THE HEALTHCARE SYSTEM in the United States is the largest of its kind in the world. Unfortunately, it is not the most effective.

Experts affirm that, when the amount of money spent is compared with the quality of healthcare received, the United States is far behind such industrial countries as Norway, Great Britain and France.\(^1\)

The common solution for these countries was to establish electronic health records (EHR) and employ them in a state-regulated network. In the United States, President Bush issued an executive order in April 2004 calling for the development of a national system of interoperable EHR for all Americans by 2014.\(^2\)

Many communities have already begun the process of transforming from paper-based to electronic-based records, but their level of success has varied. While many disparate entities, both public and private, are spending huge amounts of money to build EHR networks, these efforts have met with varying levels of success and many questions remain as to the return on investment (ROI) for the development of these networks. According to The Standish Group International Inc., a Boston-based research firm, each year the cost of failures and unnecessary overspending for information technology projects is about $55 billion.\(^3\)

“The outcome of the Santa Barbara Project, a regional health information organization [RHIO], however, suggests that other local efforts to create health information exchanges would do well to address the value question upfront, at the beginning of their work,” said David Holmquest, chief executive of the California Regional Health Information Organization (CalRHIO). “Today, creating a sustainable business model—particularly, a model that will support the initial costs of constructing information exchange platforms and linking local providers and other entities—is one of the biggest challenges for nascent health information exchange [HIE] efforts.”\(^4\)
SEARCHING FOR A SOLUTION

Unlike basic healthcare equipment or office functions which provide obvious and often singular efficiency improvements, clinical and decision-support applications are more complex to analyze in terms of ROI.

Quantifying the value of EHR networks on healthcare delivery involves understanding the impact of many interrelated factors involving patient care, clinical practices, medical outcome and organizational structure. Some healthcare organizations have successfully employed modeling and simulation to gain a broader perspective on their business processes across multiple areas before they invested a lot of time and money implementing changes, and have thus avoided costly and ineffective process changes.

Danbury Hospital, with the help of IBM Healthcare, employed modeling and simulation to analyze how technology could affect several different aspects of process flow by identifying key impacts on efficiency. After an EHR system was implemented, patient safety and in-patient throughput increased from 5.8 percent to 8.1 percent, and the number of exchanges among physicians, nurses and secretaries in the paper entry system was reduced. When Danbury had a proposition to change the bed mix, the IBM team demonstrated that the results from the change would be far from what was expected. Like many hospitals today, Banner Health, a Phoenix-based hospital, was faced with space limits and process constraints in its Emergency Department as a result of high patient volume. Incorporating guidelines and suggestions from the Institute for Healthcare Improvement (IHI) and other successful providers resulted in some improvement, but the process was slow and painful, and results did not meet expectations. With the use of modeling technology, it achieved a phenomenal 50-percent to 300-percent improvement in patient waiting times. Patient satisfaction increased from the 9th to the 99th percentile, and productivity improved with out any staff increases.

A NEW APPROACH

Agent-based modeling and simulation (ABMS) is a new alternative to traditional modeling techniques. ABMS allows decision-
makers to experiment using a simulated healthcare system that closely mimics the real world. With very little upfront investment, policymakers can use agent simulations to pose various health delivery and use scenarios, and examine the outcome in terms of expected cost and long-term system dynamics.

ABMS models comprise independent agents that act according to simple rules. An “agent” within the model can represent any entity that takes an action. It could be an institution, a patient, a physician, an organization, or a group of any of them. Interacting agents create patterns of behavior that can be either expected or unexpected. Simulating the agents’ decisions and interactions allows analysts to follow how system-level as well as individual-level patterns emerge from simpler rules defined at the individual level. ABMS helps decision-makers understand macro-level effects generated by micro-level behavior through time. Figure 1 (page 40) shows a possible representation of individuals and groups at differing levels within a healthcare organization. ABMS modeling can show how the effects of individual physicians can influence actions of agents at the group level (e.g., hospitals and insurance agencies), as well as perhaps affecting policies at the organization level. The two-way feedback (e.g., how policies affect physicians’ behavior) can also be modeled and analyzed with ABMS models.

Unlike basic healthcare equipment or office functions which provide obvious and often singular efficiency improvements, clinical and decision-support applications are more complex to analyze in terms of ROI.

Agents may act intentionally or unintentionally, and overall outcomes may represent the cumulative effect of many thousands of individual agent actions and interactions among agents. Figure 2 (above) shows possible relationships between various
agents within a simulation. These relationships may be modeled as behaviors and actions within an ABMS system. A healthcare-based ABMS model can provide answers to questions such as how to avoid undesirable events, plan interventions and achieve an optimal balance to ensure stakeholders’ ROI. ABMS helps in analyzing an organization’s alternative courses of actions in response to precipitating events. Because of its unique ability to analyze a wide range of vulnerability management solutions, it is employed for a variety of practical business and government purposes.²

BROAD USAGE OF ABMS IN BUSINESS AND GOVERNMENT

In 1997, an ABMS technique was used by the Bios Group for the NASDAQ stock market to evaluate the impact of tick-size reduction before it employed new trading policies. NASDAQ could not afford a negative reaction from investors. An agent-based model was used to evaluate the effect of regulatory changes under various conditions in order to study unpredictable behavior of investor agents and uncover possible vulnerabilities in the system. The study provided much faster outcomes and did not involve any losses.³

In early 2003, the US Army Training and Doctrine Command Analysis Center (TRAC) experimented with agent-based modeling techniques. Its primary focus was to use ABMS as an exploratory tool for analyzing alternative approaches to defense mobilization problems. The agent-based model was used to simulate different economic conditions under various scenarios and by doing so, it helped in understanding the impact of changes in the market conditions. The study evaluated the effect of regulatory changes in the market and how these changes impacted the behavior of investor agents. The model was able to capture the complex interactions between the various stakeholders in the market. The study showed how ABMS could be used as a tool for analyzing alternative approaches to defense mobilization problems.⁴

EMCAS is the latest tool in Argonne National Laboratory’s suite of analysis software for modeling electric power systems. ABMS was used to model a decentralized electricity market. This tool reflects an interaction between real-life market participants (agents), such as electric generation companies, demand companies, consumers, regulators, and system operators. Each company agent has its own objectives, such as maximizing profit, reducing risk exposure, and increasing market share. The interaction is conducted in multiple layers (physical, economical, financial and regulatory) within nested time scales.

It is used to study adequacy of the transmission system to support market operations; existence of loopholes for extreme behavior of stakeholders; potential levels of profitability for stakeholders; customer satisfaction; and influence of policymakers on the market. EMCAS is successfully employed by a number of organizations in the United States and other countries to test the effectiveness of alternative mitigation measures for their respective electrical markets.

ADDRESSING HEALTHCARE NEEDS WITH ABMS

With many successes, agent-based simulation has shown that it is well-suited for the study of complex, heterogeneous, non-linear systems such as healthcare. Agent-based simulations are an ideal alternative to upfront investment in systems that have an unknown impact on quality and cost. The challenge of any modeling process is to define and measure quality and ROI from various stakeholders’ perspectives and provide a viable solution for all parties involved. ABMS can do exactly this and provide actionable outcomes for decision makers by evaluating various stakeholders’ goals and the complex processes needed to reach those goals. It can help build trust among the players and prepare them for real collaboration and ensure a shared vision and mission.

BUILDING THE MODEL

As an example, in the area of EHRs and health information exchange (HIE), ABMS can be used to model how individual players (agents) interoperating with each other at the micro-level can impact the results at the broader macro-level. This could allow decision makers to select the best approach for EHR interoperability on the basis of the results of the modeling outcomes. HIE encompasses numerous stakeholders, including, but not limited to, hospitals, physicians, clinics, insurance companies, government agencies, patients, and pharmacies. Each one has, in addition to common concerns like legal liability, ownership of data, competitiveness among the same service providers, and funding issues, its own individual objectives in collaborating with the HIE. Specific HIE concerns for some of the key stakeholders include the following:

Hospitals and large clinics. Objectives are to eliminate medical errors, improve personnel workflow, minimize waiting time for patients (ERs), change admission (less paperwork and clearer instructions), better utilize the equipment and workforce, decrease the number of uncompensated episodes and minimize any additional cost of medical staff training.

Small clinics and physicians. Goals are to get faster access to patient records, increase efficiency, eliminate manual management of paper-based health records, obtain user-friendly EHR applications and minimize the number of administrative personnel.

Medical laboratories. Goals are to simplify the placement of laboratory orders by physicians, eliminate errors related to those orders, achieve a paperless and nearly effortless process, get faster billing systems and improve interactions with physicians and patients to provide better service.

Insurance companies. Goals are to get control of patients’ health histories, eliminate unnecessary treatments, manage payments and get the patient out of the system (pay-for-performance).

Government agencies. Objectives are to provide the best regulations to support fair market, establish proper incentives for EHR implementation (tax cuts, grants), insure patient privacy,
control any deviations or misinterpretations and properly manage Medicaid, Medicare and Social Security funds.

**Pharmacies.** Goals are to establish electronic prescription systems and provide prescription medications for patients on travel.

**Pharmaceutical, biotechnology and medical equipment companies.** Goals are to access public information that can be used to direct future research or changes in the business setup.

**Patients.** Goals are to ensure patient confidentiality, get access to one's own records, get preventive medicine, get access to information and be active in community leadership.

**Employers.** Goals are to minimize the number of employee sick days, popularize preventive medicine, and spread awareness of possible complications.

Each one of these stakeholders can be implemented as an individual agent in an agent-based model. The setup may include different levels and groups of agents in a treelike structure (see Fig. 1). For example:

- Government, HIOs, and other big players as organizational level agents;
- Partners constituting HIO, government agencies, employers, and community organizations as a management-level agents; and
- Employees, patients, doctors, nurses, etc. as individual agents.

All these agents interact in a complex virtual network that reflects the real world. To help one visualize these dependencies, here's an example. A doctor can play the role of a CEO representing one of the HIO partners but can also be an employee and a potential patient. The doctor can act as a patient as well as a provider depending on his current role within the simulation as time passes.

**ASSESSMENT OF ALTERNATIVE ACTIONS**

By using agent-based modeling, the healthcare delivery system can be designed effectively by means of considering and contrasting a myriad of alternatives. These alternative designs must be evaluated for their performance, cost and ability to meet stakeholder expectations. Factors such as the following need to be taken into account before organizational and financial commitments are made:

For patients, there may be a need to estimate waiting times, service times, quality of service, data portability, privacy, medical care choices, personal information access, access to healthcare worker performance information, prescription tracking and other factors. For healthcare workers, there may be a need to estimate the effects of various methods of performance measurement, resource allocation strategies, incentive design support, medication delivery error rates, procedural error rates and other factors. For information networks, there may be a need to estimate bandwidth, latency, capacity provisioning and other requirements. For the data servers, there may be a need to estimate throughput, response times, storage capacity and other requirements. At the system level, there may be a need to consider security, scalability and reliability issues. Ultimately, costs need to be estimated at all levels as well as a measurement of the return on investment for a chosen implementation.

One worthwhile goal for an example ABMS model of EHR issues would be to evaluate which business model for EHR interoperability provides the best solution for future financial sustainability for HIOs.

Four broad provider-centric approaches for EHR interoperability and data ownership and three approaches for consumer-centric health records can be considered for modeling. Also, a number of revenue generating models for HIOs could be plugged in for analysis.

**PROVIDER-CENTRIC MODELS**

1. **Transaction models.** These often involve traditional electronic exchanges, such as e-mail, faxes, and regular postal mail of both the clinical and financial information among patients, providers, and insurance agencies.

2. **Centralized models.** These typically have a central database that stores all the patient data. Providers and caregivers access and update this information for each patient encounter.

3. **Federated models.** These accommodate the access of information among disparate EHR systems. They eliminate the need for a central database and enable the HIE organizations to attain interoperability, although some work is involved in making the data accessible by multiple entities.

4. **Combined (hybrid) models.** These combine a hosted physician EHR with a data repository.

**CONSUMER-CENTRIC MODELS**

1. **Smart card models.** Smart card or thumb-drive-based systems can provide personal control over the creation, management, and exchange of personal health information. Information can be within the exclusive control of an individual who can carry it along on hospital visits.

2. **Health data bank model.** The data bank maintains complete personal health records, acting as a “safety deposit box” for all personal health records. Accessing it is much like accessing one’s financial information from a bank account.

3. **Employer-based personal health records model.** In this system, all employee health records are maintained by the employer.

**REVENUE-Generating MODELS**

1. **Electronic commerce model.** This model represents a consortium of regional payers and providers.

2. **Service provider model.** This defines specific service packages that are delivered to its members.

3. **Provider cost reduction model.** This helps eliminate a duplication of services or unnecessary services not paid by payers.

4. **Public health informatics.** This acts as a resource for public health departments, academic programs, pharmaceutical and biotechnology companies, and medical device manufacturers.

Multifaceted simulation systems are initially built by using relatively simple simulation formulations; complexity can be added gradually. The simulations are structured so that it will be simple to swap alternative models of various processes in and out of the overall framework. This allows the decision-makers to try out various alternative hypotheses regarding these complex processes and see which ones tend to produce the most realistic and reasonable outcomes. This makes the system far more useful and enables it to be used for other future evaluations of processes.

All alternative models can be compared and analyzed on the
basis of several different financial metrics, such as financial management (cost-savings), staff management (increased efficiency), workflow management (improved patient-flow in emergency departments), utilization management (individual stakeholder ROI), information management (ease of implementation), communication management (central formulary), network management (security constraints) and testing management (to eliminate future implications).10

EXPERIENCE WITH AGENTS

Several years ago, Argonne began to investigate the use of agent-based simulation technologies to address healthcare quality, cost and risk issues. In a pilot study, interacting simulation agents represented persons (as patients, healthcare providers, etc.) and organizations such as medical departments, employers and insurers. The agents representing individual persons also carried object-based models of their physiologies, represented at sufficient detail to support simulation of the onset and progression of various medical conditions and the effects of interventions, including influences of disease risk factors. The pilot simulation provided predicted measures of performance and effectiveness for various alternatives in policies, guidelines, protocols, diagnostic equipment, medications and so on that took into account several key aspects of performance: clinical outcomes, utilization, logistics and costs.

A number of agent-based healthcare simulation initiatives are currently either underway or in planning stages. Argonne is presently collaborating with investigators at the RAND Corporation in RAND Health’s new Comprehensive Assessment of Reform Efforts (COMPARE) initiative. COMPARE is a nonpartisan attempt to develop and promote analytical tools and methodologies to help inform the debate on US national healthcare policy reform. The COMPARE simulation system will be a comprehensive framework within which ongoing, routine, and multidimensional evaluations of the impact of policy changes on the functioning of the US healthcare system can be conducted. It will include appropriate analytical tools for evaluating the magnitude of both intended effects and unintended consequences of proposed policy changes. COMPARE will attempt to explicitly represent the entire US healthcare picture, including characteristics and relevant dynamic behaviors of Federal and state governments and government regulatory agencies, health insurance providers, healthcare providers (for example, all 6,000 or so US hospitals will be represented individually), employers with their various benefit packages and individual persons and households, embedded in social networks relating to family, employment, finance, insurance, etc. The COMPARE simulation software is intended to be operational in advance of the 2008 national elections.

CONCLUSION

Although these healthcare simulation projects have somewhat different problem characteristics and specific goals, the main thrust is the same: to use agent-based simulation to provide decision-makers with a broader and deeper context in which to evaluate the consequences of adopting various alternative plans and policies before a lot of money and effort are expended to implement one or more of them. The complex, diverse and highly interlinked factors that come into play in making good decisions on how to “best” deploy and use EHRs make this decision process an excellent candidate for similar ABMS treatments. EHR-related issues that could be addressed effectively in this manner would include, for example, healthcare provider improvements in current services and possible opportunities for new services, new specialty units, etc.; government influence (effects of policy change and HIPAA requirements); ownership of data (EHR); short-term and long-term viability of HIE; information security issues; usefulness of HL7 forms as a standardized data exchange format; cost effectiveness and quality of patient care; patient satisfaction; pay-for-performance metrics; and frequency of using systems.

Finally, decision-makers and leaders are seeking to achieve a national level of interoperability within varied EHR systems, but this is a complex and daunting task. Therefore, analyzing HIE models by using ABMS, then implementing them at a local or regional level and gradually expanding this to a national level, might be the most practical approach given that the ultimate goal is to achieve universal buy-in from all stakeholders and to put the process on an ongoing path of success that is reflected in the ROI.

Agent-based modeling and simulation allows decision-makers to experiment using a simulated healthcare system that closely mimics the real world.

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