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RESEARCH ARTICLE

Reviewing the Benefits and Costs of Electronic Health Records and Associated Patient Safety Technologies

Nir Menachemi · Robert G. Brooks

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Abstract In the current paper, we describe the challenges in measuring return on investment (ROI) and review published ROI studies on health IT. In addition, given the absence of a robust ROI literature base, we review the general benefits and potential costs of various health IT applications including electronic health records (EHRs), computerized physicians order entry (CPOE) systems, and clinical decision support systems (CDSS). We conclude that articles examining these benefits are much more common than studies examining ROI itself. This trend suggests the early stage of this knowledge base. Additional research utilizing broader perspectives and multidisciplinary techniques will be needed before a better understanding of ROI from health IT is achieved.

Keywords Health information technology · EHR · CPOE · CDSS · Patient safety · Return on investment

Introduction

The combination of increasing costs and other market pressures have contributed to a struggle among US hospitals to stay financially viable. As such, when considering an investment in new technology, expensive acquisition costs force today's healthcare leaders to study the "business case" associated with their purchase [1, 2]. To examine the financial impact, including potential benefits, of new technology, return on investment (ROI) analyses have been gaining popularity in healthcare.

N. Menachemi (✉) · R. Brooks
Division of Health Affairs, Florida State University, Tallahassee, FSU College of Medicine,
1115 W. Call Street, Tallahassee, Florida
e-mail: nir.menachemi@med.fsu.edu

Nevertheless, numerous challenges exist when trying to measure the ROI for health information technology (IT). As a result, a dearth of academic research exists on the topic. In fact, upon review, we have found only a handful of scientifically rigorous assessments of health IT ROI in peer-reviewed academic publications. The lack of availability of such studies may have impeded adoption of health IT, despite the fact that the IOM has recently articulated numerous benefits of IT in improving health outcomes [3]. Therefore, the information presented in the current study will be valuable to healthcare leaders interested in further understanding the benefits and costs of investing in health IT systems.

In this paper, we briefly describe the challenges in measuring ROI and review published ROI studies on health IT. In addition, given the absence of a robust ROI literature base, we review the general benefits and potential costs of various health IT applications including electronic health records (EHRs); computerized physicians order entry (CPOE) systems, and clinical decision support systems (CDSS). Within each section we describe costs categories such as hardware, software, implementation, training, support, and loss in productivity. In addition, we describe benefits of each IT application in categories such as increased revenues (e.g., improved charge capture, improved cash flow), averted costs (e.g., reduced supply and transcription costs, improved utilization of tests, improved productivity), and other less-tangible benefits. In each case we draw heavily on published work to highlight costs and benefits.

Challenges in measuring ROI

Despite the wide-spread availability of financial analytical tools used to conduct ROI analyses, several challenges impede the use of these tools in the study of health IT. For example, the benefits produced by IT are not the same as

benefits produced by other investments. Unlike a traditional medical technology (i.e., MRI or CT scanner) for which services can be billed, use of IT does not necessarily produce an additional direct income stream or a billable service. Instead, most health IT is designed to improve or enable a new process, not necessarily to produce a new billable product or function. This makes measuring its financial impact challenging, particularly when employing traditional methodologies for calculating ROI. For institutionally based administrators, who are used to dealing with "cost centers," the diffuse nature of the benefits of a new health IT system make an accurate ROI more essential—yet more difficult to obtain.

Another challenge beyond measuring direct ROI is the fact that many times the value associated with IT, particularly of improved service and product quality, does not accrue to the investing healthcare organization. Investments by hospitals, for example, in IT may yield benefits to patients or healthcare payers who do not directly pay for these higher quality services. Recently, experts noted that hospitals and other providers get paid the same regardless of the safety or quality of the care they deliver [4]. Furthermore, in many situations, disincentives actually occurs regarding the utilization of IT to improve safety and quality [5]. It has been noted that error-prone inpatient care leads to higher revenues through longer hospital stays and bills for higher paying diagnoses resulting from adverse events [6]. The disincentive is even greater on the outpatient side where approximately 90% of the financial benefits of IT accrues to the payers and purchasers of care [7, 8] despite the fact that physicians most often make the initial capital investment.

Lastly, many of the benefits associated with health IT are difficult to measure because they do not all translate into financial terms. For example, it can be difficult to financially measure improved quality of care or reduction in medical errors from the use of EHR or CPOE systems. Furthermore, actual benefits of many intensive IT installations can only be studied under retrospective observational conditions. Since it can take a significant amount of time to plan, design, and implement a given IT application and installation, the lag for accumulating the necessary data to evaluate costs and benefits makes it difficult to calculate ROI prospectively.

ROI studies of health IT

Even with the above challenges with ROI estimation, researchers have attempted to estimate net financial benefits and costs of implementing EHR systems in the primary care and ambulatory settings [9–11]. For example, Wang *et al.* [9]. performed a cost-benefit analysis over a 5-year period by aggregating data from their installed EHR system, other published studies, and from expert opinion. Their study demonstrated a positive ROI with the primary areas of savings including reductions in drug expenditures, improved utilization of radiology tests, improvement in charge capture, and decreased billing errors.

Similarly, Barlow *et al.* [10] examined the economic effect of implementing a commercial EHR product in a 59-physician outpatient clinic. By examining data prior to, and after, the installation of an EHR system, a positive ROI was realized. Their EHR implementation was associated with direct reductions in spending and increases in revenue during the study period. Specifically they reported a first year savings of almost $1 million directly attributable to the EHR. This savings was realized by reducing transcription expenses by $380,000, improving revenues by $100,000 due to improved coding, savings from eliminating the need to develop new patient charts ($160,000), savings due to lower space requirements ($248,000) and cost avoidance due to no increase in chart room FTEs while patient volume had doubled ($62,000).

Also in the outpatient setting, Cooper [11] published a case study in which he describes the processes, costs and benefits of implementing an EHR in a solo pediatric physician practice. In his report, he compared raw unadjusted data from before the EHR implementation, to data from 6 years later (after EHR implementation). Overall, numerous benefits attributed to the EHR were noted. For example, the practice saw an increase in patient visits without adding new staff. Additionally, the practice was able to increase revenues by 271% which resulted in an increase of physician profit of 102%. Moreover, because of an increase in productivity and efficiency, the practice was able to increase overall patient volume by 83% and the number of patient visits per day by 62%. The practice did increase office hours by 20%, but the additional patient traffic was possible due to the time saved by eliminating chart pulls, decreasing charting time, decreased patient wait time, decreased drug refill time, and decreased telephone call turnaround time. Overall, this anecdotal study does provide some evidence of the benefits of EHR implementation in a solo-private practice physician office environment.

With respect to other healthcare settings, a recent report by the federal government's General Accounting Office (GAO) highlighted a series of case reports that demonstrate evidence of IT benefits. For example, the use of a barcode medication system as part of an EHR in a North Carolina medical center prevented 3209 medication errors and saved nearly $850,000 in 1 year. Furthermore, the use of an EHR system in a large hospital in Pennsylvania reduced transcription costs by 50% and saved $1000 per physician per year due to improved formulary compliance. Additionally, the GAO report included a case review of a New York-based hospital which utilized an integrated EHR/CPOE system in both its inpatient and outpatient settings. The system reportedly reduced adverse drug reactions, cut turnaround time for radiology reports and medication processing, and decreased the average length of

stay by 32% over the 6 year period that it took to complete the installation. In addition, the hospital attributed one quarter of a 38% increase in revenues during the same 6 years directly to the use of the EHR system.

Of particular note, despite the major emphasis in the US on advancing the adoption of IT in the healthcare setting, very little in the way of ROI research as been done to specifically assess hospital-based IT. Recently however, the State of Massachusetts has established a consortium to assess the feasibility of implementing CPOE in all Massachusetts hospitals. The group released a report [12] that suggested that fully implementing CPOE programs in all of their state's acute care hospitals would cost roughly $210 million overall. This investment, they project, would have the potential to generate $275 million in net cost savings annually to the State of Massachusetts' healthcare system, not including the significant improvements to patient safety.

Finally, in another recently published study [13] of the inpatient setting, researchers examined the feasibility and potential financial impact of implementing CPOE systems in all hospitals of a rural state. Using IT and financial data for Iowa hospitals, they worked with vendors to estimate the costs necessary to implement CPOE in all hospitals in their state. They then constructed a simulation model using the estimates of initial and ongoing CPOE costs mapped to Iowa hospitals based on size and location. They concluded that CPOE implementation would substantially increase operating costs, especially for rural and critical access hospitals, but suggested that the cost savings and revenue enhancement would offset CPOE costs particularly in the larger hospitals.

Costs and benefits of patient safety related IT

Although numerous health IT applications exist, a select number of them have received the most attention in the media and the literature because of their promise to improve patient safety. These applications include EHRs, CPOE systems, and CDSS. In the absence of sufficient ROI research, the following section describes the costs categories and potential benefits for these applications.

Electronic health records (EHRs)

EHRs are a paperless form of the medical record that requires the healthcare provider to enter patient information into a computer system instead of doing so on paper. In comprehensive EHR systems, there are interfaces with computer systems in the laboratory, radiology department, pharmacy, and billing departments. Providers receive clinical and test result data from these other systems directly into the EHR. These and other features help streamline the billing processes. The EHR is also known by various other names and acronyms including electronic medical record (EMR), electronic patient record (EPR), and computerized patient record (CPR), among others. In this report, we use the term EHR to represent any such technology.

EHR costs

Many factors contribute to the cost of implementing an EHR system. The existing IT infrastructure, including the degree to which current disparate hospital information systems are already integrated, contribute to the cost of upgrading to an EHR platform. Additionally, the size of an organization and the number of capable IT staff available to assist the vendor in implementation, customization, and user training can influence the cost of an upgrade. Lastly, the computer adeptness of current providers and staff, and the strategic commitment of an organization to IT can influence the allocation of resources necessary to implement a new EHR.

Various experts have commented on the costs of EHR implementation. For example, researchers estimated a total project cost of approximately $19 million for a 7-year long EHR installation in a 280-bed acute care hospital with 16 satellite clinics, a research institute, and a network of about 400 employed physicians [14]. In the ambulatory setting, estimates for the initial costs of implementing an EHR are $50–$70 K for a three-physician office [15]. Other estimates from the ambulatory setting average $10–$20 K per provider for an EHR installation [16]. However, very low cost "mini" EHR systems are also available that may provide some of the benefits of EHR [17]. Overall, the specific and general cost categories for a typical EHR implementation include the following:

- *Hardware*: EHR installation typically requires numerous pieces of interconnected hardware. This includes computer terminals, servers, network hardware, printers, scanners, and other related hardware.
- *Software*: This category includes the costs of designing and developing the EHR software and tailoring it to an organization so that it can interface with other existing systems such as registration, scheduling, pharmacy, laboratory, etc. Software costs are typically priced on a per-provider basis and have been estimated at $2500–$3500 per provider for the initial software purchase [9].
- *Implementation*: costs related to this category include workflow process redesign, initial training of IT personnel, and conversion of historical paper chart information into electronic data usable by the EHR. This later task can be particularly expensive for older institutions or those with large numbers of patient encounters.
- *Training and support*: The introduction of a new system will require both initial and on-going training of end-users. Training costs will include staff support needed to train

users on the new software system at the time following installation and also during an intensive learning period that follows. Support costs will include maintenance costs of the hardware, updates to the software, and on-going long-term technical support for users.

- *Temporary reduction in staff productivity*: As end-users learn a new system, a temporary reduction in productivity can be expected. One estimate of the expected productivity loss is 20% in the first month, 10% in the second month, and 5% in the third month, with productivity returning to baseline levels subsequently [9]. This temporary loss of productivity can also be expected in the outpatient setting [15]. Research has suggested that the extra time it takes physicians to learn how to use EHRs effectively can be a significant barrier to its use [18].

EHR's benefits

A review of the literature suggests that most of the benefits from using EHRs fall under one of the following categories; increased revenues, averted costs, or other less-tangible benefits. The following discussion of benefits are organized by these types of benefits.

Increased revenues can also be realized when implementing an EHR. The following is a discussion of the potential increased revenue opportunities related to EHR implementation.

- *Improved charge capture/decrease in billing errors*: EHR systems help assure accurate and timely capture of charges for medications, medical supplies, and clinical services. They also provide documentation of actual administration of medications and services thus improving charge capture [14, 19]. According to some experts [20, 21] inaccurate coding results in a loss of 3–15% of total potential revenues for healthcare providers.
- *Improved cash flow*: Revenue enhancements can be realized from EHR systems when improved charge capture and billing result in a reduction of outstanding days in accounts receivable and the reduction of lost or disallowable charges are billed for [15, 19].
- *Enhanced revenue*: EHR systems can be configured to generate reminders to both patients and clinicians when health maintenance visits are due. This can aid in modifying patient flows under varying reimbursement arrangements and enhance revenues [20].

Averted costs are realized when an IT intervention restructures workflows in such a way that some costs associated with the previous way of conducting business are eliminated, reduced, or replaced at a lower level. The following are benefits of EHR that can result in averted costs.

- *Reduced supply and printing costs*: The cost of creating and maintaining medical records which includes clerical supplies, cost of paper, and printing costs are reduced when using EHRs [22]. One organization estimated a 90% reduction in the paper backlog within a few months of implementing an EHR [23].
- *Improved utilization of tests*: The use of an EHR has eliminated the need for healthcare staff to send hard copies of test results to physicians for review before adding the information to the patient's chart [23]. This reduced lost and redundant information and assured a result is posted to the medical record as soon as it becomes available. Additionally, Wang *et al* [9] report improved utilization of radiology results from EHR use.
- *Reduced transcription costs*: EHR use can result in reduced medical transcription costs by utilizing structured flow sheets, clinical note templates, and point-of-care documentation [15]. Research suggests that a typical outpatient physician encounter generates about 40 lines of transcription. A typical three-physician practice sees about 12,000 annual patient visits and cost estimates of transcribing information is approximately $0.11 per line [15] resulting in over $50,000 in expenses. Other researchers have estimated the savings from transcription costs to be $300–$1000 per month, per physician [20]. Therefore, depending on the medical setting implementing an EHR, transcription costs saved can be substantial.
- *Improved productivity*: EHR often improves workflows by reducing redundancies and improving resource utilization [21]. As a result, individuals become more productive when they do not have to postpone their own tasks while waiting for others to finish theirs [24]. Overall, by improving resource utilization and minimizing duplication of efforts, an improvement in productivity and reduction in costs can be expected [15].
- *Better availability of information and elimination of chart pulls*: EHR use eliminates the need to pull, route, and refile paper charts [15]. Considerable effort is typically spent creating, filing, searching for, and transporting charts [14]. By eliminating the need to do so, one study estimated a savings of approximately $5 per chart pull at their institution [9]. Other benefits of eliminating chart pulls are related to avoiding providers frustrations associated with not being able to access a patient chart when needed [22].
- *Reduced cost for recruitment through improved clinician satisfaction*: EHR technology can reduce providers' paperwork burden creating additional time during the patient encounter to deliver care [23, 25]. Specifically, one study demonstrated that the use of EHR reduced office visit times by 13% for physicians and 1 min for each pre-exam interview for nurses [26]. This time savings can increase provider satisfaction with their daily work routine [21]. In turn, increased satisfaction can reduce turnover which is a growing and increasingly expensive problem in health care, particularly for nursing [27] and health system phar-

macists [28]. Moreover, evidence suggests that EHR use can improve medical staff relations by increasing physicians' workflow efficiency and satisfying the information needs of practicing clinicians [29].

Many additional benefits exist that can be realized by utilization of an EHR. However, these additional benefits are difficult to financially quantify. A discussion of these *less-tangible benefits* follows.

- *Improved quality*: EHR systems have the potential to improve quality of care, particularly when they are coupled with imbedded features such as CPOE and CDSS [15]. Research indicates that EHR is linked to improved outcomes including better infection control [30], improved prescribing practices [31] and improved disease management [21] in hospitals. In the outpatient setting, improvements in quality are also possible. For example, Cooper [11] improved practice immunization rates and quality review scores in a private pediatric solo practice with EHR use. Lastly, EHR systems may help clinicians score better under pay for performance incentive arrangements.
- *Improved patient safety*: Similar to improvements in quality, EHR can specifically result in improved patient safety. For example, an EHR that utilizes CPOE can achieve a reduction in medication errors in hospitals [32] and help clinicians identify root causes of adverse events in hospitals and outpatient settings after they occur [33]. Moreover, EHR can enable providers to rapidly identify and notify individual patients about important changes in drug therapy such as those related to the recent Vioxx withdrawal [34].
- *Improved patient education*: Certain features of an EHR can simplify patient education [21]. For example, EHR products can be used as tools for the provider to illustrate or explain procedures or conditions to patients, and handouts can be printed directly from the system [20].
- *Improved coordination of care*: The EHR allows all clinicians on a healthcare team to document their care and to access relevant and timely information about their patients. This fosters an improved level of communication and can facilitate improved coordination of care overall [35], and specifically for chronic care management [36, 37]. Additionally, the email feature built into many EHRs can result in improved communication by allowing staff the ability to message each other from any workstation [21]. The built-in email feature also allows for real-time communication regarding shared responsibly among clinicians. This provides the ability to simultaneously accomplish tasks and may yield significant time savings [11].
- *Improved legal and regulatory compliance*: The use of an EHR allows for increased security of data and enhanced patient confidentiality through controlled and auditable provider access. These features allow for easier compliance with most state and Federal regulations, including HIPAA, for record keeping and reporting [15]. Moreover, such systems can also assist in regulatory and accreditation reporting (e.g., CMS, JCAHO) by providing much of the required information through analysis of existing patient data sets [38].
- *Improved ability to conduct research*: Electronically available data for EHR systems will allow for improved ability to quantitatively analyze trends and identify evidence-based best practices more easily. Data from EHRs could be de-identified and integrated into larger data repositories where research can be conducted to improve patient safety, medical knowledge, and public health [39].
- *Improved business relationships*: EHR can put hospitals in a better bargaining position with insurers and payers compared with less-wired hospitals. Further, EHRs can enhance patient satisfaction by reducing waiting times [40]. Similarly, more timely practice patterns increase providers' job satisfaction as noted above.

Computerized physician order entry

CPOE is a technology that allows physicians to enter orders into a computer instead of handwriting them. By computerizing the order process, structure and control are introduced. In the case of medication ordering, an electronic system forces the indication of a precise dose, route, and frequency. The system can also eliminate the problem of illegible handwriting, incomplete or lost information, and makes every prescription traceable to the provider. These systems can also provide the latest information about a drug and cross reference allergies, interactions and other problems of a patient with the chemical entity being prescribed [41].

Drug errors are common medical mistakes that cause the death of one person every day in the United States and injure more than a million people each year [42–44]. Drug errors can occur in the process of prescribing, transcribing, dispensing, administering, or monitoring medication and may lead to adverse drug events. In addition, the estimated costs related to adverse drug events (due to counteractive therapy, increased lengths of stay, etc.) has been found to be $2500–$4500 per inpatient event [45]. Moreover, the average claim related to liability for an adverse drug related event is estimated to be between $376,000 [46] and $668,000 [40]. As such, CPOE is particularly well suited to prevent medication related errors and prevent financial losses associated with these events.

Costs of CPOE

Similar to EHRs, the costs of CPOE can vary widely for a given institution. Typically, costs include technical develop-

ment, process redesign, implementation and support costs [47]. Technical costs include hardware, software, and integration with existing systems. A robust IT infrastructure is typically required to support CPOE so start-up costs often include overall network upgrades. In the absence of a need for major network upgrades, CPOE cost estimates for a 500 bed hospital are approximately $8 million with an annual maintenance cost of $1.35 million [48]. Purchasing commercial CPOE systems is generally more expensive than developing such a system internally [49]. Wireless capabilities for the system will add additional costs. Smaller hospitals, however, with existing integrated systems may experience lower costs [47]. Lastly, an existing organizational culture characterized by collaboration and trust and an ongoing process that includes active clinician engagement in adaptation of the technology can substantially improve a CPOE installation and potentially lower its overall costs [50]. Specific costs of a CPOE system may include:

- *Hardware*: This set of costs includes servers, desktop and wireless handheld computers, printers, and a general upgrade to the organization's IT infrastructure, as needed.
- *Software*: The software license fee represents a small part of the total cost of a CPOE project [48, 51].
- *Implementation*: Costs in this category include physical installation of the relevant components, process redesigns, and process improvements [47]. When implementing a CPOE system, existing workflows need to be reworked in a straightforward manner to efficiently interface with the new system. This process should heavily involve end-users.
- *Support*: Clinicians need to be trained before implementation. After implementation, several hours of support on the system will be necessary as well [47]. Additional ongoing support will also be necessary, particularly for several weeks after an installation. In one hospital, one support person was available per shift for every 30 acute-care beds and every 10 intensive care beds [52].

Benefits of CPOE

The benefits of this technology are listed below. Each description is accompanied by evidence from the research literature. Additionally, a recent report [8] has examined the benefits to the United States healthcare system overall that can be expected from widespread adoption of CPOE in the ambulatory setting. Even with the benefits noted below, recent literature documents the obstacles associated with CPOE implementation and use [53].

- *Medical error reduction*: CPOE yields accurate, legible, timely orders that have been checked for errors. Even the simplest systems have demonstrated significant reductions in medical errors [52]. Research suggest that a 55% reduction in serious medication errors is possible when using a CPOE [32]. Additional evidence exists that suggests CPOE has the ability to reduce medication errors in pediatric inpatients as well [54]. Moreover, when more complex systems are utilized, a synergistic effect between ordering process and decision support systems can be realized. When CPOE was linked to decision support, a reduction in serious medical errors by as much as 83% was achieved [55]. With adverse drug events costing an average of $2500–$4500 per inpatient occurrence [45], and occurring in as many as 10% of admissions [56], the ability of CPOE to avoid such costs is substantial.
- *Drug interaction checking*: CPOE allows interaction checking which usually involves drug–drug, drug–allergy, or drug–food interactions. However, the most effective interaction checking depends, to a large extent, on obtaining information regarding the patients' drug history, allergies, and other clinical information that often is not available electronically unless an EHR system is integrated [57].
- *Improved compliance with formularies and dosing guidelines*: Many CPOE systems provide formulary information viewing. Formulary viewing allows physicians to choose medications that are covered by an insurer or pharmacy benefits manager [57]. Studies have demonstrated that CPOE can improve compliance with formulary and drug guidelines [31, 58]. Improved formulary compliance and better adherence to drug guidelines can result in drug expenditure savings [15].
- *Improved charge capture*: CPOE systems improve the accuracy of charge capture, which should result in streamlined billing (and payment), as well as preemption of billing disputes and government scrutiny. Plus, CPOE offers more efficient inventory and supply chain management [59]. In one randomized control study of CPOE usage, charges in the intervention group were 12% higher and captured more accurately than in the control group [60].
- *Improved workflows and productivity*: CPOE serves to transform business and clinical processes, accelerate transactions, and streamline interactions. Evidence suggests that CPOE can yield significant decreases in turnaround times and process improvements [61]. In addition, these improved efficiencies may result in improved employee moral and retention [59].
- *Standardization of ordering process and decreased redundancy*: A CPOE system, in its most basic form, standardizes the ordering process by forcing the indication of a precise dose, route, and frequency. Additionally, CPOE systems eliminate lost orders and illegible handwriting, monitor for duplicate orders, and can generate related orders automatically [39].
- *Ability to customize the ordering process to individual physician needs*: A CPOE system can be specifically tai-

lored to the prescribing needs of a given physician [62]. By doing so, improved ordering times and satisfaction with the system is possible.

- *Community image and good will*: Experts suggest that early adopters of CPOE benefit from a public relations improvement by taking a high-profile approach to patient safety. The marketing notion of providing the highest quality of care using cutting edge technology may provide a competitive advantage to organizations and attract increased patient volumes [38, 59].
- *Improved satisfaction among patients and clinicians*: Because CPOE can streamline processes, reduce medical errors, and decrease the needed time for administrative tasks, physicians report positive satisfaction with use of such systems [63, 64].
- *Reduction of paper and paper based processes*: CPOE helps reduce the amount of money spent on preprinted forms and may eliminate the need for paper-based processes [62].
- *Improved reimbursement rates*: The Leapfrog Group—a consortium of "Business Roundtable" companies and health purchasers who provide medical benefits to more than 20 million Americans— intends to provide higher reimbursement rates for organizations that implement CPOE (www.leapfroggroup.org).

Clinical decision support systems

CDSS is defined as any software package designed to directly aid in clinical decision making in which characteristics of individual patients are matched to a computerized knowledge base for the purpose of generating patient-specific diagnostic assessments or care recommendations [65]. Many different CDSS applications exist and include, but are not limited to, drug alerts, rule-based alerts, reminders, clinical guidelines and pathways, clinician work lists, and systems designed to improve chronic disease management [39]. In the most advanced configurations, CDSS include additional functionality such as ad hoc querying, diagnostic assurance, a7nd therapy critiquing [66]. But at a minimum, CDSSs work by synthesizing and integrating patient-specific information, performing complex evaluations, linking to evidence-based practice guidelines, and presenting results to clinicians in a timely fashion. Theoretically, these benefits can improve diagnostic and treatment regimen decision making.

Costs of CDSS

CDSS are available for many different applications. For example, a CDSS can be as simple as a small software program that checks drug dosing on a CPOE, or something as elaborate as an automated alerts generator for clinicians. This latter application involves complex algorithms that comb through clinical data (e.g., lab results) to find abnormal values. Once an abnormal value is detected, the system automatically generates a message alerting the clinician of this finding [67]. The automated message can be in the form of an email, voicemail, system message, or pager alert. The idea of the alert is to get the pertinent information to the clinician as soon as it is discovered so that an intervention can occur immediately if needed.

These two examples of CDSS highlight the potential variability in scope, functionality, and type of available systems. As such, quantifying or generalizing potential costs for this category of IT applications has proven to be difficult. Therefore, the following section will focus specifically on potential benefits of such systems.

Benefits of CDSS

- *Reduction of length of stay (LOS)*: Numerous types of CDSS have been linked to a reduction of LOS. Clinical pathways, for example, ensure patients are given treatment regimens that are more likely to get them well quickly [29]. Even fractional reductions in LOS can create sizeable financial benefits through both the reduction of cost per case as well as an increase in hospital capacity [68]. Moreover, a CDSS involving a computer generated informational message directed at physicians was able to result in a slightly earlier discharge from the hospital for patients [69].
- *Decreased drug costs*: When CDSS is used in conjunction with CPOE, clinicians have better access to evidence-based care studies and can act accordingly to reduce prescription costs. A recent study found that the average cost per new prescription dropped about $4.16, and the average cost of a new or refilled prescription was $4.99 lower when CDSS was used [70]. These researchers estimated that 6-month savings from new prescriptions and refill were about $3450 per clinician.
- *Improved preventive care*: Two meta-analyses of the benefits of clinical reminders found that CDSS can improve clinician's use of blood pressure assessment, vaccinations, Papanicolaou tests, and other preventive care tests [65] as well as breast cancer screening, and colorectal cancer screenings [69].
- *Improved drug administration*: CDSS can improve the process of ordering medications by checking for appropriate doses and for interactions with allergies, other drugs, diet, or contraindications. For example, researchers [71] programmed a hospital information system to generate alerts in clinical situations with increased risk for adverse events. Their results indicated that out of the 1116 system notifications of potential errors to prescribing physicians, 596

(53%) changed their prescription to reflect the changes suggested by the system [71]. They further reported that of these 596 alerts, almost half (44%) were not recognized by the physician at the time of care.

- *Decreased medication errors*: In a system where CDSS was used in conjunction with a CPOE, researchers demonstrated an 83% reduction in serious medication errors at an academic medical center [32, 55].
- *Decreased time needed for ordering appropriate treatment*: Researchers have used a computer system to detect critical conditions and automatically notify the responsible physician via the hospital's paging system. They found that a CDSS reduced the time until an appropriate treatment was ordered for patients who had critical laboratory results [47].

Summary and conclusion

The current paper reviewed the ROI literature for health IT and described the categories of costs and benefits that are associated with popular patient safety-related IT applications. Studies examining the benefits of health IT are much more common than studies examining ROI itself. Although a few rigorous ROI studies have been conducted, they have been limited to a few settings, or to several individual IT applications. Additionally, many of the ROI studies found in the peer-reviewed literature have been case studies. These trends are indicative of the challenges in scientifically measuring many of the costs and benefits of health IT applications, and suggest the early stage of this knowledge base. Additional research utilizing broader perspectives and multidisciplinary techniques will be needed before a better understanding of ROI from health IT is achieved.

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