MODELING THE DYNAMICS OF ELECTRONIC HEALTH RECORDS ADOPTION IN THE U.S. HEALTHCARE SYSTEM

NADIYE O. ERDIL
Ph.D. Candidate
Department of Systems Science and Industrial Engineering
State University of New York (SUNY) at Binghamton
PO Box 6000 Binghamton, NY 13902
607-768 2809
nadiye@binghamton.edu

C. ROBERT EMERSON
Professor
Department of Systems Science and Industrial Engineering
State University of New York (SUNY) at Binghamton
PO Box 6000 Binghamton, NY 13902
607-777 7663
remerson@binghamton.edu

ABSTRACT
The adoption of Electronic Health Records (EHRs) moves slowly despite a near consensus in the healthcare industry that their use could be a critical factor in addressing quality and cost issues. Barriers and benefits of EHRs, the adoption process, and potential remedies to speed up the process are subject to numerous studies. In this study, a casual loop diagram of the EHR adoption process is developed and discussed. Through this model, factors influencing the process and the relationships between them are examined. The model is intended to be the backbone of future stock-flow models which will provide a test bed to explore an understanding of the EHR adoption process and to evaluate various policy options.

Keywords: *Electronic Health Records, System Dynamics, Simulation, Casual-loop Diagram*

INTRODUCTION
Rapidly rising healthcare costs, its burden on the U.S. economy, its effects on peoples' lives, population health, and furthermore, the concerns of inferior healthcare quality are compelling forces behind this nation's efforts to improve the delivery of healthcare. To guide these efforts, better integration and effective utilization of Health Information Technology (HIT) with an emphasis on Electronic Health Records (EHRs) is one of the propositions that is brought up often [1, 2 , 3, 4 ,5]. Nonetheless, EHR adoption moves slowly regardless of a near consensus that their use could be a critical factor in addressing the issues listed above [6, 7, 8, 9, 10]. Many proponents, including bipartisan supporters in Congress, have not yet been successful in speeding up the adoption pace. There is a general search for explanations.

Healthcare systems are complex systems. The highly fragmented structure of the United States healthcare system along with its financial flow challenges the understanding of healthcare system-problems. With little understanding of the healthcare system's behavior and the problems associated with it, evaluating the response of the system to interventions becomes a daunting task. Nevertheless, it is not unsolvable. This study takes up a System Dynamics (SD) approach to tackle this problem. The SD methodology provides tools to study complex problems in system behavior; and more importantly, it allows exploration of policy options, through simulation. The main objective of this study is to uncover the dynamics of the Electronic Health Record adoption process in the United States healthcare system, and then to evaluate the impacts of various policy decisions that might accelerate this adoption.

BACKGROUND

Several studies have been conducted which analyze the EHR adoption process in the United States healthcare system. Commonly listed benefits of EHRs are classified under: (1) improved patient safety and quality of care; and (2) reduced costs. These benefits result from capturing more accurate and more complete health information on a patient's entire health history and structuring data more efficiently for easier and quicker access. Often stated benefits include avoided duplicate tests, improved coordination and management of chronic conditions and preventive services, increased efficiency in scheduling and communication, improved billing and claims processing, improved reporting for public health and clinical research, reduced medical mistakes, improved workflow, and so on [2, 3, 11, 12, 13]. On the other hand, commonly cited barriers to the adoption process, which are identified as the causes of the slow adoption pace, are high costs, delayed return on investments, misaligned financial benefits, third party payer system, fragmented system, first mover disadvantage, lack of standards on terminology and technology, security and privacy issues, the political process, and so on [4, 6, 7, 10, 14, 15, 16, 17, 18].

Studies exploring EHR adoption provide insights to the issues in the adoption and the implementation process. They reveal that the EHR adoption process in the U.S. healthcare system is a healthcare system structure and policy issue [6, 7, 14, 19]. A common approach in these studies is to analyze the system in a piecemeal fashion. This divide-and-conquer approach deconstructs the problem so that factors can be studied in isolation. A systems approach would complement the existing research. Such an approach would allow for analysis of the system as a whole. The goal would be understanding of the underlying factors in the adoption process that determine the behavior of the overall complex system. In this effort, this research uses a System Dynamics model, allowing for the study of various policy decisions.

METHODS

The System Dynamics methodology is used in the analysis of complex systems. Complex systems are defined by large number of variables, multiple interacting feedback loops, nonlinear relationships, and a dynamic nature. Analysis of causes and effects in complex systems does not follow simple if-then statements. For example, closing of the chains of causes and effects may spread through time or the causes may not be found in the immediate vicinity of the effects [20]. The SD methodology is built on the supposition that it is the system structure and policies that are usually the home to causes [20]. The methodology was introduced by Jay W. Forrester in the early 1960s to study complex systems such as the urban dynamics problem. Today, it has a wide range of applications including healthcare. The attributes of the U.S. healthcare system, matching with the characteristics of a complex system, fortify the use of the SD methodology.

Casual loop diagrams and stock-flow diagrams are two of the SD modeling techniques. A casual loop diagram is a pictorial representation of the major factors and feedback loops. It captures the underlying structure of the dynamics of the system which arise from the interaction of two types of feedback loops. A reinforcing (positive) loop is a snowball effect where a change in a state produces a result which pushes the system to create more of the same change. A balancing (negative) loop, on the other hand, creates forces to reverse a change. The second modeling technique, a stock-flow diagram, is an augmentation of casual loop diagrams. Stock-flow diagrams consist of stocks that are accumulations of resources, and flows that are rates of changes that fill and drain these resources. These models can be simulated using SD simulation software.

As mentioned before, the main objective of this study is to develop an understanding of the EHR adoption process and to evaluate various policy options. This will be accomplished through developing a stock-flow model of the system which will provide a test-bed for simulation. To build such a model, the study started with a casual loop model which is the focus of this paper. The model, which is discussed in the following sections, captures the cause and effect relationships (feedback loops) among factors influencing the adoption process.

RESULTS

The Casual Loop Model

The causal loop model, discussed in this study, captures the major variables that have been identified through a literature review. Topics that frequently turn up in the literature, and are stressed by experts, constitute the foundation of the model shown in Figure 1. Although stocks and flows are not commonly used in causal loop diagrams, this model contains two stocks and a flow to emphasize the focus of the model. The stocks *Adopted_Population* and *Not_Yet_Adopted_Population* represent the number of providers that have and do not have EHR systems in use. The flow *adopting* indicates the number of providers adopting per time.

Some of the variables in the model are aggregated over many individual factors such as *cultural_barrier* which represents the organizational cultural issues including change management, resistance to new technology, commitment, etc. Cultural issues are barriers that prevent providers from adopting EHR systems. On the other hand, *industry_pressure* stands for the forces in the healthcare industry that might accelerate the adoption of EHR systems. Provider organizations using EHRs, insurer/payer organizations, and the regulation sector tend to be the sources of these forces. While *market_maturity* reflects the maturity level of the EHR products in the market, *EHR_usage_performance* indicates the productivity gains from an EHR system implementation.

The plus/minus signs on the arrows, in Figure 1, indicate how one variable changes as a result of a change in the other. The plus sign represents change in the same direction, while the minus sign corresponds to the opposite direction. The reinforcing and the balancing loops are shown with letters R and B respectively.

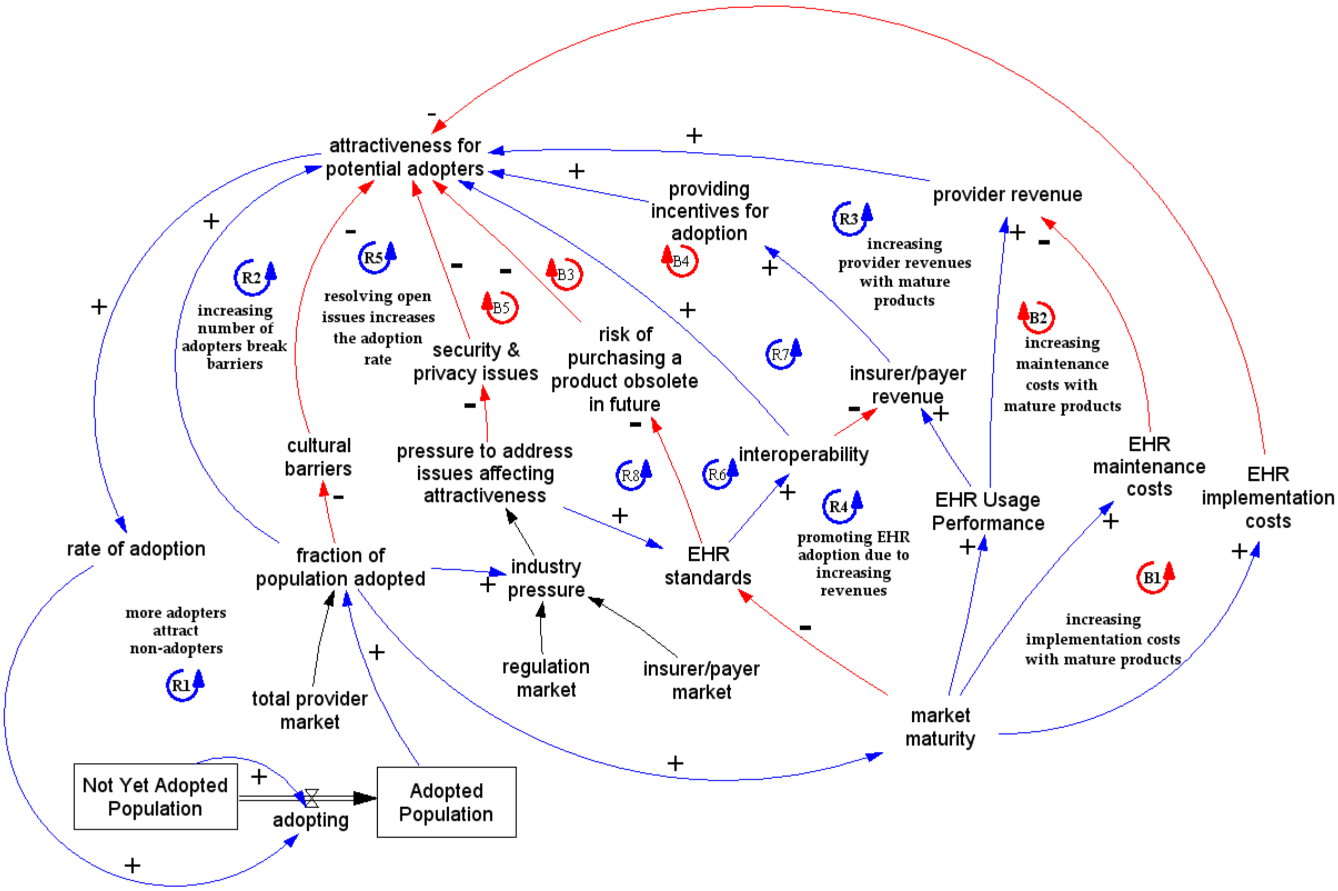

Figure 1 EHR adoption process in the U.S. Healthcare System - the Causal Loop Model

The Feedback Loops

The overall goal of this study is to obtain a model, such as Figure 1, that encloses the factors influencing the EHR adoption process and the use of that model to test policy changes. This is accomplished through the feedback loops captured by the casual loop model. A starter model, shown in Figure 1, exhibits the feedback loops identified thus far in this study. The following section outlines each of these loops. It should be noted that although the loops are presented separately, they are not disconnected. On the contrary, the work of their interactions is what determines the dynamics of the system.

The causal loop diagram in Figure 1 is built around the provider population which is divided into two as adopted and non-adopted population. The model assumes that once adopted a provider does not abandon an EHR system. Therefore, there is only one direction to the flow which is from the non-adopted population to the adopted population. All of the loops originate from the adopted population.

Considering which stakeholder in the healthcare system is affected by the feedback loops shown in Figure 1, the model can also be divided into two: the provider sector and the insurer\payer sector.

Provider Sector:

Provider sector can be further broken into two parts: financial effects and behavioral effects. Financial effects would capture loops such as EHR system maintenance costs; and behavioral effects would cover loops such as the influence of system-interoperability on the providers' actions. The loops that capture behavioral effects on providers' actions are R1, R2, R5, B3, R6, B5 and R8; and the loops that show financial effects are B1, B2 and R3.

Loop R1 'more adopters attract non-adopters' (Figure 2)

As the adopted population grows, the increasing presence of EHR systems would attract the non adopted population. This, in turn, increases the rate of adoption.

Loop R2 'increasing number of adopters break barriers' (Figure 3)

As the number of EHR users increases, EHR systems would become the norm. In response, the forces that prevent the spread of EHRs, cultural barriers in this case, start to diminish. Consequently, the negative affect of cultural barriers on the attractiveness of EHR products decreases; therefore, the rate of adoption increases which results in more providers adopting.

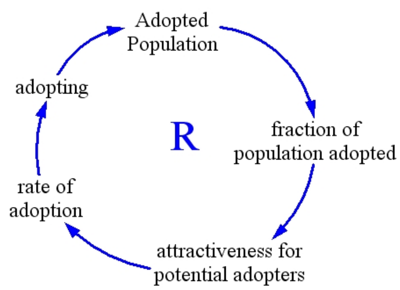

Figure 2 Loop R1 'more adopters attract non-adopters'

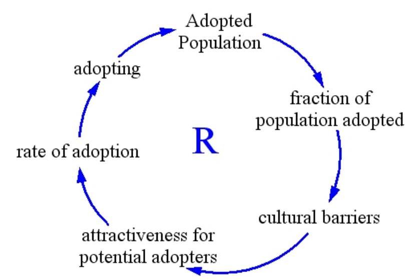

Figure 3 Loop R2 'increasing number of adopters break barriers'

Loop R5 'resolving open issues increases the adoption rate' (Figure 4)

An increasing presence of EHR systems would create a force over the healthcare industry to address EHR related issues particularly since more people would be affected. Increased pressure, however, does not always develop solutions to issues. But, the model assumes that it does, to reduce the complexity. Therefore, in this loop, the negative influence of security & privacy issues on EHR system's attractiveness is lessened as the pressure to address these issues increases. In response, the rate of adoption increases and produces more system adoptions.

While the mechanics indicate that Loop R5 is a reinforcing loop, it should be noted that pressure from the adopter population only would not be enough to force the industry to take actions. Therefore, this loop would not be dominant until the other players such as the regulation market and the insurer/payer market get involved.

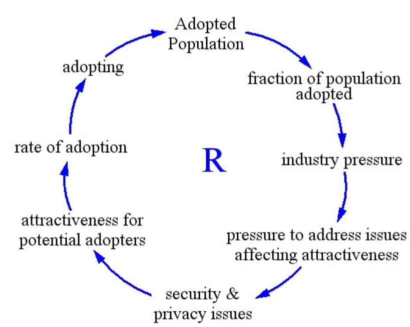

Figure 4 Loop R5 'resolving open issues increases the adoption rate'

Loops B3 and R6 'effects of interoperability' (Figure 5 & 6)

Interoperability is assumed to be an incentive to potential EHR system adopters. Therefore, increasing levels of interoperability would attract more users. The system behavior reflecting interoperability is dependent on EHR standards. In the model, there are two factors influencing EHR standards: *market_maturity* and *pressure_to_address_issues_affecting_attractiveness*. As a result, there are two loops, B3 and R6, involving interoperability.

Common to most emerging technology markets, the EHR product market started with no uniform standards. Therefore, there are numerous products on the market that are not compatible with each other. As the market grows with no uniform standards (since the U.S. healthcare system does not have a uniform standard set - even now) [10, 21] vendors' increasing proprietary interests keep building systems which complicate the achievement of standards. This interaction is captured in Figure 5 by the arrow from *market_maturity* to *EHR_standards*. Loop B3 indicates that as *market_maturity* increases the possibility of achieving a uniform standards set decreases; this, in turn, lengthens the time to achieve system interoperability. Since interoperability is considered as an attractive factor, without it, EHR systems' attractiveness would decrease, and thus, the number adopting would decrease. Nevertheless, the healthcare industry can push for EHR standards which would then be captured by a second loop. Loop R6 shows that the healthcare industry's pressure accelerates the standardization process, and thus, the reaching of the system interoperability. This situation would then step up the adoption process creating a reinforcing loop working against Loop B3.

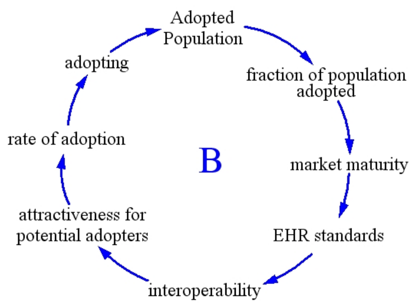

Figure 5 Loop B3 'barrier to interoperability'

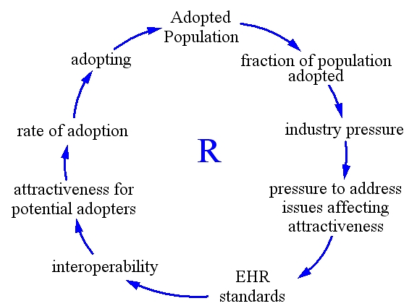

Figure 6 Loop R6 'encouraging interoperability'

Loops B5 and R8 'risk of purchasing products obsolete in future' (Figures 7 & 8)

Loops B5 and R8 are similar to Loops B3 and R6. In this case, the factor affected by *EHR_standards* is the risk of purchasing a product that might become obsolete. Loop B5 shows the effect of evolving market, and Loop R8 captures the influence of the industry pressure. With the market prolonging the achievement of uniform EHR standards, the risk of purchasing a product obsolete in future increases. But, then again, the pressure built up to address EHR issues would accelerate the process of agreement on EHR standards generating a reinforcing loop working against Loop B5.

Considering the general view of the system reflected by the model and compared to other factors represented in the model, *risk_of_purchasing_a_product_obsolete_in_future* is a weak factor in terms of its influence on the adoption process. However, the purpose of this research is to develop a model that can be used to test policies and as a backbone for future larger models. Although, this factor has a negligible affect on the current model, including this factor shows how the base model can be enlarged.

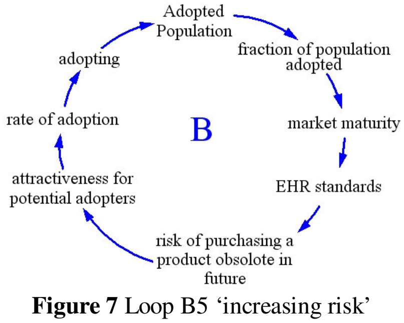

Figure 7 Loop B5 'increasing risk'

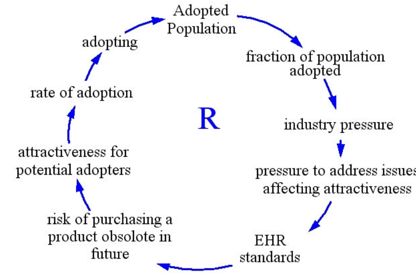

Figure 8 Loop R8 'decreasing risk'

Loop B1 'increasing implementation costs with mature products' (Figure 9)
An increasing number of EHR users would attract investors and vendors into the EHR product market; and the competition in the market would increase. As can be seen in new technology markets, the progress will accelerate, and new and more mature products will evolve. In this model, all these responses are accumulated under the variable *market_maturity*. With increased competition, ideally, a decline in implementation costs should be observed. However, considering how fast the digital technology advances, and thus new and improved structures are needed to support the advancements, implementation costs of EHR products would increase as more enhanced products are released. Increased implementation costs would then diminish EHR systems' attractiveness. Diminished attractiveness then lowers the rate of adoption which implies less providers adopting per time.

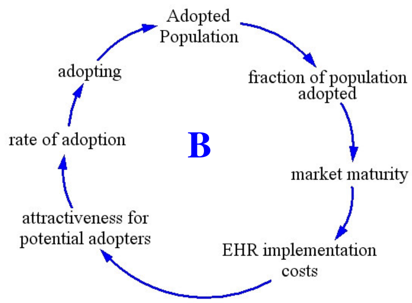

Figure 9 Loop B1 'increasing implementation costs with mature products'

Loop B2 'increasing maintenance costs with mature products' (Figure 10)
Similar to implementation costs, software maintenance costs increase with enhanced products. Therefore, a balancing effect is seen in Loop B2. Increasing EHR maintenance costs reduce the provider revenue, which in turn cause the attractiveness of EHR products to decline. Declining attractiveness would negatively affect the rate of adoption, causing fewer providers to acquire EHR systems.

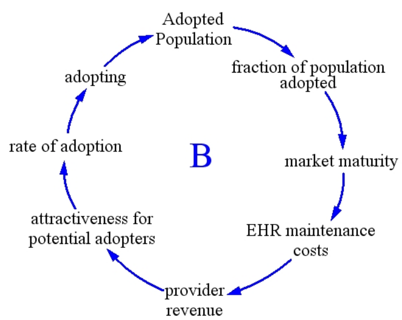

Figure 10 Loop B2 'increasing maintenance costs with mature products'

Loop R3 'increasing provider revenues with mature products' (Figure 11)
Similar to Loops B1 and B2, Loop R3 shows the effects of market maturity on EHR products. The assertion is that a maturing market produces enhanced products. In this case, the characteristic reflected is the performance of the EHR products. 'Performance' indicates the improvements realized at a provider's facility as a result of the EHR system employment. As more sophisticated and intelligent EHR products are released, greater improvements would be observed, particularly when compared to previous periods where the EHR products were still considered an emerging technology. Increased return on investments resulting in increased provider revenues attracts more potential users. Therefore, the adoption rate starts to accelerate.

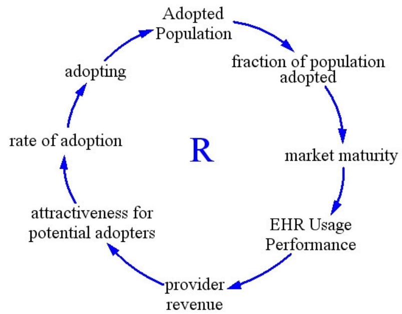

Figure 11 Loop R3 'increasing provider revenues with mature products'

Insurer\Payer Sector:

The loops that capture financial effects on insurer\payers' actions are B4, R7 and R4.

Loops B4 and R7 'providing incentives for adoption' (Figures 12 & 13)

In Loops B3 and R6, a provider's response to changing levels of interoperability is discussed. In this section, the response of insurers/payers is modeled. Loop B4 captures the industry's efforts that lead to increasing interoperability. Loop R7, on the other hand, brings in the market's resistance that slows down this process. Similar to Loops B3 and R6, there are two loops working against each other. However, for the insurer/payer, the path from the market creates a reinforcing loop, while the path from the industry generates a balancing one. In the case of providers' response (Loops B3 and R6), it is the opposite. This is because the high level of interoperability is in the providers' best interest. The interoperability works the opposite way for the insurer/payer because it provides the infrastructure to share (and exchange) not only the clinical information, but also the financial information. While the insurer/payer would benefit from clinical data sharing, the outcome of financial data sharing would outweigh this benefit [14]. Loop B4, then, captures the influence of increasing interoperability on the insurer/payer behavior, while Loop R7, working against Loop B4, shows the effects of decreasing levels.

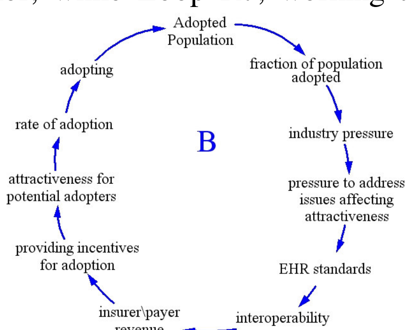

Figure 12 Loop B4 'insurer\payers' decreasing interest in providing incentives'

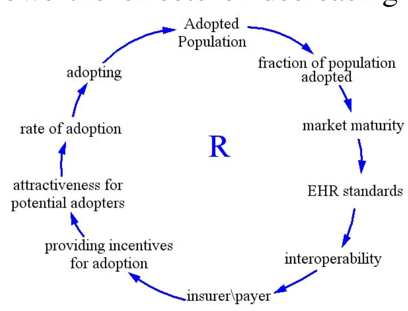

Figure 13 Loop R7 'insurer\payer's increasing interest in providing incentives'

Loop R4 'promoting EHR adoption due to increasing revenues' (Figure 14)

Similar to the case in Loop R3, increasing EHR usage performance also increases the insurer\payer revenue. As more providers use EHR systems, the greater benefits are realized by the insurer\payer. To encourage EHR usage then, the insurer\payer starts developing programs such as higher reimbursement rates for EHR users. These incentives attract non-adopters, and thus the rate of adoptions increases generating more adopters per time.

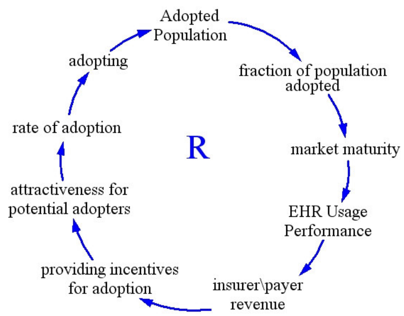

Figure 14 Loop R4 'promoting EHR adoption due to increasing revenues'

DISCUSSION

In this paper, an SD model was presented to study the EHR adoption process in the United States healthcare system which is a complex process. Factors included in the model were drawn from a literature review through which issues were brought up and captured. With the issues and the underlying factors identified, a casual loop diagram was developed to grasp the dynamics of the system.

This causal loop method reflects the anticipated behavior of the overall system, as given in the literature. Taking a Systems Dynamics view brings a new approach to the study of the adoption process. Feedback loops discussed in the previous section, reveal how the factors influencing the process interact and how these interactions affect the behavior of the system. Since implementation and maintenance costs, security and privacy issues, and misaligned financial benefits are the most commonly listed issues in the adoption process, loops B1, B2, R5, B4, R7, R3 and partially R4 are expected to be the significant feedback loops of this model. R4 is considered partially significant because the model, in its early stages, represents only a part of the picture involving financial benefits.

The overview of the model does not show a particular dominant loop that could force the system to go in a particular direction. This, in fact, could be the explanation for the current adoption patterns. More work remains to be done to draw a firm conclusion. A stock-flow diagram spawned from this causal loop model is needed for testing such assertions. In order to have a sound stock-flow model, working with experts is needed to finalize the factors included in the model in addition to the literature review. The next step, then, is to gather quantitative data for the simulation.

This study has several limitations that are identified as future work for the extension of this starter model. The model reflects only the provider and the insurer/payer organizations interests in the adoption process. Other stakeholders include patients, the regulation sector, high-tech industry, general public, etc. These stakeholders also have interests and influences on the process; and should be included in future work in order to improve the representation of the system.

Several assumptions of the model that could be altered include (1) there is no withdrawal once a provider organization adopts an EHR system, (2) increasing pressure leads to the generation of solutions, and (3) increasing levels of interoperability hurts insurer/payer revenues. The latter assumption is based on a view articulated in the literature [14, 15], but there is no quantitative data that supports this assertion.

The objective of this research is to bring a System Dynamics approach to the analysis of the EHR adoption process as a test vehicle for policy and regulatory decisions. The proposed approach is valuable in several ways. First, the model can be free of bias in terms of portraying the system; therefore, it provides a common study ground for interested parties. Second, an overall view of the system is presented by the model; as a result, factors and their interactions can be examined without losing the systems perspective on the issue. Third, the casual loop modeling is capable of capturing feedback loops in the system; thus, it provides a helpful structure for understanding the system behavior. Finally, a simulation test-bed that evaluates policies and strategies can be obtained by expanding the causal loop model, which is the ultimate goal of this research; consequently, developing a tool for policy makers. This paper presents the initial stage of this research where SD modeling is applied to obtain a preliminary casual-loop model.

CONCLUSION

This study brings a systems perspective to the analysis of EHR adoption process in the United States healthcare industry by utilizing the System Dynamics methodology. The casual loop model offers insights to understanding the major factors influencing the adoption process and their interactions, as well as the feedback loops that operate in the system. The study, in its early stages, is limited in terms of factors included. Nonetheless, it provides a foundation for development of larger causal loop models and stock-flow models.

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About the Authors

Nadiye O. Erdil, (B.S., Computer Science – M.S., Industrial Engineering) is a Ph.D. candidate in System Science at Binghamton University. Her research interests include health systems and health information systems.

C. Robert Emerson is professor of Industrial and Systems Engineering at Binghamton University. His research interests include finding solutions to policy questions within complex systems. The applications range from manufacturing to healthcare.