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Electronic Health Record Systems Investment Valuation:

A System Dynamics Approach

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ABSTRACT

Implementing Electronic Health Record (EHR) systems is on the agenda for most of the healthcare organizations in the next few years. Decision makers need to do a cost-benefit analysis to value EHR investments. The major question for decision makers is what the benefits of such systems are. We propose the use of System Dynamics (SD) to measure the benefits of EHR systems. A System dynamics approach as a predictive tool maps complex relationships among the healthcare processes into a model by which one can dynamically measure the effect of any changes in the parameters over time. The System dynamics model’s objective is to analyze the impact of EHRs in a healthcare setting during and after its implementation. Simulation of EHR implementations using system dynamics model produces useful data on the benefits of EHRs that are hard to obtain through empirical data collection methods. The results of an SD model then can be transformed into economic values to estimate financial indices.

Keywords: Electronic Health Record, System Dynamics, Cost Benefit Analysis, Simulation

INTRODUCTION

Healthcare organizations are to utilize Electronic Health Record (EHR) technology in the next few years. In order to employ Information Technology (IT) in the health sector, hospitals need to evaluate such an investment. Many shortages in healthcare systems are due to inaccessible data, information, and knowledge. Knowledge management and information systems have to be utilized in many healthcare organizations, but the managers have to guarantee that such an investment is financially justifiable. A recent study by Menachemi et al. (2006) shows a positive relationship between IT adoption and financial performance in hospitals. They employ a macro level approach to study the link between IT and hospitals performances. Their results indicate that the adoption of IT applications in administrative, clinical, and strategic areas in hospitals improves the financial indices such as ROA, cash flow ratio, operating margin, and total margin. Effectiveness in organizations is another aspect of improvements made by IT. Information Technology assets could be utilized in strategic places in healthcare organizations to improve decision making processes (Forgionne and Kohli, 1996). Quantifying tangible and intangible benefits of IT in clinical and decision making processes is a difficult task. We propose to use a system dynamics technique to estimate EHR benefits through a simulation. The results of the SD model then can be transformed into economic values to estimate financial indices.

Information Technology investments have a lot of uncertainties on their outcome and thus it is hard to evaluate them at the beginning. IT investment payoffs will be achieved over time. IT benefits usually go back to both profitability and quality in an organization. An example of the former is when an IT investment leads to speeding up the tasks and thus reducing work forces. An example of the latter is when an IT investment decreases the errors in task processing and thus increases the accuracy of task results (Devaraj and Kohli, 2000).

IT budget counts for 2.5 to 3 percent of operating budget in the worldwide healthcare spending and IT capital claims 15 to 30 percent of all capital (Greenwalt and Riney 2007, Glaser 2003). Spending in an IT project reduces the amount of funding available for investing opportunities in other areas such as biomedical equipment, or a building to support the growth of clinical services. These opportunities are proved to be profitable with less uncertainty, thus finding an optimal portfolio of IT investments and other investments in healthcare organizations is a challenging and difficult task. Evaluating and justifying different IT investment proposals are complex challenges within healthcare systems (Glaser 2003, Greenwalt and Riney 2007). Healthcare managers need to decide on IT asset investments as opposed to investing in some other technologies, such as biomedical equipments which have immediate results such as more patients, and more physicians’ satisfactions in the healthcare systems. Indeed, managing IT investment is just as important as managing other investments within the healthcare system.

Information Technology has been utilized in healthcare organizations far less than the average IT applications in other industries in service and manufacturing sectors. One of the reasons that healthcare organizations have not adopted IT as much is the failure of the existing systems (Burke et al., 2002). This might be because of the design of the system, or a new IT might not be appropriate for a setting, or it might not be adapted within an organization by the users. Failure of existing systems might also have some financial roots. IT asset investment valuation could help healthcare managers adjust the financial expectations on IT investments before designing and implementing any new IT project.
Administrative IT systems which deal with billing, data processing, and other administrative issues have been utilized in hospitals for quite some time (Anderson, 1997). On the other hand, clinical information systems such as Electronic Health Record have not been used extensively in healthcare systems. President Bush, in April 2004, invited the healthcare industry for a widespread use of EHR by 2014 (White House report, 2004). Healthcare centers are to implement EHR by 2014. However, by the summer 2006 only about 25% of physicians reported that they are fully or partially using EHR. There are many different aspects of EHR implementation, such as choosing appropriate technology, project management, the case of quality, and return on investment which all should be studied to understand the barriers that keep EHR adoption rate low (HIMSS, 2007). One can divide EHRs adoption barriers into two categories. One category includes behavioral issues that are related to physicians and medical staff information technology acceptance attitude (Ilie, 2005; Walter and Lopez, 2008). On the other hand, financial barriers are also a major factor in IT adoption in any organization and, in particular, in healthcare. In this research, we look into the issues with EHRs benefit realizations and return on investment.

The Healthcare Information and Management Systems Society (HIMSS) defines EHR as “a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting. Included in this information are patient demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data and radiology reports.” EHR is to automate clinicians’ workflow as well as to serve as an evidence-based decision support system. Studies on EHR show that implementation of such systems improves safety, quality, and efficiency in health care systems (Hillestad et al., 2005). In particular, the key impact of EHRs has been in improving adverse drug event and increasing physician’s efficiency (Poissant et al., 2005).

Adoption of EHR technologies requires considerable investments in technologies as well as training and changing management. Such investments have to be evaluated systematically. System dynamics has been extensively used as a quantitative technique in order to measure the changes made in healthcare processes (McDaniel and Driebe 2001, McDonnel 2004). In this paper, we propose to use a system dynamics technique to estimate and measure the benefits of an EHR system. A system dynamics technique helps managers quantify EHR benefits in order to justify their IT budget and predict the return on investment on the current IT projects.

**EHR SYSTEM DYNAMICS MODEL**

The objective of the System Dynamics (SD) is to analyze the impact of EHRs in a healthcare setting during and after its implementation. The SD model allows us to map the impact of the new investment on all business processes, and to identify and quantify the benefits of such an investment in an organization. Simulating the SD model leads to producing the data needed to estimate the variability of the benefits/payoffs of such an investment. EHRs bring significant changes to healthcare organizations that are large and complex. The change rate and the amount of EHR benefits could vary depending on different contexts. For example, the availability of resources in healthcare organizations is a factor that influences the rate of change and benefits received from an EHR. An SD model captures the variability of the context of an EHR dynamically. A System dynamics approach as a predictive tool maps complex relationships among the healthcare processes into a model by which one can dynamically measure the effect of any changes in the parameters over time. The result of an SD model then can be transformed to economic values to estimate financial indices.

We choose to have SD modeling for this problem for a couple of reasons. Firstly, it is difficult to collect financial data such as the extra revenue caused by EHRs from hospitals. Therefore, simulation is one way to produce data needed when lack of existing and historical data on the performance of an IT is an issue. Secondly, an EHR, similar to many other IT systems, influences different processes in a healthcare setting. System dynamics has been introduced to map out the integration of IT systems into the organizations. Our system dynamics model analyzes the impact of EHRs in a healthcare setting during and after its implementation and estimates these financial data through simulation. For example, SD model can capture some EHRs’ tangible benefits in ‘online patient charts’, ‘electronic prescribing’, ‘laboratory order entry’, ‘radiology order entry’, and ‘electronic charge capture’ (Wang et al., 2003).
**Research Question**

This study proposes a system dynamics simulation model in order to quantify and measure EHR benefits. The question is how tangible and intangible benefits of EHRs improve the health care processes. EHR benefits realization and translating them into economic values are the major challenge for decision makers in order to justify their investments on this technology. Decision makers in healthcare settings need to identify EHRs impact on their business processes and ensure such effects are so significant that spending a lot on such investments is strategically to the benefit of their organizations.

Our system dynamics model helps managers to measure the performance of health care processes that are integrated with EHR systems.

**Research Method**

System dynamics has been used extensively in the area of information technology which usually changes an organization's business processes and behavior. Using system dynamics, possible changes in organizations are projected and analyzed through conceptual models and simulations (Sterman, 2000; Gregoriades and Karakostas, 2004; Céline, 2005). The SD technique also has been used in evaluating IT investments: Marquez and Blanchar (2006) developed a system dynamics model to analyze a variety of investment strategies in a high tech company. Their simulation allows them to analyze strategies and trade-offs that are hard to investigate in real cases. A system dynamics model can capture IT benefits that are sometimes nonlinear and achieved over years (Dardan and Busch, 2006).

Using an SD model, we need to draw causal loop diagrams for all processes that lead to some benefits. This is a quantitative step in which conceptual model of the processes, variables, and relationships are identified. This causal loop diagrams are then transformed into mathematical equations that represent the relations among variables in the causal loops. The equations and Stock-and-Flow diagrams are used then to simulate different practical and theoretical scenarios.

In the next section, we look into how EHR affects two processes of Electronic note and Electronic prescribing, as two common processes in hospitals.

**Causal loop**

Electronic note (E-note) and Electronic prescribing (E-Rx), as two common processes in EHRs, contribute to having lower number of staff and higher patients’ safety. Figure 1 shows the causal loop diagram for two processes of Electronic note and Electronic prescribing. The sign of each arrow shows the direction of change between each two elements. A positive relation means both elements change in the same direction but a negative relationship means the elements change in opposite directions. For instance, the positive link from E-note to patient’s safety (Figure 1) indicates that implementing E-note increases patients’ safety. Using e-note allows physicians to have access to the most up-to-date version of treatment progress notes that leads to lower number of errors and consequently higher patient’s safety. On the other hand, the negative link from E-note to staff/nurse means that implementing E-note decreases the staff hour needed. Paper notes had to be stored and retrieved by some staff and implementing E-note leads to automating the processes and reducing the number of steps in the processes and thus it lowers the staff hour needed (Mohr and Freguson, 2005).

Electronic prescribing mapped in Figure 1 also shows some impact on the patients’ safety and reduction of staff. When a physician uses an EHR order entry, the system automatically reviews the patients’ history of prescriptions and checks for allergies and drug interactions. The decision system also gives automatic alerts related to the order entry. All of these lead to having better patient safety in the treatment system.

The next element affected by E-Rx is Adverse Drug Events (ADE) that is the largest part of adverse events in the hospitals. Moreover, most of ADEs are caused by physicians and nurses. Improving the ordering process by an automated system and alerting potential risks of drugs in EHRs decrease the rate of ADEs significantly. Electronic prescribing also reduces the number of steps in order entry process and consequently reduces the number of staff needed.

The causal loop diagram shows different benefits of EHRs such as lower rate of ADEs, lower staff hour, and higher patient’s safety. These relationships and effects can be translated to mathematical equations for simulation purposes.
E-note and E-prescribing processes are implemented over time. Based on the case studies done on EHRs, we consider a lifecycle of 7 years in order to completely implement an EHR system. Generally in a comprehensive model for a hospital, we can map all the complex processes, such as radiology and laboratory order entry, within an EHR system in order to understand the causal relationships among processes and entities in the workflows. For instance, a reduction in the number of staff might be caused by E-note, E-Rx, or any other processes. Having all the parameters in the SD model, e.g., the rate of staff reduction by every process, we can interpret the economic value of improvements led by EHRs throughout all possible processes. In the next section, we show how one can simulate causal loops to quantify EHRs benefits.

**Example case**

We look at the changes in staff hour led by E-note and E-Rx (Figures 1 and 2). Lower number of staff caused by EHRs leads to more revenue in hospitals. We simulate these two processes for 10 different hospitals and calculate the extra revenue as returns by EHRs. We also discuss the formulation and Stock and Flow diagram of E-note and E-Rx processes and show the simulation result for 10 virtual clinics that are equipped to EHRs.
Notations and Formulations

Formula 1 is the main equation representing the relationships in Figure 2. This equation shows that the staff hour is reduced by improvements via E-note and E-Rx. Erx reduces staff hour by improving ADEs rate (formula 2). Enote also reduces staff hour by decreasing error rates in the process (formula 3). Here are the equations derived from the current causal loop diagram (Figure 2) and stock and flow diagram (Figure 3) (parameters are highlighted in the equations).

\[
\text{Staff-hour (t+1)} = \text{Staff-hour (t)} - \text{Erx_reduce_hour(t)} - \text{Enote_reduce_hour(t)}
\]

2. \(\text{Erx_reduce_hour (t)} = \text{#electronic Rx(t)} \times \text{(rate of ADEs per paper rx)} \times \text{(staff-hour required to fix an ADE in paper rx)}\),

where

- \#electronic Rx(t): # of electronic rx written at time t
- \text{constant1 Rx: # of electronic Rx one staff would write in one hour}
- \#electronic Rx(t) = \text{(constant1 Rx)} \times \text{Staff-hour (t)}
- \text{constant2 Rx: rate of ADEs per paper rx}
- \text{constant3 Rx: staff-hour required to fix an ADE in paper rx}

3. \(\text{Enote_reduce_hour (t)} = \text{#electronic Enote(t)} \times \text{(rate of error per paper note)} \times \text{(staff-hour required to fix an error in paper note)}\),

where

- \#electronic note (t): # of electronic notes written at time t
- \text{constant1 nt: # of electronic notes one staff would write in one hour}
- \#electronic note(t) = \text{(constant1 nt)} \times \text{Staff-hour (t)}
- \text{constant2 nt: rate of error per paper note}
- \text{constant3 nt: staff-hour required to fix an error caused by paper note}
We plug in all the parameters above into formulation 1 as follows:

\[
\text{Staff-hour(t+1)} = \text{staff-hour(t)} - \text{constant1-rx} \times \text{constant2-rx} \times \text{constant3-rx} \times \text{staff-hour(t)} - \text{constant1-nt} \times \text{constant2-nt} \times \text{constant3-nt} \times \text{staff-hour(t)}
\]

Assume '\(\text{constant1-rx} \times \text{constant2-rx} \times \text{constant3-rx} = \text{constant-rx}\)' and '\(\text{constant1-nt} \times \text{constant2-nt} \times \text{constant3-nt} = \text{constant-nt}\)' then formulation 1 can be simplified as the following:

\[
\text{Staff-hour(t+1)} = \text{staff-hour(t)} \times (1 - \text{constant_rx} + \text{constant_nt})
\]

where \(\text{constant}_rx + \text{constant}_nt < 1\)

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**Figure 3 E-note and E-Rx Stock and Flow diagram**

![Diagram](image)

We used Vensim software as an SD tool to draw the diagrams and do the simulation.

**SIMULATION**

The parameters of the SD model are determined based on the experiences gained from some case studies by Empirica, Inc\(^1\). For example, it has been shown that the rate of reduction in lab duplicate tests or staff hours is about 5 to 10 percent. Table 1, for instance, shows how the staff hours are reduced in a clinic over a period of 7 years if staff reduction rate by e-Rx (constant-rx) and staff reduction rate by E-note (constant-nt) are both at .02. As shown in the table, if a clinic implements EHR completely (after 7 years), the staff hours have been reduced by about 25 percent.

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\(^1\) [www.empirica.biz](http://www.empirica.biz)
We generate the data for 10 virtual clinics. Assuming that they have 10 staff positions each and positions should be filled 24 hours every day (365 * 24 * 10), we have 87600 staff hours for one year per clinic before implementing EHRs. To estimate the volatility of return by reduction in staff hour, we estimate the parameters for virtual EHR sites as shown in Table 2.

Given the total hours saved by EHR, we can now convert reduction in staff hours to some economic value by assigning a value to one staff hour. Assume one hour costs $50 and one hour reduction means $50 saving in the costs for hospitals.

The simulation above is only a small example of our approach. For a more precise and complete simulation we can change the parameters value and generate the results for 50 to 100 sites.

**CONCLUSION**

Healthcare IT has to be developed more extensively and needs financial analysis of investment to assess the profitability of any spending in these economic conditions. IT benefits are complex, hard to measure, and usually achieved over time. Our study, using a system dynamics model as a technique used in economics of Information Technology, proposes a robust approach for a healthcare IT cost-benefit analysis in a non-traditional way.

System dynamics technique has not been used in EHR investment assessments. This model can serve as a predictive model of performance and can simulate different practical scenarios. The results of such a simulation then can be analyzed and transformed to economical values in a cost benefit analysis.

The simulation in this study was limited to measure the impact of EHR through E-note and E-Rx on staff reduction.
However, EHR impacts processes in every department, such as radiology lab and pharmacy, in a health care institution and SD modeling can be used to simulate those effects. In a future research, we will propose a comprehensive SD model that maps all tangible and intangible benefits of this technology throughout a health care system.

REFERENCES


