.09 days and DS: -.22 days). In all cases, differences in lengths of stay were modest in either direction.

Figure 7. Odds of Inpatient Complications and Higher CIT Score



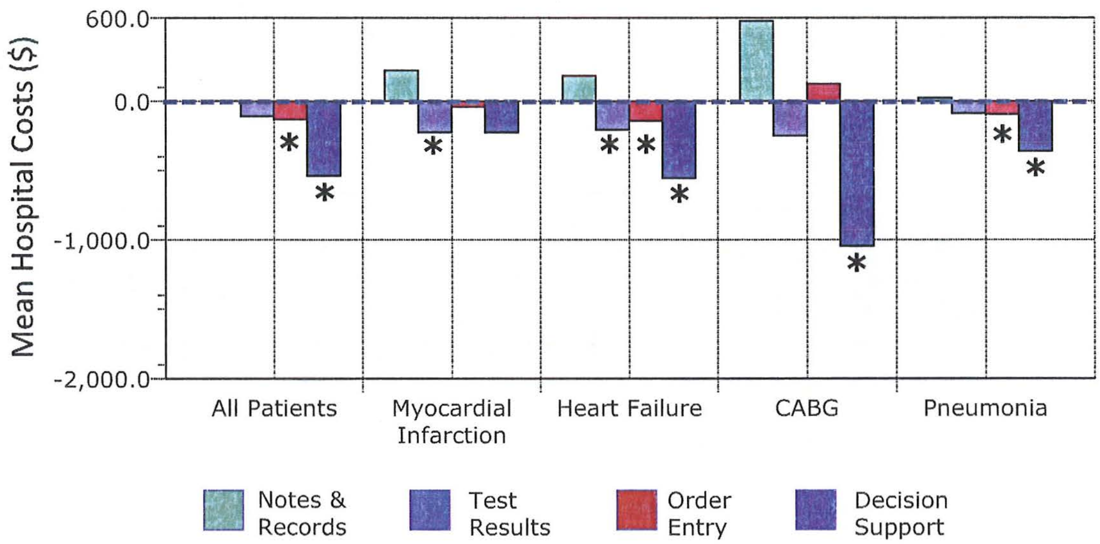
From Amarasingham, R et al., Archives of Internal Medicine, 2009.

Conclusions from the TEXCITE Study

Our study provides empiric evidence that greater automation of a hospital's information system may be associated with reductions in mortality, complications and costs.[44] Higher decision support scores were associated with statistically significant reductions in the odds of complications among all causes and for myocardial infarction specifically, and with reductions in the odds of death for pneumonia. Among the remaining associations that were not statistically significant, all showed trends toward reductions in mortality and complications. Prior reports have suggested that decision support helps clinicians manage large sources of incoming data, provides context for decision making in the light of guidelines, and may help physicians avoid "sins of omission," reputed by some authors to be the largest source of medical errors. [45-49]

Higher order entry scores were associated with reductions in the odds of death for myocardial infarction and coronary artery bypass graft surgery. Prior studies of order entry at single institutions have shown mixed results with respect to mortaliy;[50, 51] nevertheless, salutary effects have been observed for other endpoints including

Figure 8. Hospital Costs and Higher CIT Score



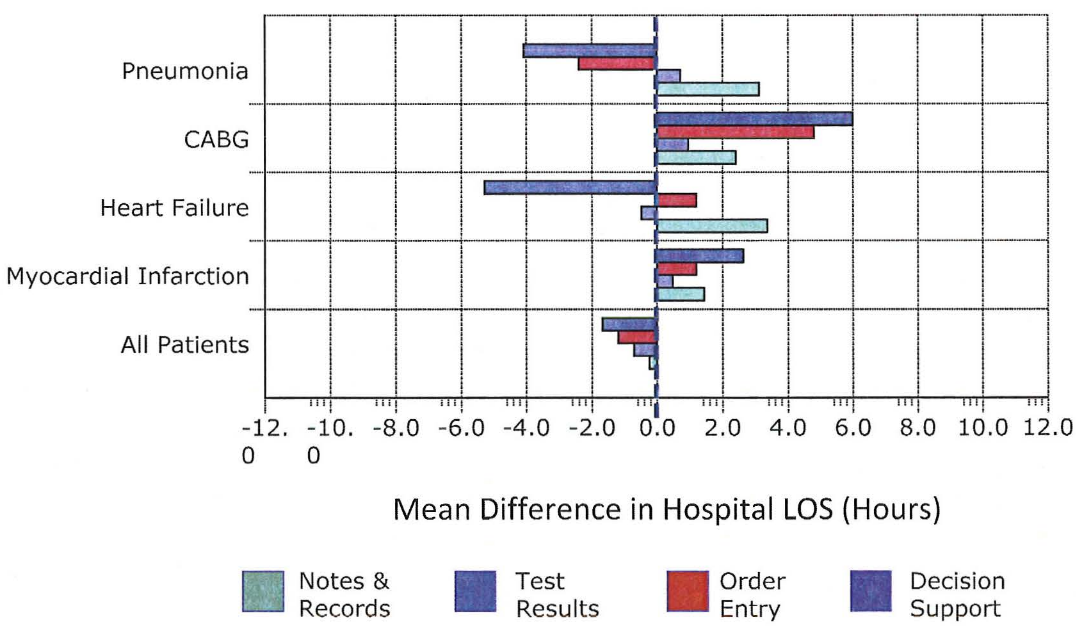
From Amarasingham, R et al., Archives of Internal Medicine, 2009.

reductions in the number of adverse drug events, improved legibility of orders and fewer callbacks to ordering physicians.[52] These factors may mediate the reductions in mortality odds we observe with order entry. Some have suggested that the use of information technologies in the clinical environment possesses certain risks, noted as "e-iatrogenesis."[53] For example, previous studies have raised concerns that problems in information representation within computerized order entry systems can facilitate errors.[54, 55] We found no relationship between the degree to which physicians orders were computerized and the rate of complications. Greater automation of test results was not associated with a lower risk of hospital death or complications. With respect to test results, it may be that a minimal level of automation is sufficient to protect patients. Given that a high proportion of hospitals have already automated test results, this minimal level is likely in place for most institutions.

Our results suggest that the relationship between automated notes & records and outcomes is nuanced but internally consistent. Each 10-point increase in the notes & records score was associated with a 15% reduction in odds of inpatient death for all causes. Hospitals in the highest tertile of the notes & records sub-domain score had a 1.4% adjusted rate of mortality, compared to a 1.9% adjusted rate among hospitals in the lowest tertile. This would suggest that for every 1,000 patients, five fewer patients die among hospitals with the highest notes & records scores. Higher scores on the notes

& record sub-domain were also associated with reduced odds of death for each of the four individual conditions examined in the mortality analysis though none were statistically significant. Smaller studies suggest that electronic documentation allows clinicians faster and more complete access to the patient record, improves communication among providers and enhances the contributions of supervising physicians.[56] In contrast, increases in the notes & records score were associated with statistically significant increases in the odds of complications for heart failure. While this may be concerning, another explanation might be that a higher complication rate simply reflects an improved capability to identify adverse events by way of electronic documentation. A similar mechanism may underlie the relationship between notes & records and costs. The remaining associations tested in the complication analyses retained the direction noted with heart failure, though no others were statistically significant.

Figure 9. Hospital LOS and Higher HIT Score



From Amarasingham, R et al., Archives of Internal Medicine, 2009.

Higher scores on test results, order entry, and decision support were overwhelmingly associated with lower hospital costs. Of the 15 associations tested in these categories, 14 demonstrated an inverse relationship between the IT score and total costs and 10 of these were statistically significant. The associated reduction in costs for some conditions was substantial. Relations are less clear with respect to length of stay and any effect is modest. Because LOS has decreased substantially over the last several decades, in part due to increased scrutiny by payers, this measure may already be so low as to be resistant to the efficiencies introduced by information technology.[57] However, hospitals for which we had responses had shorter lengths of stay on average, than non-responders. It is possible that for hospitals with longer LOS at baseline, the effect of clinical information technologies might be more profound.

Our approach incorporates what some have described as the *socio-technical environment* of the clinical workplace. This view holds that a successful IT implementation jointly optimizes both the technology and the social aspects of an organization (e.g. its policies, values, norms and culture).[58] To properly account for the impact of clinical information technologies in a way that can be replicated, the information technology variable must be measured in the context of the socio-technical environment in which it is implemented. This study measures a hospital's level of automation based on physicians' daily interaction with the information system, avoiding simple terminological definitions that may not account for usage, maturation, and capabilities of the information system. If there is insufficient user training, if the technology itself is unfriendly, or if the physician and organizational routines are not aligned with the technology, the IT score for that hospital will be low, regardless of the cost or scope of the technologic acquisition. This study also includes more hospitals and hospitals of greater organizational variety than prior studies, overcoming criticisms that a small number of specific academic hospitals are overrepresented in examinations of clinical information technology.[23] Finally, our results are congruent with recent studies suggesting that the adoption of clinical information technologies remains low but follows certain patterns.[59, 60] Our findings are consistent with these patterns, lending our methods, and measurement tool, an independent measure of validity. For example, the computerized display of lab results has been among the first aspects to be automated.[60] In the last decade, digitization of radiological images has also increased.[60] Both of these components fall under the test results sub-domain, which in our study showed the greatest degree of adoption. Electronic decision support is perhaps the most challenging component to implement since it requires all other components first. Our results, in which scores for notes & records are higher than order entry and decision support, are consistent with this pattern of adoption.

Conclusions

My personal belief is that hospitals which do not emphasize a culture of safety or encourage continuous improvement are probably incapable of replicating the type of socio-technical environment that would produce a high score in our study and more importantly, a sound return on investment. In this sense, the distinction between whether a hospital's superior outcomes are due to its emphasis on quality or because of its investment in clinical information technologies becomes less meaningful since both are likely required to produce a high-functioning socio-technical environment. Future studies, using mixed or qualitative methods at several representative sites may help clarify these relationships. Our results also indicate that, as disease conditions are unique, the factors resulting in better outcomes for these conditions are themselves unique. Indeed, the lack of statistical significance among certain associations may simply indicate that clinical information technology is not a panacea for all disease conditions.

We found that for certain conditions, greater automation of a hospital's information system may be associated with substantial reductions in mortality, complications and costs, suggesting that information technologies, properly designed and executed around clinical workflows, could meet that promise. If these improvements were realized in hospitals throughout the country, the impact on the U.S. healthcare system could be profound. However, it is likely that even our study does not forecast the full potential of health information technology. There is enormous capacity for what Dr. David Bates has called "third or fourth order benefits" that are likely not yet realized.[61] Electronic capture of health care data will allow the burgeoning use of electronic predictive modeling, natural language processing, electronic coordinating systems, syndromic surveillance, electronically amplified study recruitment, personalized healthcare delivery, and virtually conducted randomized controlled trials. Beyond what we have shown with respect to mortality and complications, the future possibilities brought about by electronic health records will likely be transformative for American medicine.

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