High-Tech Diagnostic Imaging Clinical Decision Support Tools Adoption: Study using a System Dynamics Approach

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Engineering Systems Division

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Master's Thesis

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Abstract

The healthcare industry in the United States (U.S.) has purchased and installed high-tech diagnostic imaging (HTDI) equipment, such as computed tomography, magnetic resonance imaging and ultrasonography, at an astounding rate, outpacing all other countries. Although HTDI has significantly enhanced a physician's ability to diagnose and treat a variety of diseases, studies have suggested that today between 20 to 30 percent of the U.S. HTDI tests do not contribute to treatment, which represents a waste of $4 to $6 billions annually and exposure patients to unnecessary radiation. To solve this problem, healthcare IT vendors have developed high-tech diagnostic imaging clinical decision support (DS) tools to reduce the inappropriate and unnecessary use of HTDI tests. This screening process should lower the overall HTDI costs and increase the quality of care. However, despite obvious benefits, adoption of the DS tools has been lower than expected. The aim of this research is to understand the current DS tools adoption process in the U.S. healthcare system and to identify potential strategies that vendors could implement to increase adoption in the future.

The system dynamics methodology is used to explore the counterintuitive behaviour vis-à-vis the adoption of DS tools. This choice is motivated by the natural fit of this methodology to study large complex systems, such as the U.S healthcare system. A detailed study of the underlying dynamics of the whole system, including the interactions of key stakeholders provides a deeper understanding of the problem. Based on the review of DS tools literature and multiple discussions with experts in healthcare, a DS tools adoption qualitative system dynamics model is created to represent the major adoption factors, their causal relationships and their effects on the overall adoption process. The proposed model offers key insights about the adoption process, including possible reasons why adoption is muted and what vendors could do to increase adoption. Based on this study, we recommend that the vendors should shift their current focus from the Providers, who are their main customers, to the Private Insurers/Payers, Government & General Public to increase adoption.

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List of Acronyms

CMS	Centers for Medicare and Medicaid Services
CPOE	Computerized physician order entry
CT	Computed tomography
DS	High-tech diagnostic imaging clinical decision support
EHR	Electronic Health Record
HTDI	High-tech diagnostic imaging
MGH	Massachusetts General Hospital
MRI	Magnetic resonance imaging
RBM	Radiology benefit management
ROE	Radiology order entry
U.S.	United States

1 Introduction

1.1 Problem Description and Research Goals

The United States (U.S.) healthcare system is the largest and the most expensive healthcare system in the world. In 2008, the U.S. healthcare spending was $2.3 trillions, which corresponds to $7,681 per person or 16.2 percent of the country's gross domestic product (GDP) (CMS 2010). With current consumption rates, by 2019 the U.S. healthcare spending is expected to reach $4.5 trillion and account for 19.3 percent of GDP (ibid).

During the past two decades, no other branch of medical technology has experienced the explosive growth in volume and variety of available services as radiology. The healthcare industry in the U.S. has purchased and installed high-tech diagnostic imaging (HTDI) equipment, such as computed tomography (CT), magnetic resonance imaging (MRI) and ultrasonography, at an astounding rate, outpacing all other countries (Iglehart 2009; Sistrom, Dang et al. 2009). As shown in Figure 1, from 2000 to 2007, the high-tech diagnostic imaging costs grew by about 10% per year compared with an average yearly cost increase for all other healthcare services of 3.3%. Consequently, the U.S. has almost twice as many MRI units per million persons as any other industrialized country - see Figure 2.

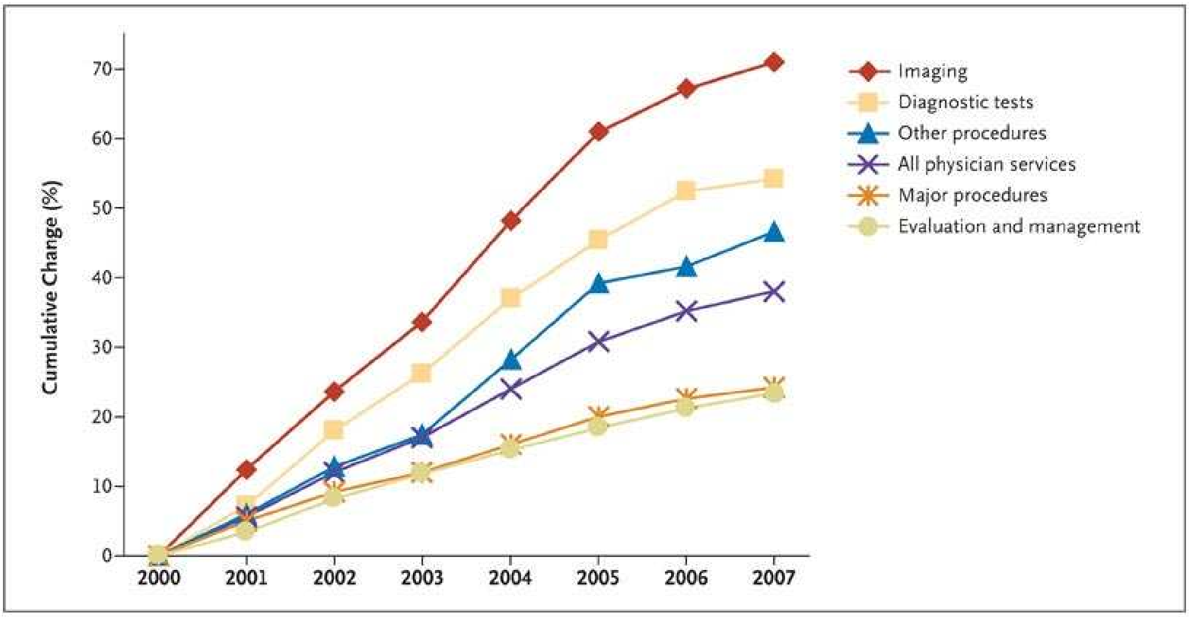

Figure 1 – Rates of Use of Imaging Services, as Compared with Rates of Other Physician-Ordered Services, per Medicare Beneficiary (2000-2007)

Source: (Iglehart 2009)

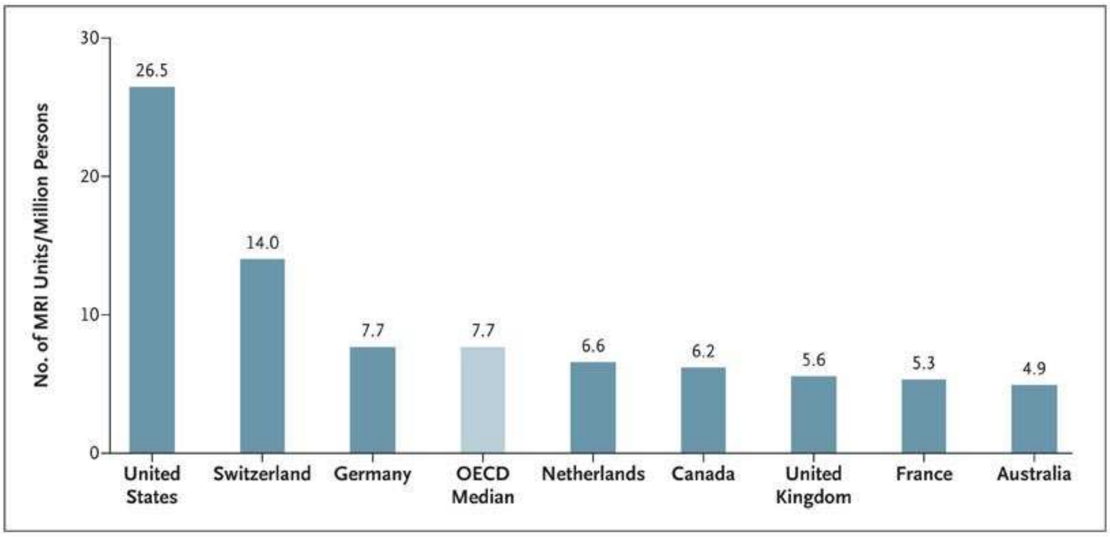

Figure 2 – Number of Magnetic Resonance Imaging Units per Million Persons (2006)

Source: (Iglehart 2009)

Although HTDI has led to significant enhancement in a physician's ability to diagnose and treat a variety of diseases, studies have suggested that today between 20 to 30 percent of the U.S. HTDI tests do not contribute to treatment, which represents a waste of $4 to $6 billions annually (Holzberger 2009; Wiley 2009) and exposure patients to unnecessary radiation. The most commonly cited reasons contributing to the overuse of HTDI in the U.S. are inappropriate use of HTDI tests, unnecessary duplication of HTDI tests, patients demanding the technology, physician self-referrals, and defensive medicine practices (Vasko 2008; Hole-Curry 2009; Vinz 2009).

To solve this problem, healthcare IT vendors have developed high-tech diagnostic imaging clinical decision support (DS) tools that reduce the inappropriate and unnecessary use of HTDI tests. This screening process will lower the overall HTDI procedure volumes and costs, and will decrease patient exposure to unnecessary radiation. However, despite the obvious benefits of the DS tools, adoption has been lower than expected.

Certain about the benefits of the DS tools, one major healthcare IT vendor offered free DS tools implementations to 10 providers in return for their willingness to publish the results. The rationale behind this decision by the vendor was that by providing incentives to the early adopters to implement the DS tools, they would be able to publish the results motivating other providers to follow. Figure 3 depicts the vendor's thought process to increase adoption.

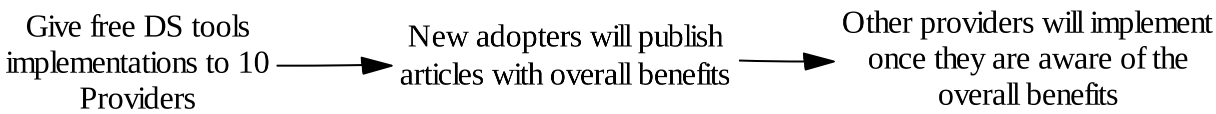

Figure 3 – Vendor's thought process to increase adoption

This strategy did not yield the expected results, however. After 6 months, the vendor discontinued this offer because no provider accepted it.

Despite the significant benefits of the DS tools and the vendor's incentives, there are only few adoption cases in the United States. Hence, this research is an attempt to understand the DS tools adoption process and identify potential strategies that vendors could implement to increase adoption.

1.2 Methodology and Framework

The U.S. healthcare system is a very complex system with multiple stakeholders driven by conflicting interests and different levels of ownership and power. In order to understand the DS tools adoption process, it is necessary to understand the dynamics of the system as a whole, including the interactions between various key stakeholders.

System dynamics methodology was selected to conduct this research because of its natural applicability for framing, understanding, and discussing complex systems. It offers the right tools to capture the stakeholders' interactions and to show the dynamics of the whole system. Developed during the mid-1950s to help corporate managers improve their understanding of the industrial enterprise dynamics (Forrester 1961), system dynamics is currently being used to study a wide range of complex problems. These include modeling of environmental systems (Meadows, Meadows et al. 1992), public policies (Lee 2005), national networking technology systems (Kelic 2005), national electric power systems (Black 2005), global air transportation systems (Bonnefoy 2008), etc. This methodology has also been used in the analysis of healthcare issues, such as the study of cost, access and quality problems in the U.S. healthcare system (Hirsch, Homer et al. 2005), the study of the German health insurance system (Grösser 2005), the study of the Ugandan immunization system (Rwashana and Williams 2008), etc.

The research was conducted by following the steps outlined below:

1. Gather data from each of the key U.S. healthcare stakeholders using semi-structured interviews, discussions and presentations from the "Symposium for evidence-based

medicine as the foundation to better care"[1] and articles from medical journals and healthcare web site.

2. Create the DS tools adoption qualitative system dynamics model by following four iterative steps:
   - Define the purpose of the model;
   - Define the model boundary and identify key variables;
   - Describe the behavior or draw the reference modes of the key variables;
   - Diagram the basic mechanisms, the feedback loops, of the system.
3. Analyze the DS tools adoption qualitative system dynamics model.
4. Identify potential strategies to increase adoption by using the insights from the model and by conducting brainstorming sessions with vendors.

1.3 Outline of the Thesis

The thesis is divided into five chapters as follows. Chapter 1 presents a brief summary of the research problem and goals, and explains why system dynamics methodology was selected for this research. Summary of the most relevant information from the literature reviewed regarding the DS tools is discussed in Chapter 2. It includes a brief overview, the most known adoption cases, the main benefits and the main adoption barriers. Chapter 3 provides details on the system dynamics methodology including the main concepts, tools and the framework used in this research. The creation of the DS tools adoption qualitative system dynamics model is shown in Chapter 4. Discussions regarding the major sources of data used

[1] "Symposium for evidence-based medicine as the foundation to better care" held in July 2009 in Seattle, U.S. and organized by General Electric Healthcare.

in this research are also included. In addition, this chapter analyzes the model and presents some strategies that vendors could implement to increase adoption. Conclusions and recommendations are presented in Chapter 5. A final perspective on the problem and contributions of this research and future research opportunities are also highlighted.

2 High-Tech Diagnostic Imaging Clinical Decision Support Tools

This chapter summarizes the most relevant information about high-tech diagnostic imaging clinical decision support tools. It includes a brief overview, the most known adoption cases, the main benefits and the biggest adoption barriers.

2.1 Overview

High-tech diagnostic imaging clinical decision support tools are clinical systems that help physicians order the most appropriate HTDI tests by providing an appropriateness score/information at the time a clinician submits the request. The appropriateness score is calculated based on the clinical indications provided by the clinician. If applicable, alternate examinations are also suggested along with their scores for comparison. The sets of clinical indications for specific examinations and the appropriateness scores/information are based on widely accepted evidence-based criteria, such as the American College of Radiology Appropriateness Criteria (ACR 2010). Figure 4 shows an example of a DS tool screen.

The DS tools can be embedded into the Electronic Health Record (EHR), the computerized physician order entry (CPOE), the computerized radiology order entry (ROE) or available via a Web site to facilitate ease of use by the providers. Figure 5 shows an example of a DS tool embedded into an EHR.

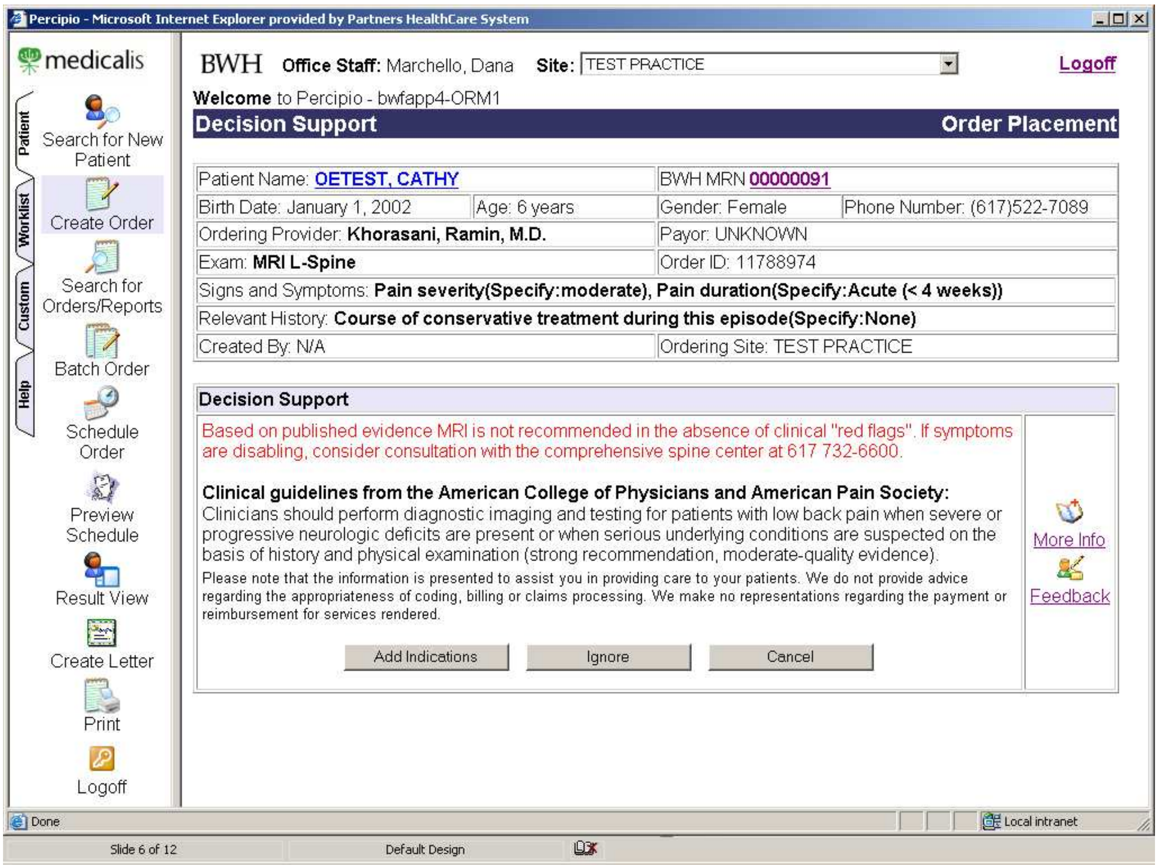

Figure 4 – Example of a DS tool screen

Source: (Khorasani 2009)

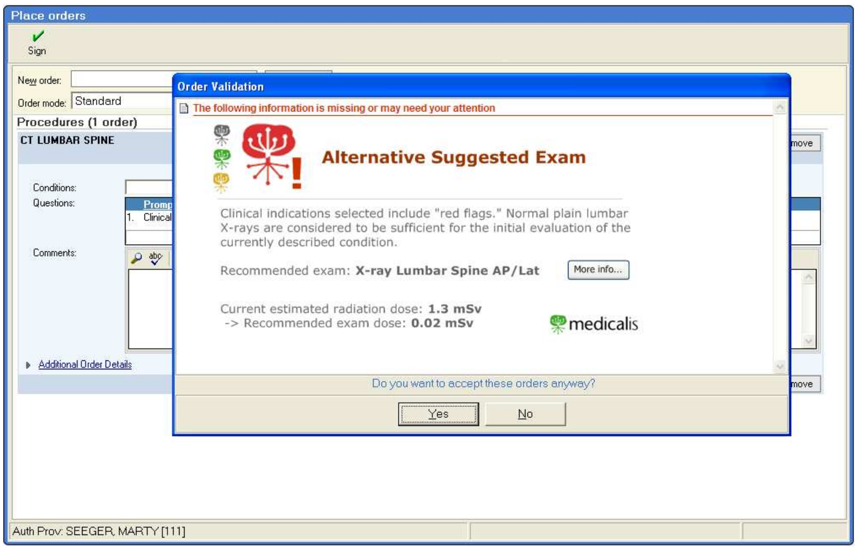

Figure 5 – Example of a DS tool embedded into an EHR

Source: (Fisher 2009)

The most commonly cited DS tools benefits include reduced overall costs, increased patient safety and quality of care and increased providers' access to the latest evidence-based criteria, to be detailed in section 2.3 (Vasko 2008; Fisher 2009; Gifford 2009; Hole-Curry 2009; Holzberger 2009; Khorasani 2009; Sistrom, Dang et al. 2009; Vasko 2009; Vinz 2009; Wiley 2009; Moan 2010). However, despite significant benefits there are only few adoption cases, which will be explored in the next section.

2.2 Adoption Cases

Two types of adoption cases are discussed in the extant literature. The first type is related to the early adopters, those institutions that see quality as a differentiator, such as Massachusetts General Hospital or Brigham and Women's Hospital. The second type includes instances where the insurers/payers allowed the providers to use DS tools instead of working with a radiology benefit management (RBM) company, as it happened in Minnesota. In this section, two of the most well known cases will be presented in detail, namely the Massachusetts General Hospital case and the Minnesota case.

Case Type I - The Massachusetts General Hospital case

From 2001 until 2007, the Massachusetts General Hospital (MGH) studied the effect of an ROE system and DS tool on growth rate of outpatient computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography procedure volumes over time at a large metropolitan academic medical center (Sistrom, Dang et al. 2009). In late 2001 a web-based computerized ROE system was implemented to allow referring physicians to request and schedule outpatient diagnostic imaging studies. In the last quarter of 2004, a DS tool was integrated into the ROE system. The ROE and DS tool assisted in ordering HTDI tests (MRI, CT, and nuclear cardiology) by providing an appropriateness score on 1-9 scale at the time a clinician submitted the request. The appropriateness scores were based on the American College of Radiology Appropriateness Criteria. Figure 6 shows an example of a DS feedback screen after submitting a request for an MRI.

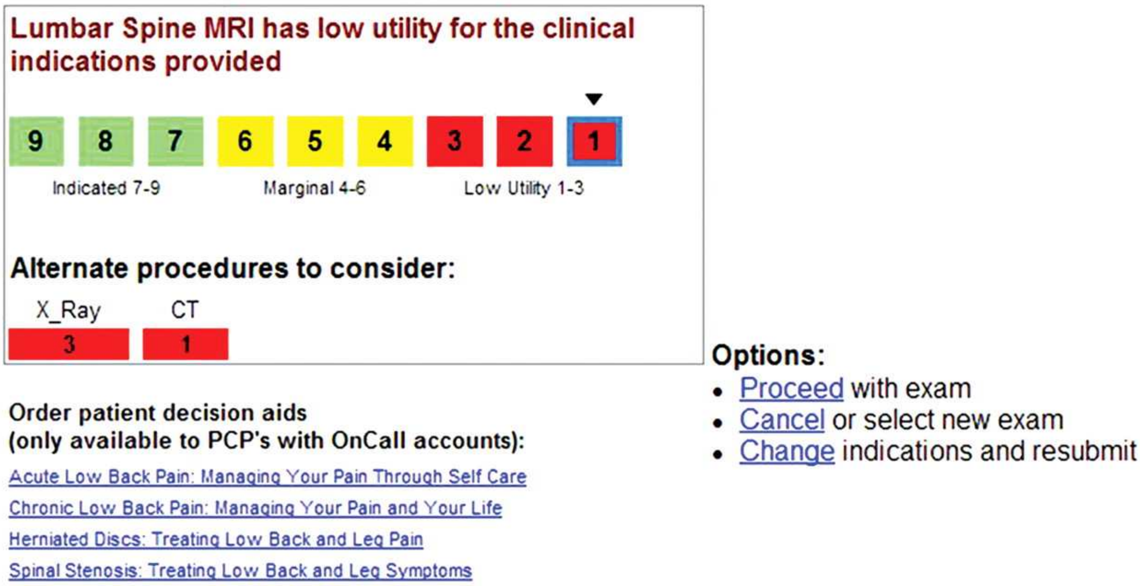

Figure 6 – Example of a DS feedback screen after submitting a request for a MRI of the lumbar spine

Source: (Sistrom, Dang et al. 2009)

As reported at the end of this study (Sistrom, Dang et al. 2009), there was a significant decrease in CT volume growth (274 units per quarter) and growth rate (2.75% per quarter) after the ROE and DS tool implementation (p-value < .001), as shown in Figure 7. For MRI, the growth rate decreased significantly (1.2%, p = .016) after ROE and DS tool implementation; however, there was no significant change in quarterly volume growth. With ultrasonography, quarterly volume growth (n = 98, p = .014) and growth rate (1.3%, p = .001) decreased significantly after ROE implementation. These changes occurred during a steady growth in clinic visit volumes in the associated referral practices.

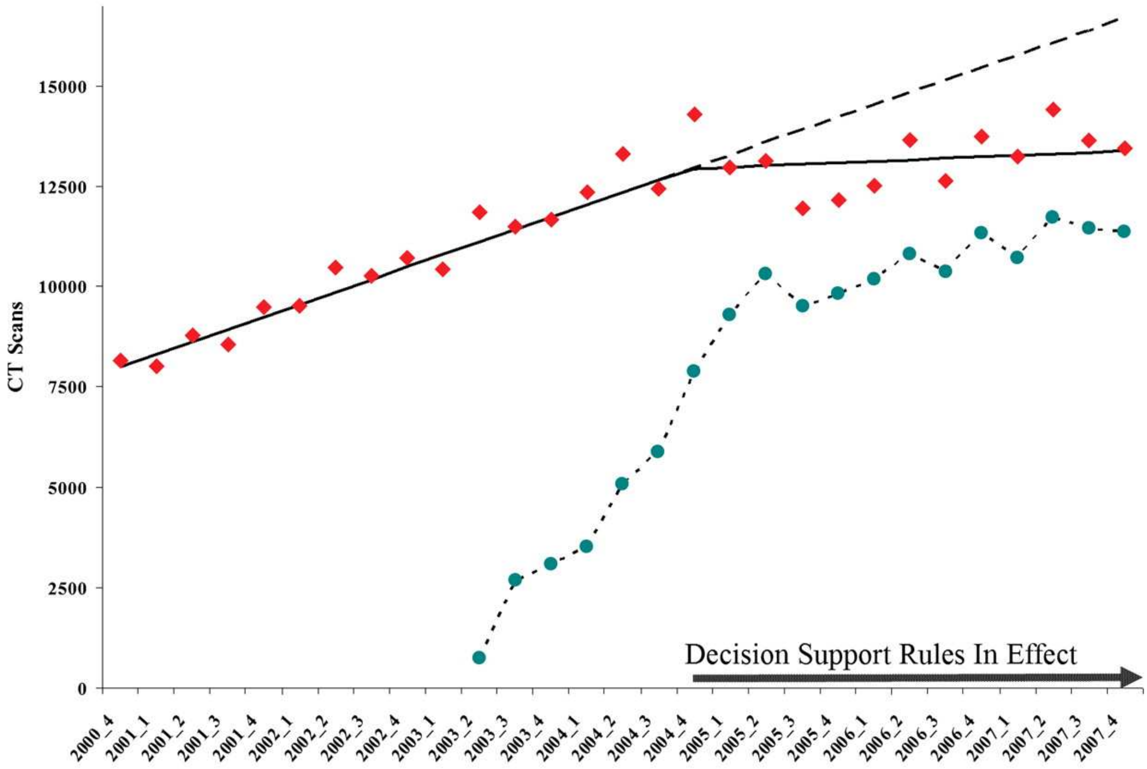

Figure 7 – Scatterplot of outpatient CT examination volumes (y-axis) per calendar quarter (x-axis) represented by red diamonds. Dotted line and teal circles depict number of CT examinations ordered through ROE.

Source: (Sistrom, Dang et al. 2009)

With this study, MGH demonstrated that implementation of an ROE system and DS tool in their large urban academic health center led to a significant and substantial decrease in the growth rate of outpatient diagnostic CT, MRI, and ultrasonography examination volume, despite continued steady growth in outpatient visit activity. The study was published in February 2009 in the Radiology Journal (Sistrom, Dang et al. 2009), and it was a big milestone for the DS tools. According to Thrall (Wiley 2009): “This article is an important milestone in shaping the conversation nationally. Until this, we did not have scientific evidence of an alternative to RBMs, but now, we have clearly demonstrated that a less intrusive and more patient-friendly option exists. That is the point-of-care–decision approach.”

Case Type II - The Minnesota case

In 2004, three Minnesota insurers/payers (HealthPartners, Blue Cross Blue Shield and Medica) were planning to implement a prior-authorization program administered by a third-party radiology benefit management (RBM) company to decrease the inappropriate utilization of HTDI. However, due to the Minnesota DS solutions pilot results, in the end, they chose a different route: offering medical groups the option to run providers-focused decision support solutions (Vinz 2009).

The Minnesota DS solutions pilot was developed in 2006 by the Institute for Clinical Systems Improvement. This pilot included more than 2300 Minnesota providers, from 5 medical groups, using point-of-order decision support criteria to order HTDI tests. The criteria were based on American College of Radiology and the American College of Cardiology standards. The DS solutions were either embedded into the provider's EHR or available via a Web site. As shown in Figure 8, the Minnesota pilot reduced HTDI claims among five insurers/payers by 3% in 2007 versus 2006. And based on the projected increase stemming from the previous four-year trend line, the reduction in claims was estimated to be 9%. When the pilot ended, the five participating medical groups continued using the DS solution option and were not subject to a prior-authorization processes administered by a third-party RBM.

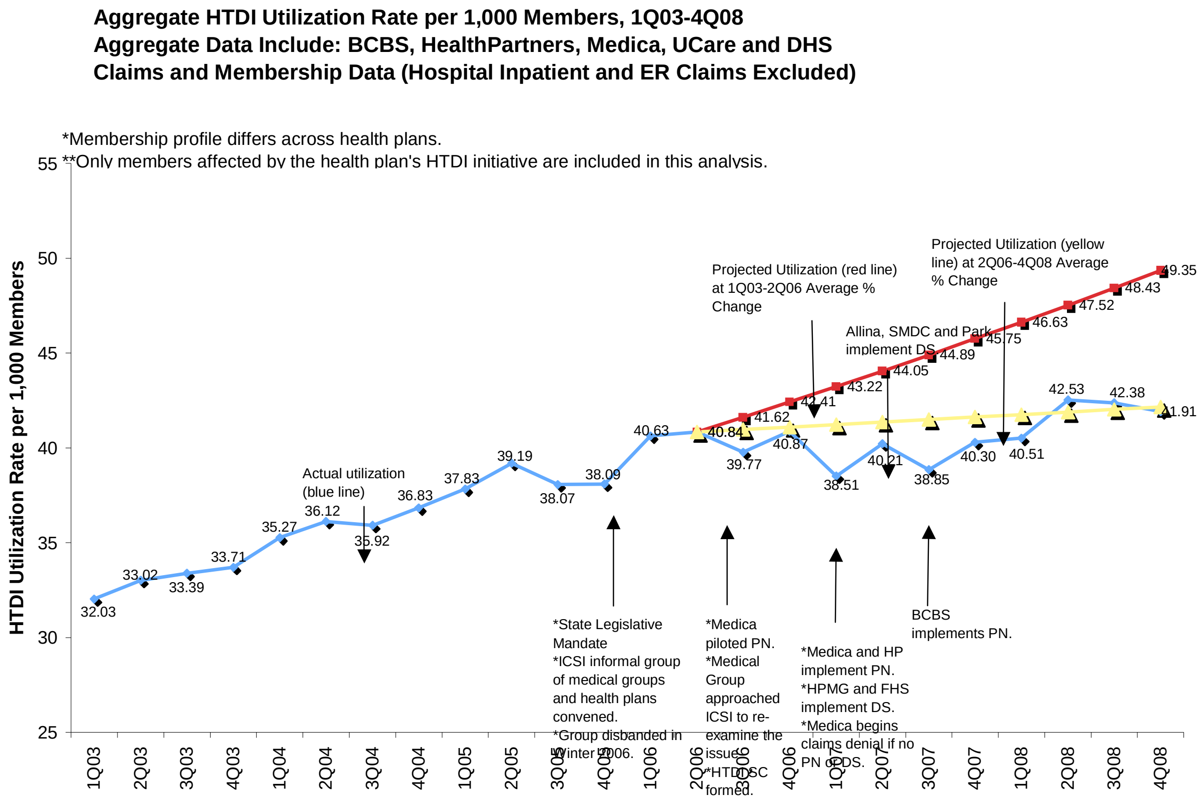

Figure 8 – Minnesota DS pilot results

Source: (Vinz 2009)

Based on the Minnesota case, if the providers have the option between the RBM process and the DS tool process, they would prefer to use the latter because it eliminates expenses and inefficiencies of the RBM process. As shown in Figure 9, the DS tool process reduces the hassle of rescheduling scans and enhances physician decision making effectiveness by providing immediate feedback on appropriateness.

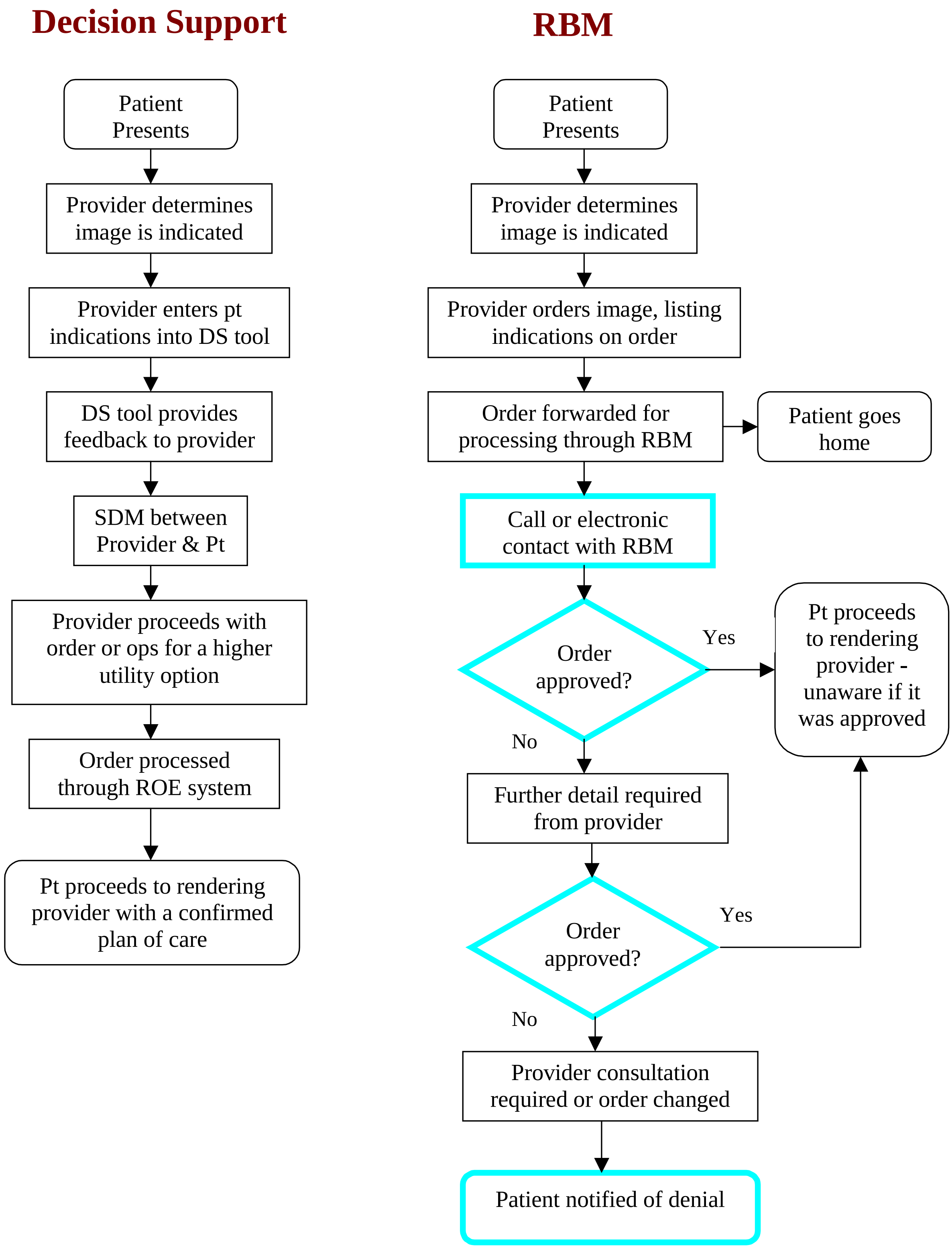

Figure 9 – DS and RBM workflows

Source: (Vinz 2009)

2.3 Benefits

As discussed in Section 2.1, the main benefits of DS tools are improved quality of care and reduced overall costs (Vasko 2008; Fisher 2009; Gifford 2009; Hole-Curry 2009; Holzberger 2009; Khorasani 2009; Sistrom, Dang et al. 2009; Vasko 2009; Vinz 2009; Wiley 2009; Moan 2010). Here we discuss these benefits in more detail.

Improved quality of care

The DS tools ensure that the right HTDI test is ordered at the right time for the right reason using widely accepted evidence-based criteria at point of care. This reduces the inappropriate and unnecessary HTDI tests and the risk of cancer caused by unnecessary radiation (Gifford 2009; Hole-Curry 2009; Holzberger 2009; Khorasani 2009; Vinz 2009).

The DS tools also enhance the patient-physician relationship because it provides education to the physician and the patient, at the point of care, and allow them to engage in the decision-making process (Gifford 2009; Khorasani 2009; Vinz 2009; Wiley 2009). As Courneya notes about this joint ownership of the decision (Wiley 2009): "That becomes an important tool as the patient and the provider decide if a study is necessary. By having good information in the exam room, the physician can show the patient that a scan is really not going to be helpful and tell the patient what to watch for when a scan might be needed in the future."

The speed with which the latest medical knowledge is disseminated through the deployment of the DS tool is another key factor contributing to the improvement in the quality of care. Without DS tools it takes between 5-14 years to get the latest evidence-based guidelines into practice, with DS tools, evidence-based guidelines can be adopted and enforced within 4-8 weeks (Khorasani 2009). According to Courneya (Vasko 2008): "Uses for imaging technology change so rapidly these days that it can be difficult for referring physicians to keep up with best uses, but with clinical decision support, new information can be rapidly disseminated. For example, the American Cancer Society's recent revisions to its breast-cancer screening guidelines. We were able to make sure the new criteria were implemented in the decision-support process so that women who needed the test were getting it more consistently, and women who did not were having a good conversation with their primary care physicians."

When compared with the RBM process, the DS tools process is faster and more efficient, as shown in Figure 9. It utilizes the latest knowledge of medical practices to eliminate the approval time and reduce the rescheduling of scans so that diagnosis and initiation of care can start earlier (Vinz 2009).

Reduced overall costs

A key objective of the DS tools is to eliminate inappropriate and unnecessary HTDI tests, thereby lowering the overall HTDI procedure volume and costs (Vasko 2008; Hole-Curry 2009; Vasko 2009; Vinz 2009; Wiley 2009). For example, the Minnesota adoption pilot, presented in Section 2.2, reduced the HTDI claims among five insurers/payers by approximately 9%, which represented an overall savings of around $28 million. The Minnesota Institute for Clinical Systems Improvement estimated that the DS tools solution has the potential to save $60 million annually when implemented statewide (Vinz 2009).

When compared with the RBM process, the DS tool process is more efficient, patient centered and cheaper (Vasko 2009; Vinz 2009; Wiley 2009). As Panza mentioned in Wiley (Wiley 2009): "The decision-support reductions in imaging volume give results comparable to those of RBMs at a fraction of the cost. When health plans see how this works, it will be hard for them to pay the RBMs 25 to 30 cents (per member, per month) when they can get this for a nickel."

2.4 Adoption Barriers

The most commonly cited DS tools adoption barriers are misaligned financial incentives, lack of research evidence, lack of market education, and providers' resistance to change (Vasko 2008; Blumen and Nemiccolo 2009; Khorasani 2009; Vasko 2009; Wiley 2009). In this section, each of these hurdles is explained in detail.

Misaligned financial incentives

Misaligned financial incentives are the most powerful barriers influencing the DS tools adoption process (Vasko 2008; Khorasani 2009). In the current payment structure of the U.S. healthcare system, the insurers/payers are the principal beneficiaries of the DS tools (due to the reduction in the HTDI claims or the elimination of the RBM costs) while the providers are expected to pay all costs associated with the adoption (which includes the implementation costs & the maintenance costs). Moreover, the providers also lose revenue due to the reduction of the HTDI volume. As Tierney points out (Vasko 2008): "The health plans' costs have decreased. As for us, when our volume's down 5% to 15%, our revenue's down 5% to 15%, but our expense base stays the same."

Lack of research evidence

Another major barrier to adoption is the lack of overwhelming research evidence about the DS tools benefits (Wiley 2009). As referred in Section 2.1, today there are only few adoption cases, which is not enough to clearly demonstrate that DS tools are the most efficient way to reduce the HTDI costs and increase the quality of care.

To increase research evidence, in 2010 the U.S. government is providing grants to the National Institutes of Health organizations for the purpose of studying the impact and effectiveness of DS tools (US_Government 2010). As Thrall mentioned in Wiley (Wiley 2009): “In passing the Medicare Improvement and Patient Protection Act of 2008, Congress authorized a demonstration program for physician-developed imaging-appropriateness criteria such as those demonstrated in the MGH study of ROE–DS. While the MGH study won’t suffice as a demonstration project, it can serve as a guide to the outside entity that eventually conducts such a demonstration. That demonstration may be a year away.”

Lack of market education

A lack of published articles, seminars, documentaries, advertisement and other such outlets that inform the market about the DS tools and benefits is another barrier to adoption (Vasko 2009). Today, not all the parties involved in the adoption process are aware that DS tools exist. As Cowsill notes (ibid): “We began to gather support for the coalition and hired a firm in Washington, DC, to help us educate people on Capitol Hill. What we heard from people is that this is the option they’d been looking for, but they never knew it existed.”

Providers resistance to change

The last barrier highlighted in the literature was the providers/physician resistance to change (Blumen and Nemiccolo 2009). Physicians resist the use of DS tools for a variety of reasons, but the main reason is the belief that the use of an EHR and DS tools will decrease clinical productivity and affect financial reimbursement. Other reasons range from not wanting a computer system to infringe on their decision making to something known as alert fatigue. Alert fatigue is when physicians have been exposed to poorly implemented EHRs that warn them continuously of possible problems as they access the system. Moreover, many of the DS tools used today have been developed without clinician input, increasing resistance to their use.

3 System Dynamics Methodology

This chapter summarizes relevant literature on the system dynamics methodology. It will not be possible to extend a detailed review of the system dynamics domain, as it is a rich field of study. We refer interested reader to Sterman (Sterman 2000) for a comprehensive discussion on this topic.

3.1 Overview

System dynamics is a methodology and computer simulation modeling technique for framing, understanding, and discussing complex systems. What makes system dynamics different from other approaches to studying complex systems is the use of feedback loops, stocks and flows. Stocks and flows help describe how a system is connected by feedback loops, which create the nonlinearity found so frequently in modern day problems.

The system dynamics methodology was developed by Professor Jay W. Forrester of the Massachusetts Institute of Technology in mid 1950s. Originally developed to help corporate managers improving their understanding of the industrial enterprise dynamics (Forrester 1961), system dynamics is currently being used in a wide range of complex problem domains. These domains include modeling of environmental systems (Meadows, Meadows et al. 1992), public policies (Lee 2005), national networking technology systems (Kelic 2005), national electric power systems (Black 2005), global air transportation systems (Bonnefoy 2008), etc. This methodology has also been used in the analysis of healthcare issues, such as the study of cost, access and quality problems in the U.S. healthcare system (Hirsch, Homer et al. 2005), the study of the German health insurance system (Grösser 2005), the study of the Ugandan immunization system (Rwashana and Williams 2008), etc.

The system dynamics methodology was chosen to conduct this research because the U.S. healthcare system is a very complex system comprising multiple stakeholders with conflicting interests and different levels of ownership and power. In order to understand the DS tools adoption process, it is necessary to understand the dynamics of the system as a whole, including the interactions of all the key stakeholders. The discussion in the following sections will make it amply clear why system dynamics tools are most suited to capture the interactions central to our inquiry.

System dynamics methodology has two distinct aspects: Qualitative and quantitative. Due to absence of “good” quantitative data about the DS tools adoption process, the quantitative analysis of the DS tools adoption process is out of the scope for this research, and therefore this study only uses the system dynamics qualitative concepts, tools and framework. In section 4.3 we revisit this point and argue that due to the nascent nature of the problem and absence of “good” quantitative data, the qualitative analysis is, in fact, better suitable for studying the DS tools adoption process challenge.

3.2 Qualitative Concepts and Tools

According to Sterman (Sterman 2000), people have the tendency to interpret experience as a series of events. Every event has a cause, which in turn is an effect of some earlier cause. This event-oriented worldview leads to an often event-oriented approach to problem solving - see Figure 10.

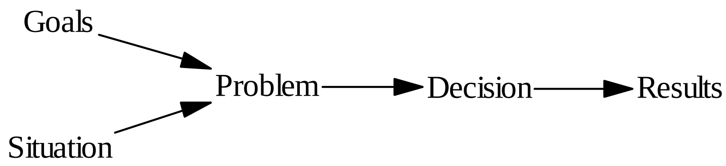

Figure 10 – Event-oriented view of the world
Source: (Sterman 2000), p. 10

However, in reality, the decisions alter the environment, leading to new decisions, and also trigger side effects, delayed reactions, changes in goals and interventions by others. All these feedbacks often lead to unanticipated results. Figure 11 shows this feedback structure. Feedback is one of the core concepts of system dynamics, and discussed in more detail in the following section.

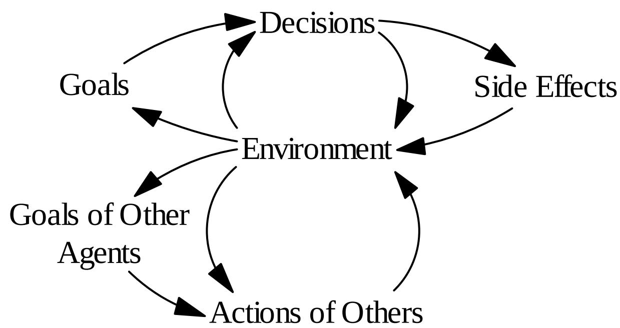

Figure 11 – The feedback view of the world
Source: (Sterman 2000), p. 11

Causal loop diagram

Causal loop diagrams are central to the application of the system dynamics approach to study any complex problem. The goal of this tool is to enhance the understanding of a problem by exposing the structure of the system and the relationships present between relevant system elements. As Sterman explains (Sterman 2000), all dynamics of a system arise from the interaction of two types of feedback loops, reinforcing (positive) and balancing (negative) loops. Reinforcing loops tend to reinforce or amplify whatever is happening in the system. Figure 12 shows an example of a reinforcing loop and explains the key concepts.

Reinforcing loop: Reinforcing loops are self-reinforcing. In this example, more chickens lay more eggs, which hatch and add to the chicken population, leading to still more eggs, and so on. The arrows indicate the causal relationships. The + signs at the arrowheads indicate that the effect is positively related to the cause: an increase in the chicken population causes the number of eggs laid each day to rise above what it would have been (and vice versa: a decrease in the chicken population causes egg laying to fall below what it would have been). The loop is self-reinforcing, hence the loop polarity identifier R. If this loop were the only one operating, the chicken and egg population would both grow exponentially. Of course, no real quantity can grow forever. There must be limits to growth. These limits are created by balancing loops.

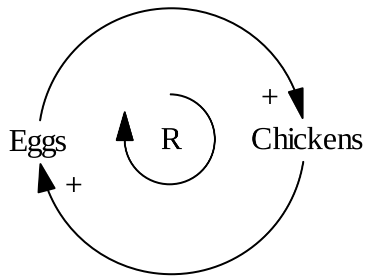

Figure 12 – Reinforcing loop
Source: (Sterman 2000), p. 13

On the other hand, balancing loops counteract and oppose change. Figure 13 presents an example of a balancing loop and explains the key concepts.

Balancing loop: Balancing loops are self-correcting. They counteract change. As the chicken population grows, various balancing loops will act to balance the chicken population with its carrying capacity. One classic feedback is shown here: The more chickens, the more road crossings they will attempt. If there is any traffic, more road crossings will lead to fewer chickens (hence the negative – polarity for the link from road crossings to chickens). An increase in the chicken population causes more risky road crossings, which then bring the chicken population back down. The B in the center of the loop denotes a balancing feedback. If the road-crossing loop was the only one operating (say because the farmer sells all the eggs), the number of chickens would gradually decline until none remained.

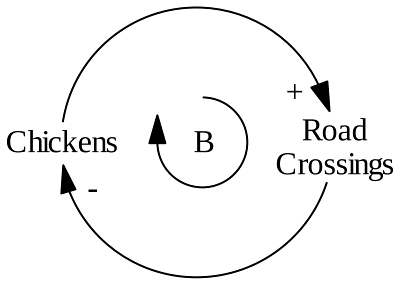

Figure 13 – Balancing loop
Source: (Sterman 2000), p. 13

A system typically comprises many such causal loops. When combined to represent the system, a comprehensive view of the system becomes available to the decision maker. Figure 14 shows the causal loop diagram that captures the feedback structure of the "eggs-chickens-road crossings" system.

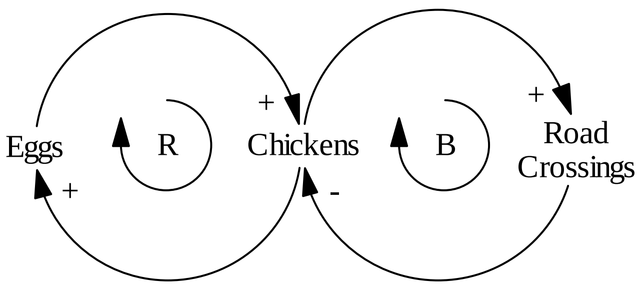

Figure 14 – Feedback structure of the "eggs-chickens-road crossings" system
Source: (Sterman 2000), p. 14

Guidelines for building causal loop diagrams

Building causal loop diagrams is not an easy task. The literature reviewed contains multiple guidelines for building causal loop diagrams. The foundation of these guidelines is built upon insights from cognitive psychology, which increases the level of complexity that individuals and groups can deal with. Here we present a summary of the key guidelines proposed by Sterman (Sterman 2000).

- Causation versus Correlation – Every link in the diagram must represent causal relationships between the variables. Do not include correlations between variables.
- Labeling link polarity – Label the polarity of every link in the diagram (+/-) and every feedback loops (R/B).
- Determining loop polarity – Count the number of negative links in the loop. If the number of negative links is even, the loop is a Reinforcing loop (R); if the number is odd, the loop is a Balancing loop (B).
- Name your loops – Give each feedback loop a number and a name. Numbering the loops R1, R2, B1, B2, and so on help the reader find each loop as we discuss it. Naming the loops helps the reader understand the function of each loop and provides useful shorthand for discussion.
- Indicate important delays in causal links – The causal diagrams should include delays that are important to the dynamic hypothesis or significant relative to the time horizon.
- Variable Names – Variables names should be nouns or nouns phrases, the actions (verbs) are captured by the causal links connecting the variables. Choose variable names for which the meaning of an increase or decrease is clear. Choose variables whose normal sense of direction is positive.

- Causal loop diagram layout - Maximize the clarity and impact of the causal loop diagrams: Use curved lines for information feedbacks. Organize the diagrams to minimize crossed lines.
- Choose the right level of aggregation – Causal loop diagrams are designed to communicate the central feedback structure of our dynamic hypothesis. They are not intended to be descriptions of a model at the detailed level of the equations. Having too much detail makes it hard to see the overall feedback loop structure and how the different loops interact.
- Don't put all the loops into one large diagram – Develop a separate diagram for each important loop.
- Distinguish between actual and perceived conditions – Often there are significant differences between the true state of affairs and the perception of that state by the actors in the system.

3.3 Qualitative Framework

There are various system dynamics modeling approaches published in the literature. In general, and as referred in section 1.2, the creation of the qualitative system dynamics models involves four different steps as outlined below (Randers 1980; Sterman 2000).

1. Define the purpose of the model;
2. Define the model boundary and identify key variables;
3. Describe the behavior or draw the reference modes of the key variables;
4. Diagram the basic mechanisms, the feedback loops, of the system.

Before we explain each step, it is important to note that the four steps are recursive. After completing each step we have to return to previous steps to incorporate new information or insights. No strict dividing lines exist between the steps.

The first step of the modeling process, deciding on the model purpose, is a two-part decision. Deciding on the model purpose means focusing on a problem and narrowing down the model's audience. By deciding on the model's purpose, we make the later choices of both components and structure feasible. We should also consider a model's primary audience. If the model's structure and behavior cannot be understood by its audience, or if it does not answer questions interesting to the audience, then the model is rendered useless

The second step, defining the model boundary involves selecting components necessary to generate the behavior of interest as set by the model purpose. After choosing what problem area to focus on, we must gather relevant data and further define the focus of the model. Relevant data consists not only of measured statistical data, but also operating knowledge from people familiar with the system being analyzed. Every feedback system has a closed boundary within which the behavior of interest is generated. We must identify all components we see as necessary for creating a model of the system, even those of which we are unsure.

After defining the model boundary and identifying key variables, some of the most important variables are graphed over time as a reference mode. A reference mode graph has time on the horizontal axis and units of the variables on the vertical axis. The reference mode captures mental models and historical data on paper, gives clues to appropriate model structure, and can check plausibility once the model is built. We construct reference modes to check for the existence of some phenomenon or behavior worth modeling. The historically observed and the hypothesized reference modes are the two types of reference modes that we may create during this step. Historical reference modes use historical data, but when no historical information is available, we must create a hypothesized reference mode. The hypothesized reference mode consists of a simplified curve, typically drawn by hand, capturing the key features of the behavior pattern of the important system components. Common hypothesized reference mode behaviors are exponential growth, exponential decay, overshoot and collapse, S-shaped growth, and damped, sustained and expanding oscillations. A hypothesized reference mode might show the future behavior once a specific policy is carried out.

The final step is deciding on the basic mechanisms of the system. Specifically, the basic mechanisms are the feedback loops in the model. The basic mechanisms represent the smallest set of realistic cause-and-effect relations capable of generating the reference mode. The basic mechanisms may also be thought of as the simplest story that explains the dynamic behavior of the system. When deciding on the basic mechanisms, we must first mentally decide on a dynamic hypothesis. A dynamic hypothesis is an explanation of the reference mode behavior and should be consistent with the model purpose. We must use a dynamic hypothesis to draw out and test the consequences of the feedback loops. Then we must create diagrams illustrating the basic mechanisms driving the system's dynamic behavior. The most common diagrams used in this phase are the causal loop diagrams, which we presented in section 3.2.

3.4 Qualitative Sources of Data

According to Sterman (Sterman 2000), much of the data we use during the qualitative phase comes from interviews and conversations with people in organizations. There are many techniques available to gather data from members of organizations, including surveys, interviews, participant observation, archival data, and so on. Surveys generally do not yield data rich enough to be useful in developing system dynamics models. Interviews are an effective method to gather data useful in formulating a model. Semi-structured interviews (where we have a set of predefined questions to ask but we are free to depart from the script to pursue avenues of particular interest) have proven to be particularly effective.

Interviews are almost never sufficient alone and must be supplemented by other sources of data. People have only a local, partial understanding of the system, so we must interview all relevant actors, at multiple levels, including those outside the organization (customer, suppliers, etc.). Interview data is rich, including descriptions of decision processes, internal politics, attributions about the motives and characters of others, and theories to explain events, but these different types of information are mixed together. We must triangulate the information by using as many sources of data as possible to gain insights into the structure of the problems situation and the decision process of the actors in it. Once we have completed the interviews, we must be able to extract the causal structure of the system from the statements of the interview subjects. The variables names are formulated so that they correspond closely to the actual words used by the person interviewed, while still adhering to the principles for proper variable name selection described in section 3.2 (noun phrases, a clear and positive sense of direction). Causal links should be built with the links suggested by the interviews and should be supplemented with other data sources such as our own experience and observations, archival data, and so on. In many cases, we will need to add additional causal links not mentioned in the interviews or other data sources.

3.5 Software

In 1958, Richard Bennett created the first system dynamics computer modeling language called SIMPLE (Simulation of Industrial Management Problems with Lots of Equations). Later on, in 1959, Jack Pugh wrote the first version of DYNAMO, an improved version of SIMPLE, which is known as the first system dynamics simulation program. Today, the most popular system dynamics softwares are iThink/Stella, Vensim, and PowerSim. In this study, Vensim 5.9e (Ventana Systems) will be used. Figure 15 shows the feedback structure of the "eggs-chickens-road crossings" system using Vensim 5.9e.

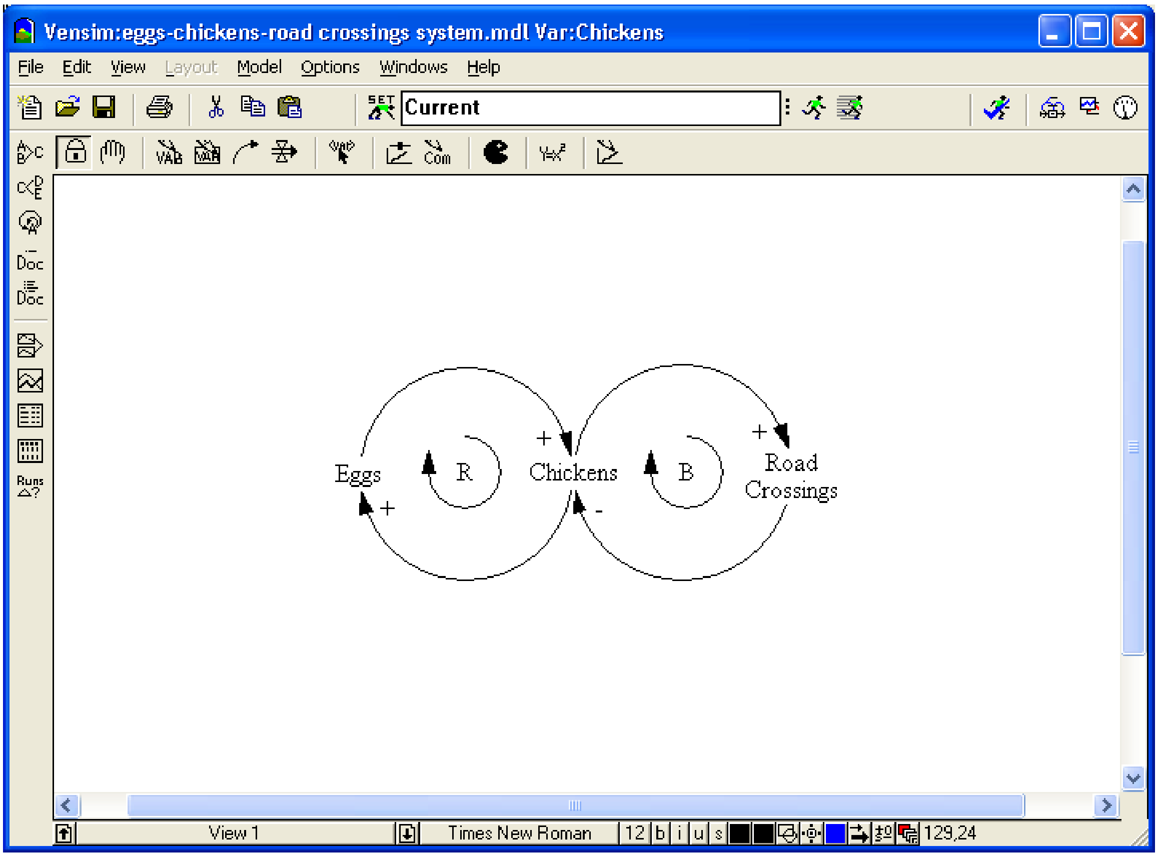

Figure 15 – Feedback structure of the "eggs-chickens-road crossings" system using Vensim 5.9e

4 DS Tools Adoption Qualitative System Dynamics Model

We present the qualitative system dynamics model for DS tools adoption in this chapter. There are four sections that describe the model development and analysis. In the first section, we explain the major sources of data used in this research. The second section shows the step-by-step process to create the DS tools adoption qualitative system dynamics model. In the third section, we analyze and discuss the insights from the model. And, in the final section, we identify potential strategies that vendors could implement to increase adoption by using the insights from the model and brainstorming sessions with vendors.

4.1 Sources of Data

As referred in section 3.4, there are many techniques available to gather data from members of organizations, including surveys, interviews, participant observation, archival data, and so on. The U.S. healthcare system is a very complex system comprising multiple stakeholders, including vendors, providers, private insurers/payers, government/payer, etc. To gain insights into the structure of the problem situation and the decision process of the key actors we need to gather data from each of the key stakeholders.

Semi-structured interviews are one of the most effective methods to gather data useful in formulating a model where limited knowledge about the system is available. Unfortunately, we did not have access to all the key stakeholders. Hence, we decided to gather data from the vendors using semi-structured interviews and gather data from the other key stakeholders using the discussions and presentations from the "Symposium for evidence-based medicine as the foundation to better care". The symposium proved to be an effective source of data because during the symposium, key healthcare stakeholders discussed and shared information about evidence-based medicine, DS tools and DS tools adoption, including presentations about their initiatives and best practices. In the symposium, the vendors were represented by General Electric Healthcare and Medicalis, the providers were represented by Brigham and Women's' Hospital, the private insurers/payers were represented by Regence and the government/payer was represented by Washington State Health Care Authority. The Institute for Clinical Systems Improvement also attended to present the DS tools adoption case from Minnesota.

To complement the information from the vendor's interviews and the symposium, other articles from medical journals and healthcare web site were also reviewed. Table 1 shows the major sources of data used in this research. The DS tools are not yet commonly used and therefore not a well documented topic. For future research on this topic, it is recommended that providers, private insurers/payers and the government/payers are interviewed to obtain primary data.

Key Stakeholders	Sources of Data
Vendors	• Semi-structured interviews with General Electric Healthcare • General Electric Healthcare discussion and presentation from the Symposium for evidence-based medicine as the foundation to better care (Holzberger 2009) • Medicalis discussion and presentation from the Symposium for evidence-based medicine as the foundation to better care (Fisher 2009)
Providers	• Massachusetts General Hospital article from the Radiology Journal (Sistrom, Dang et al. 2009) • Brigham and Women's' Hospital discussion and presentation from the Symposium for evidence-based medicine as the foundation to better care (Khorasani 2009)
Private Insurers/Payers	• Regence discussion and presentation from the Symposium for evidence-based medicine as the foundation to better care (Gifford 2009)
Government/Payer	• Washington State Health Care Authority discussion and presentation from the Symposium for evidence-based medicine as the foundation to better care (Hole-Curry 2009) • U.S. Department of Health and Human Services articles from the U.S. Department of Health and Human Services web sites (CMS 2009; CMS 2010; US_Government 2010)
Others	• Institute for Clinical Systems Improvement discussion and presentation from the Symposium for evidence-based medicine as the foundation to better care (Vinz 2009) • American College of Radiology article from the American College of Radiology web site (ACR 2010) • Radiology Business Journal articles from ImagingBiz.com (Vasko 2008; Vasko 2009; Wiley 2009) • Diagnostic Imaging article from DiagnosticImaging.com (Moan 2010) • Milliman research report from Milliman publications (Blumen and Nemiccolo 2009) • The New England journal of medicine article from The New England journal of medicine (Iglehart 2009)

Table 1 - Sources of data on DS tools

4.2 Model Creation

This section discusses the creation of the DS tools adoption qualitative system dynamics model following the four steps presented in section 3.3. Although we describe the steps in a sequential order, the steps are iterative and this will be highlighted throughout the section as needed.

Step 1 - Define the purpose of the model

The first step of the modeling process, define the model purpose, has two parts: Decide the model purpose and narrow down the model's audience.

For our research, as discussed in section 1.1, the purpose of our model is to understand the DS tools adoption process and to identify potential strategies that vendors could implement to increase adoption. And the audience for our model is the vendors, which are most interested in insights based on a simple, easy-to-understand model with highly aggregated components.

Step 2 - Define the model boundary and identify key variables:

Considering the large number of variables, developing a one-to-one representation of the system in study is difficult. Therefore, simplifications and assumptions in the model are inevitable. In this research, a model that captures the main issues/factors affecting the DS tools adoption process is the focus. These issues have been identified with the help of the vendors' semi-structured interviews, the "Symposium for evidence-based medicine as the foundation to better care" and literature reviewed. Topics that are frequently discussed, issues that are stressed by experts will be the sources of factors included in the model. In addition, while the model mimics the dynamics of the process from a system's perspective, when a specific point of view is needed to properly define a variable and integrate it into the model, the vendors' view will be taken into consideration.

Table 2 lists the key variables that were included in the final DS tools adoption qualitative system dynamics model. As referred before, the development of system dynamics models is an iterative process, the original variables list only included factors stressed during the symposium, highlighted in the literature reviewed and discussed during the first interview, such as the DS tools benefits, barriers, etc. The variables list changed throughout the construction of the causal loop diagram (step 4) and the multiple interviews with the vendors.

It is important to note that the key variable names correspond closely to the actual words used during the interviews, symposium and the literature reviewed, while also adhering to the principles for proper variable name selection described in section 3.2 (noun phrases, a clear and positive sense of direction).

Key Variables
Research evidence & market education about overall cost/quality benefits
Providers with DS tools
Interest from potential adopters
Providers awareness of quality benefits
Providers awareness of cost increase/revenue decrease
Providers resistance to change
Private insurers/payers awareness of cost reduction
Private insurers/payers provide incentives for adoption
Government/payer awareness of cost/quality benefits
Government intervention/provide incentives for adoption
Public awareness of cost/quality benefits
Public pressure

Table 2 – Variables included in the final DS tools adoption qualitative system dynamics model

Step 3 - Describe the behavior or draw the reference modes of the key variables:

As referred before, the DS tools is not yet a well documented topic and therefore no historical data was found during the data gathering. However, with the help of the vendors, we created hypothesized reference modes for the “providers with DS tools” variable, as shown in Figure 16.

The “Providers with DS tools – No incentives” line represents the current behavior of the “Providers with DS tools” variable: The adoption is increasing at a very slow rate. The “Provider with DS tools – With incentives” line represents the expected behavior if the private insurers/payers and/or the government/payer provide some kind of incentives for adoption: The adoption should increase with an S-shaped growth, similar to what happens with other technologies’ adoption. As is the case when developing the hypothesized reference modes, there are no numerical values on the y-axis of the graph because the goal is to capture the hypothesized current and future behavior patterns.

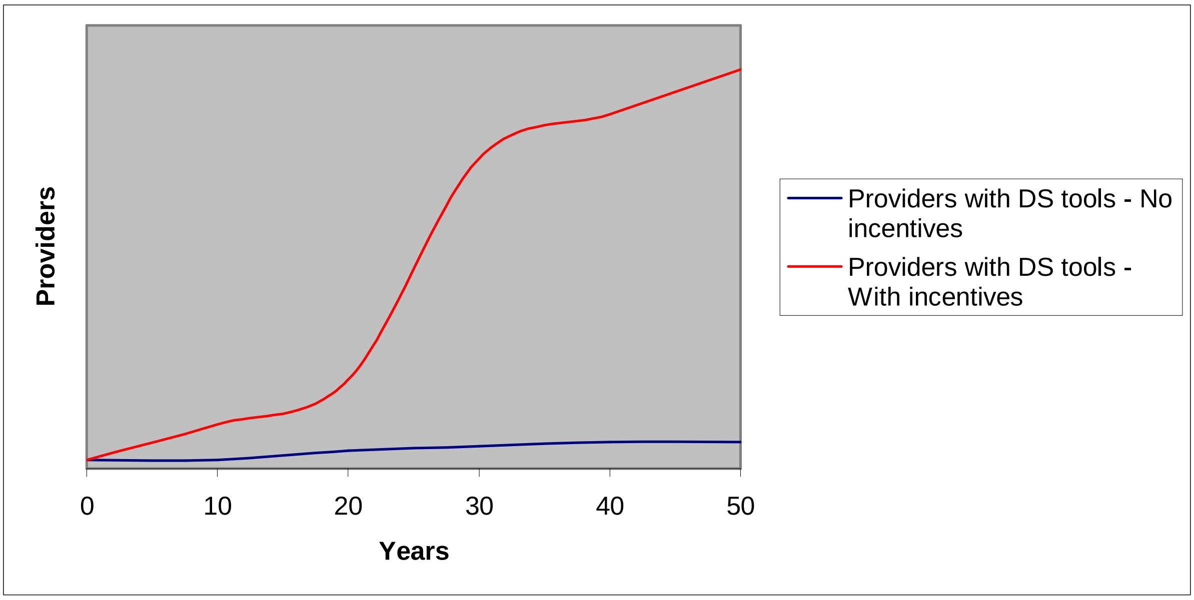

Figure 16 – Hypothesized reference modes for DS tools adoption

Step 4 - Diagram the basic mechanisms, the feedback loops, of the system:

The final step is defining the causal feedback loops capable of generating the reference modes. Starting with the first list of key variables, identified in step 2, causal links were built with the links suggested in the interviews and supplemented with implied links from the symposium and the literature reviewed. After multiple iterations, which required multiple interviews with the vendors, and following the causal loop diagrams guidelines published in Sterman (see section 3.2), a DS tools adoption causal loop diagram was created to represent the major adoption factors, their causal relationships and their effects on the overall adoption process. Figure 17 shows the final version of the DS tools adoption causal loop diagram.

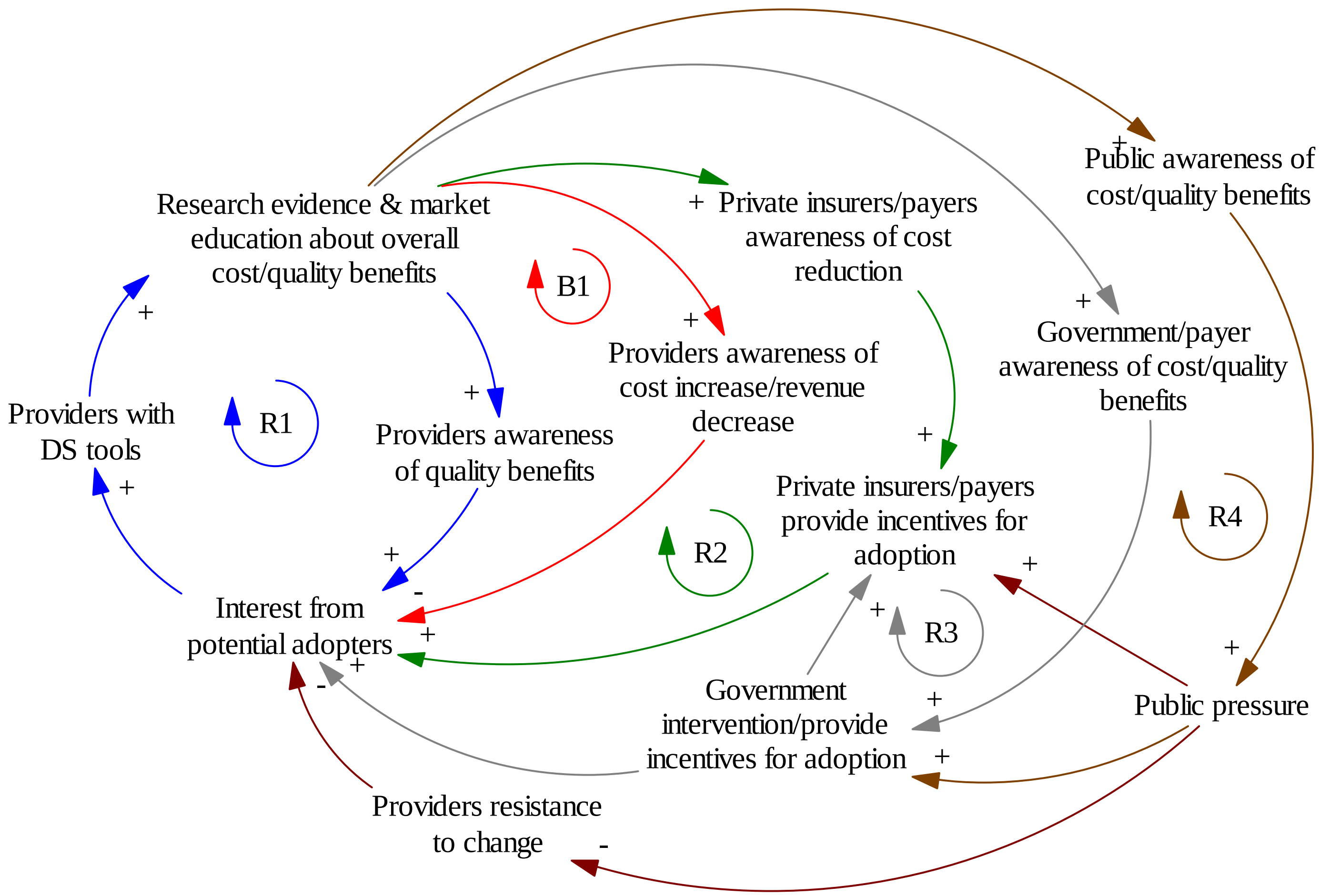

Figure 17 – DS tools adoption causal loop diagram

Below we explain the feedback loops identified in Figure 17. A loop pad, which is a graphical representation of the cause and effect relationship in each loop, is shown. It should be noted that although the loops are presented separately, they are not disconnected. On the contrary, interactions among them is key to determining the system dynamics.

Loop R1 – Providers awareness of quality benefits loop

It is safe to assume that as more providers use DS tools, there would be an increase in the research evidence and market education (published articles, seminars, documentaries, advertisement, etc) about the overall DS tools cost/quality benefits. More research evidence and market education would further increase the providers' awareness about the quality of care benefits, which would increase the interest from potential adopters, specially those that see quality as a differentiator. All these cause and effect relationships are captured by loop R1, as shown in Figure 18.

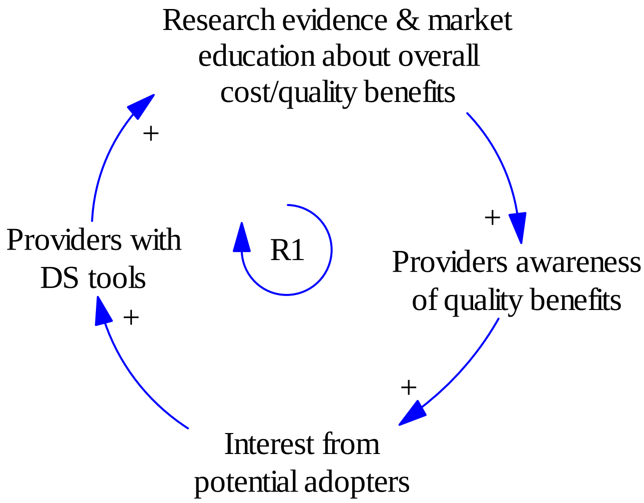

Figure 18 – Providers awareness of quality benefits loop

Loop B1 – Providers awareness of cost increase/revenue decrease loop

More research evidence and market education would also increase the providers' awareness of their cost increase (implementation & maintenance costs) and revenue decrease (reduction in the HTDI volume), which would decrease the interest from potential adopters. Loop B1, in Figure 19, represents these causal relationships.

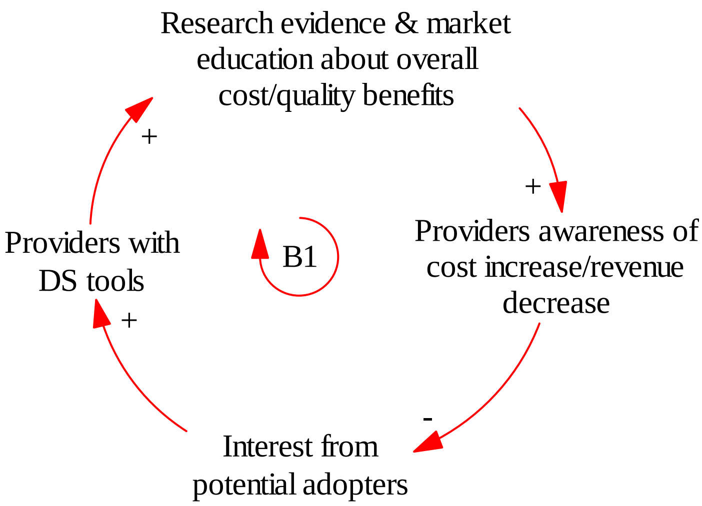

Figure 19 – Providers awareness of cost increase/revenue decrease loop

Loop R2 – Private insurers/payers awareness of cost reduction loop

More research evidence and market education would increase the private insurers/payers awareness of their cost reduction (reduction in the HTDI claims or elimination of the RBM costs). Once the private insurers/payers are aware of their cost reduction, they would potentially provide incentives to increase provider's adoption. Figure 20 depicts these causal relationships.

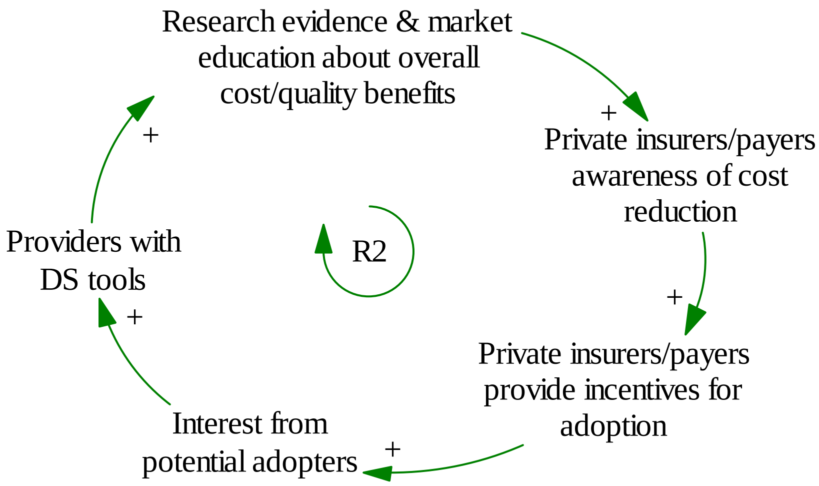

Figure 20 – Private insurers/payers awareness of cost reduction loop

Loop R3 – Government/payer awareness of cost/quality benefits loop

More research evidence and market education would increase the government awareness of the overall cost/quality benefits. The government would potentially intervene and would provide incentives to increase provider's adoption. The government is the biggest payer in the U.S. and accountable for approximately 45% of the total U.S. healthcare costs (CMS 2010). Once the U.S. government intervene, they would influence the private insurers/payers to also provide incentives to increase provider's adoption (Moan 2010). These causal relationships are represented in Figure 21.

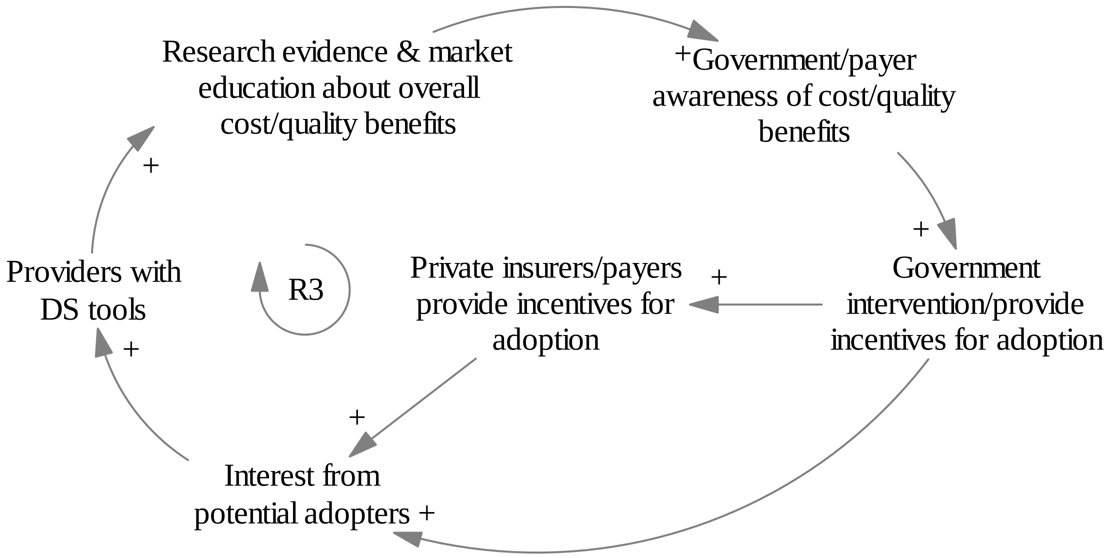

Figure 21 – Government/payer awareness of cost/quality benefits loop

Loop R4 – Public awareness of cost/quality benefits loop

Loop R4, in Figure 22, shows that once the Public is aware of the cost/quality benefits, they would put a lot of pressure on the Private insurers/payers, Government and Providers. The Private insurers/payers would potentially provide incentives to increase provider’s adoption (because of the public pressure & government influence and because of the costs reduction represented in loop R2). The Government would potentially intervene and would provide incentives for adoption (because of the public pressure and because of the overall cost/quality benefits represented in loop R3). The Providers resistance to change should also decrease, which would increase the potential interest for adoption.

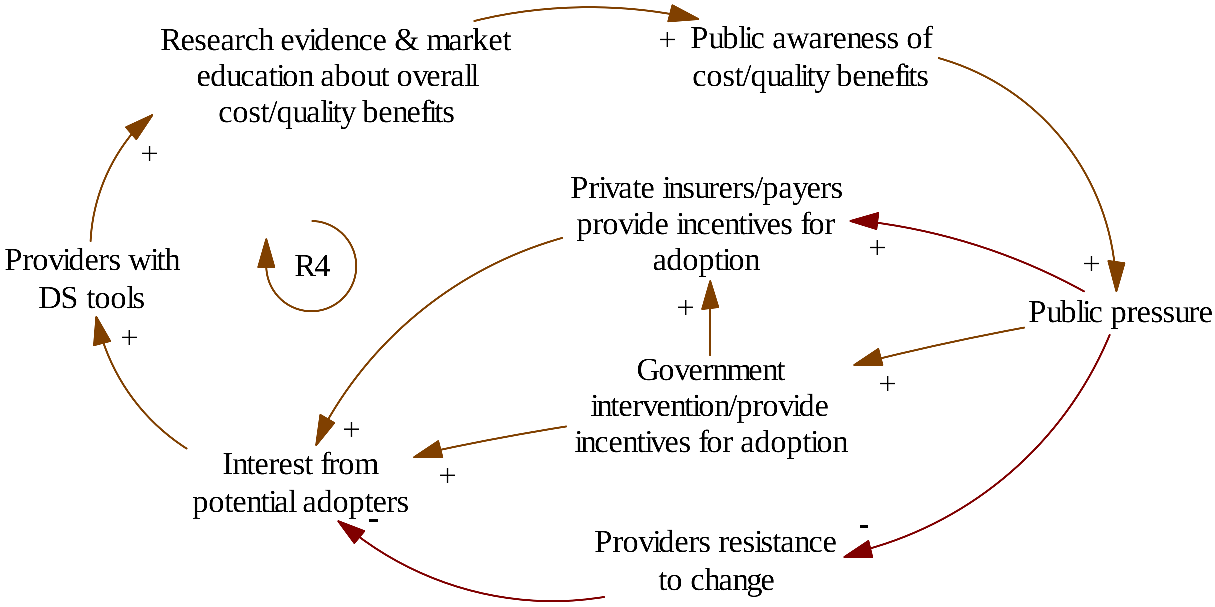

Figure 22 – Public awareness of cost/quality benefits loop

The DS tools adoption causal loop diagram (Figure 17) reflects the anticipated behavior of the overall system (current and future behavior). The feedback loops reveal how the factors that influence the process interact, and how these interactions affect the behavior of the system.

4.3 Model Discussion

The concept of building and analyzing qualitative system dynamics models emerged in the 1980's, most prominently in the writings of Eric Wolstenholme, Geoff Coyle and Peter Senge (Wolstenholme and Coyle 1983; Wolstenholme 1985; Senge 1990; Coyle and Alexander 1996; Coyle 1999; Coyle 2000) as a way of thinking about systems without the necessity of developing a quantitative model as is required in conventional system dynamics methodology. While the development and analysis of qualitative system dynamics models is fraught with potential pitfalls as George Richardson (Richardson 1986; Richardson 1997) has pointed out, Coyle and Wohstenholme argue that the value of the process of developing qualitative models stimulates probing dialogue that facilitates sharing of insights and knowledge across a group and for building stronger understanding of the issue or problem modeled. Groups often find that building a good qualitative model (with its inherent dialogue and discussion) resolves the issue such that quantitative models may not be critical for gaining insights and strategic assessment of the issue. Complex problems plagued by high levels of uncertainty and information constraints are not good candidates for traditional quantitative model development and analysis.

The qualitative system dynamics models, particularly in the form of causal loops diagrams, have been shown to stimulate deeper dialogue, to increase the level of complexity that individuals and groups can deal with, and to aid in communicating and sharing perceptions and concepts. Today, the majority of the articles in the system dynamics domain, such as the presentations at the System Dynamics Annual Conferences use qualitative system models, usually in the form of causal loop diagrams, for presenting model structure and analysis, supporting the perception that qualitative system models communicate more clearly and efficiently than conventional quantitative system dynamics models although the latter can convey more information.

Accordingly, we propose that studying the DS tools adoption process challenge is best suited for the qualitative system dynamics model approach. A qualitative approach is uniquely applicable in this instance due to the novel nature of the problem and absence of ‘good’ quantitative data. By allowing us to gather rich insights much more quickly and efficiently than the traditional quantitative system dynamics models, we will be able to initiate a structured and productive dialogue to bring attention to key issues plaguing this domain. It is important to reiterate that the DS tools are one of the key developments that hold out hope for the rapidly deteriorating performance of the healthcare system, which is critical to the overall health of any economy and society.

Key insights into the DS Tools adoption challenge

In this section, we use the DS tools adoption causal loop diagram to help us presenting the key insights that we learned from the process of developing the DS tools adoption qualitative system dynamics model.

The DS tools adoption causal loop diagram (Figure 17) is a graphical representation of the feedback structure of the system, and reflects the anticipated behavior of the overall system (current and future behavior). This diagram contains one balancing loop (B1) competing with four reinforcing loops (R1, R2, R3 & R4). As Donella Meadows notes (Meadows and Wright 2008): "Systems often have several competing feedback loops operating simultaneously, those loops that dominate the system will determine the behavior".

Due to the vendors' effort, the providers seem to be aware of the DS tools, which means that loops R1 and B1 should be active. Today, however, the adoption of the DS tools in the U.S. healthcare system is very limited suggesting that loop B1 is currently the dominant loop. This seems to make sense because all the providers in the U.S. system are private companies, and like any other private company, their ultimate goal is to maximize profitability. Except the world-class healthcare providers, such as the Massachusetts General Hospital or the Brigham and Women's Hospital, the implementation of DS tools at most providers is likely to reduce their profitability due to the cost increase (implementation & maintenance costs) and revenue decrease (reduction in the HTDI volume). This also explains why the original vendor's strategy, which was to focus on providers (See Figure 3), did not yield the expected results.

Through the process of developing the DS tools adoption qualitative system dynamics model, it has become clear that in order to increase adoption, the stakeholders that are the principal beneficiaries of the DS tools (payers and patients) would need to be aware of the DS tools and their benefits so that they could influence adoption. This is represented in the DS tools adoption causal loop diagram by loops R2, R3 and R4. Because today adoption is very low, this seems to indicate that loops R2, R3 and R4 are currently non-active or dormant, and therefore to increase adoption, it is important to strengthen these reinforcing loops to make them the dominant loops and change the system's behavior. Based on this insight, the vendors, who are trying to increase adoption, should shift their focus from the Providers, who are their main customers, to the Private Insurers/Payers, Government/Payer & General Public to strengthen loops R2, R3 and R4 respectively. In the next section some strategies that vendors could implement to strengthen these loops will be explored.

As referred before, the development of system dynamics models is an iterative process, each iteration results in a better and more robust model. Our goal is to continually gain deeper insights into the structure of the problem to frame more effective hypothesis and ideas. Accordingly, we strive to include the most important factors at each iteration, but our model and it implications are unlikely to ever be "complete". However, the process of developing the DS tools adoption qualitative system dynamics model, which included data and opinion from a variety of sources along with a visual model that follows guidelines from cognitive psychology, allow us to better understand the DS tools adoption process in the U.S. healthcare system.

4.4 Potential Strategies to Increase Adoption

In this section we present potential strategies that vendors could implement to strengthen loops R2, R3 and R4, and consequently to increase adoption. These strategies were formulated by using the insights from the model and by conducting brainstorming sessions with vendors.

Strategies to strengthen the private insurers/payers awareness loop (R2)

The healthcare IT vendors enjoy strong influence over the care delivery practices. Accordingly, they should leverage the few existing cases, such as the MGH case and the Minnesota case presented in Section 2.2, and focus some of their advertisement/sales efforts on educating the private insurers/payers market.

Strategies to strengthen the government/payer awareness loop (R3)

The government is starting to be aware of the DS tools cost/quality benefits. As part of the American Recovery & Reinvestment Act, in 2010 the U.S. government is going to provide grants to the National Institutes of Health organizations that propose to study the impact and effectiveness of DS tools (US_Government 2010). The vendors should partner with world-class healthcare providers to apply for these grants and be part of this study to increase research evidence and government/payer awareness.

As referred before, in the U.S., the private market economy dominates the healthcare industry. Therefore, unlike other industrialized nations, the role of the government has been minimal in all areas except regulation and the payment of the publicly funded section of the healthcare market[2], which is run by the Centers for Medicare and Medicaid Services (CMS), an agency of the Department of Health and Human Services. For regulation, since there are no statutory health insurance schemes, there has been no strict government control on the healthcare sector other than health policies and laws. Due to the increasing costs of healthcare, however, circumstances are pushing the government to redefine its role, and take a firm stand. In this regard, the government has started to emphasize the concept of cost vs. quality. Working

[2] The publicly funded section of the healthcare market targets people who are not employed. There are two types of publicly funded insurance: Medicare and Medicaid. Medicare provides coverage to people 65 years and older and some people with disabilities under age 65; and Medicaid covers selected low-income individuals who cannot afford private insurance.

with several government affiliates and/or many non-profit organizations, the government is pushing for improvements in quality of healthcare while reducing costs.

As alluded to throughout this research, an overarching strategy is hard to achieve due to fragmented structure of the U.S. healthcare system. There are too many players with different interests and different levels of ownership and power and it is quite difficult to align them. The U.S. healthcare system does not have a central authority that can preside over these conflicts of interest, and therefore it is critical that the U.S. government, who is the biggest U.S. healthcare payer, acknowledge that DS tools offer one of the most effective ways to decrease the government/payer HTDI costs and increase quality of care. We believe that the referred grants are the first government intervention/incentive for adoption, however, once the government/payer acknowledge the importance of the DS tools, it would potentially enforce adoption by providing incentives to those providers that demonstrate meaningful use of DS tools. The idea behind this proposal is similar to what the government is doing to enforce the EHR adoption (CMS 2009).

Strategies to strengthen the public awareness loop (R4)

Today the general public is not aware of the DS tools and their cost/quality benefits. To create public awareness, vendors could use some of their advertisement budget to educate the general public. However, to increase the advertisement impact, the vendors should highlight how DS tools could reduce some of the key U.S. healthcare issues already simmering in the media and known to the general public. These include the issue of increasing U.S. healthcare costs that can bankrupt families, businesses and the government medicare/Medicaid (CMS), and the overuse of HTDI technologies that can cause cancer in the future. Some examples of the headlines regarding these key U.S. Healthcare issues are presented below.

“President Obama: Federal Government 'Will Go Bankrupt' if Health Care Costs Are Not Reined In” – ABC News (Travers 2009)

“Study Links Medical Costs and Personal Bankruptcy - Harvard researchers say 62% of all personal bankruptcies in the U.S. in 2007 were caused by health problems - and 78% of those filers had insurance” – BusinessWeek (Arnst 2009)

“How to Cut Health-Care Costs: Less Care, More Data: Health costs are bankrupting small businesses and even conglomerates like General Motors as well as millions of families. Medicare is on track to go broke by 2017, and our long-term budget problems are primarily health-cost problems.” – Time (Grunwald 2009)

“CT Scan Radiation May Cause Cancer Decades Later, Study Finds: If CT scan use remains at its current level or higher, eventually 29,000 cancers every year could be related to past CT scan use. That number is equal to about 2 percent of the 1.4 million cancers diagnosed each year in the U.S. The number of CT scans should be reduced, they said, citing previous reports that 30 percent or more may be unnecessary.” – Bloomberg (Ostrow 2009)

“Radiation from CT scans linked to cancers, deaths: CT scans deliver far more radiation than has been believed and may contribute to 29,000 new cancers each year, along with 14,500 deaths, suggest two studies in today's Archives of Internal Medicine. In many cases, CT scans can be lifesaving. In other cases, there's no evidence a CT scan is really better than other approaches, Smith-Bindman says.” – USA Today (Szabo 2009)

“New Focus on Dangers of CT Scans: Dose of Radiation Varies Greatly from One Hospital to Another; Skyrocketing Scans Could Lead to 29,000 New Cancer Cases” – CBS Evening News (LaPook 2009)

5 Conclusions and Recommendations

The healthcare industry in the United States (U.S.) has purchased and installed high-tech diagnostic imaging (HTDI) equipment, such as computed tomography, magnetic resonance imaging and ultrasonography, at an astounding rate, outpacing all other countries. Although HTDI has significantly enhanced a physician's ability to diagnose and treat a variety of diseases, studies have suggested that today between 20 to 30 percent of the U.S. HTDI tests do not contribute to treatment, which represents a waste of $4 to $6 billions annually and exposure patients to unnecessary radiation. To solve this problem, healthcare IT vendors have developed high-tech diagnostic imaging clinical decision support (DS) tools to reduce the inappropriate and unnecessary use of HTDI tests. However, despite obvious benefits, adoption of the DS tools has been lower than expected.

The aim of this research was to understand the DS tools adoption process in the U.S. healthcare system and to identify potential strategies that vendors could implement to increase adoption. To reach these goals, this research used the system dynamics methodology because it enhances the understanding of complex systems, such as the U.S healthcare system, by showing the dynamics of the whole system, including the interactions of all the key stakeholders.

Based on the review of the DS tools literature and multiple discussions with experts in the healthcare domain, a DS tools adoption qualitative system dynamics model was created to represent the major adoption factors, their causal relationships and their effects on the overall adoption process. The DS tools adoption qualitative system dynamics model provided some key insights about the adoption process, including the reason why adoption is not happening and what vendors could do to increase adoption. Based on the insights from this model, the vendors, who are trying to increase adoption, should shift their focus from the Providers, who are their main customers, to the Private Insurers/Payers, Government & General Public to increase adoption.

The main contributions of this research include:

1. Summarization of the relevant information regarding the DS tools from specialized literature and discussions with healthcare experts. This summary was presented in Chapter 2, and it includes a brief overview, the most known adoption cases, the main benefits and the main adoption barriers.

2. The DS tools adoption qualitative system dynamics model, presented in Chapter 4, which allows us to better understand the DS tools adoption process in the U.S. healthcare system.

3. Increased awareness of the DS tools and formalization of the DS tools adoption problem in the U.S healthcare system.

Being one of the first of its kind, this study is by no means comprehensive and without limitations. One obvious future research effort would be to review and validate the proposed model. Indeed, expanding the DS tools adoption qualitative system dynamics model to include other stakeholders (such as RBMs and patients), breaking down the existing stakeholders (such as distinguish providers by type and size), among others would present another opportunity to add richness to the model and generate even more powerful insights.

The insights and recommendations presented in this study were developed based on qualitative analysis of the system dynamics model. As mentioned in Chapter 3, the quantitative analysis of the DS tools adoption process was out of the scope for this research, and creates several opportunities for future research. One obvious opportunity would be to pursue the creation of a system dynamics simulation model using the DS tools adoption qualitative system dynamics model from this research. The simulation model could be used to test various vendor strategies suggested in Chapter 4. This would help identify strategies that would yield the best results. The simulation model could also be used to test potential government interventions, such as different reimbursement policies, to evaluate their impact on the DS tools adoption process.

References

ACR (2010). "ACR Appropriateness Criteria." Retrieved June 5th, 2010, from http://www.acr.org/SecondaryMainMenuCategories/quality_safety/app_criteria.aspx.

Arnst, C. (2009). "Study Links Medical Costs and Personal Bankruptcy." Retrieved May 12th, 2010, from http://www.businessweek.com/bwdaily/dnflash/content/jun2009/db2009064_666715.htm?campaign_id=rss_daily.

Black, J. W. (2005). Integrating Demand into the U.S. Electric Power System: Technical, Economic, and Regulatory Frameworks for Responsive Load. Enginnering Systems Division, Massachusetts Institute of Technology. **Ph.D.**

Blumen, H. and L. Nemiccolo (2009). "The convergence of quality and efficiency and the role of IT in healthcare reform ". Retrieved June 10th, 2010, from http://publications.milliman.com/publications/healthreform/pdfs/convergence-quality-efficiency-role-RR06-01-09.pdf.

Bonnefoy, P. A. (2008). Scalability of the Air Transportation System and Development of Multi-Airport Systems: A worldwide Perspective. Enginnering Systems Division, Massachusetts Institute of Technology. **Ph.D.**

CMS (2009). "Medicare And Medicaid Health Information Technology: Title IV Of The American Recovery And Reinvestment Act." Retrieved May 12th, 2010, from http://www.cms.gov/apps/media/press/factsheet.asp?Counter=3466&intNumPerPage=10&checkDate=&checkKey=&srchType=1&numDays=3500&srchOpt=0&srchData=&keywordType=All&chkNewsType=6&intPage=&showAll=&pYear=&year=&desc=&cboOrder=date.

CMS (2010). "National Health Expenditure Data." Retrieved June 27th, 2010, from http://www.cms.gov/NationalHealthExpendData/02_NationalHealthAccountsHistorical.asp#TopOfPage.

Coyle, R. G. (1999). Qualitative Modeling in System Dynamics or What are the wise limits of quantification. 17th International Conference of the System Dynamics Society. S. D. Society. Wellington, New Zealand.

Coyle, R. G. (2000). "Qualitative and Quantitative Modelling in System Dynamics : Some Research Questions." *System Dynamics Review*(16): 225-244.

Coyle, R. G. and M. W. D. Alexander (1996). "Two Approaches to Qualitative Modeling of a Nation's Drug Trade." *System Dynamics Review*(13): 205-222.

Fisher, M. (2009). Medicalis. Symposium for evidence-based medicine as the foundation to better care. Seattle, U.S., GEHC.

Forrester, J. W. (1961). Industrial dynamics. [Cambridge, Mass.], M.I.T. Press.

Gifford, J. (2009). Regence Radiology Quality Initiative (RQI) Program Symposium for evidence-based medicine as the foundation to better care. Seattle, U.S., GEHC.

Grösser, S. (2005). Modeling the Health Insurance System of Germany: A System Dynamics Approach. 23rd International Conference of the System Dynamics Society. S. D. Society. Boston, U.S.

Grunwald, M. (2009). "How to Cut Health-Care Costs: Less Care, More Data." Retrieved May 11th, 2010, from http://www.time.com/time/politics/article/0,8599,1905340,00.html#ixzz0nfHpp8M0.

Hirsch, G., J. Homer, et al. (2005). Achieving Health Care Reform in the United States: Toward a Whole-System Understanding. 23rd International Conference of the System Dynamics Society. S. D. Society. Boston, U.S.

Hole-Curry, L. (2009). Using Evidence For Better Health Policy. Symposium for evidence-based medicine as the foundation to better care. Seattle, U.S., GEHC.

Holzberger, K. (2009). Our Role in Driving Responsible Imaging. Symposium for evidence-based medicine as the foundation to better care. Seattle, U.S., GEHC.

Iglehart, J. K. (2009). "Health Insurers and Medical-Imaging Policy." The New England journal of medicine **360**: 1030-1037.

Kelic, A. (2005). Networking Technology Adoption: System Dynamics Modeling of Fiber-to-the-Home. Enginnering Systems Division, Massachusetts Institute of Technology. **Ph.D.**

Khorasani, R. (2009). Using Healthcare IT to Enable Evidence-Based Medicine: Radiology as case example. Symposium for evidence-based medicine as the foundation to better care. Seattle, U.S., GEHC.

LaPook, J. (2009). "New Focus on Dangers of CT Scans." Retrieved May 12th, 2010, from http://www.cbsnews.com/stories/2009/12/14/eveningnews/main5979332.shtml.

Lee, T. P. (2005). Examining Local SocialWelfare Policy Implementation Using System Dynamics Perspective. 23rd International Conference of the System Dynamics Society. S. D. Society. Boston, U.S.

Meadows, D. H., D. L. Meadows, et al. (1992). Beyond the limits : confronting global collapse, envisioning a sustainable future. Post Mills, Vt., Chelsea Green Pub. Co.

Meadows, D. H. and D. Wright (2008). Thinking in systems : a primer. White River Junction, Vt., Chelsea Green Pub.

Moan, R. (2010). "Experts see big implications for radiology in federal clinical decision support efforts." Retrieved June 8th, 2010, from http://www.diagnosticimaging.com/practice-management/content/article/113619/1514172.

Ostrow, N. (2009). "CT Scan Radiation May Cause Cancer Decades Later, Study Finds." Retrieved May 11th, 2010, from http://www.bloomberg.com/apps/news?pid=20601124&sid=aETXq6qDpjNY.

Randers, J. (1980). Elements of the system dynamics method. Cambridge, Mass., MIT Press.

Richardson, G. P. (1986). "Problems with causal-loop diagrams." Retrieved September 8th, 2010, from http://www.sysdyn.clexchange.org/sdep/Roadmaps/RM4/D-33312-2.prd.

Richardson, G. P. (1997). "Problems in Causal-Loop Diagrams Revisited." *System Dynamics Review*(13).

Rwashana, A. S. and D. W. Williams (2008). "System Dynamics Modeling in Healthcare: The Ugandan Immunisation System." International Journal of Computing and ICT Research **1**(1): 85-98.

Senge, P. M. (1990). The fifth discipline : the art and practice of the learning organization. New York, Doubleday/Currency.

Sistrom, C. L., P. A. Dang, et al. (2009). "Effect of Computerized Order Entry with Integrated Decision Support on the Growth of Outpatient Procedure Volumes." Radiology Journal **251**: 147-155.

Sterman, J. (2000). Business dynamics : systems thinking and modeling for a complex world. Boston, Irwin/McGraw-Hill.

Szabo, L. (2009). "Radiation from CT scans linked to cancers, deaths." Retrieved May 12th, 2010, from http://www.usatoday.com/news/health/2009-12-15-radiation15_st_N.htm.

Travers, K. (2009). "President Obama: Federal Government 'Will Go Bankrupt' if Health Care Costs Are Not Reined In." Retrieved May 12th, 2010, from http://blogs.abcnews.com/theworldnewser/2009/12/president-obama-federal-government-will-go-bankrupt-if-health-care-costs-are-not-reigned-in.html.

US_Government (2010). "ARRA OS Recovery Act Limited Competition: Impact of Decision-Support Systems on the Dissemination and Adoption of Imaging-Related Comparative Effectiveness Findings (UC4)." Retrieved April 20th, 2010, from http://grants.nih.gov/grants/guide/rfa-files/RFA-OD-10-012.html.

Vasko, C. (2008). "Minnesota's Bold Experiment: Radiologist as RBM." Retrieved June 5th, 2010, from http://www.imagingbiz.com/articles/view/minnesotas-bold-experiment-radiologist-as-rbm/.

Vasko, C. (2009). "Coalition Forms to Promote Clinical Decision-support Tools." Retrieved June 10th, 2010, from http://www.imagingbiz.com/articles/view/coalition-forms-to-promote-clinical-decision-support-tools.

Ventana Systems, I. "Vensim." Retrieved January 15th, 2010, from http://www.vensim.com.

Vinz, C. (2009). Minnesota Experience Decision-Support. Symposium for evidence-based medicine as the foundation to better care. Seattle, U.S., GEHC.

Wiley, G. (2009). "MGH Decision-support Study: A Shot Across the RBM Bow." Retrieved June 6th, 2010, from http://www.imagingbiz.com/articles/view/mgh-decision-support-study-a-shot-across-the-rbm-bow/.

Wiley, G. (2009). "RBMs: The Debate Heats Up." Retrieved June 5th, 2010, from http://www.imagingbiz.com/articles/view/rbms-the-debate-heats-up/.

Wolstenholme, E. F. (1985). A Methodology for Qualitative System Dynamics. 3rd International Conference of the System Dynamics Society. S. D. Society. Denver, U.S.

Wolstenholme, E. F. and R. G. Coyle (1983). "The Development of System Dynamics as a Rigorous Procedure for System Description." *Journal of the Operational Research Society*(34): 560-581.