Making sense of U.S. health care system dynamics

James P. Thompson

University of Strathclyde Business School
Department of Management Science
c/o 55 Reservoir Road
Farmington, Connecticut 06032 USA
Telephone +1 860 676 8152
Email: james.thompson@strath.ac.uk

CIGNA HealthCare
Economic & Operations Research
900 Cottage Grove Road A142
Hartford, CT 06152
Telephone +1 860 226 8607
Email: jim.thompson@cigna.com

Abstract

Complexity of organization and resulting dynamic behavior are prominent attributes of the U.S. health care system. These characteristics often compel analysts to deconstruct problems and take a piece-by-piece approach. However, such a piecewise approach may miss subtle and powerful interactions within the larger health care system structure. System dynamics methodology can be applied to identify and resolve issues arising in complex social systems such as health care. In a commercial managed care organization, a comprehensive system dynamics simulation model of the U.S. health care system helps users to make sense of systemic behavior and forecast key trends.

Introduction

In the United States, health care is a constellation of potential and active consumers, service and product providers, legislative and regulatory institutions, and paying entities. Even a cursory review of literature on the subject of health care indicates that, for the most part, we try to make sense of health care in pieces. While this piecewise approach to making sense is essential in many instances, it runs the risk of missing how even small forces leveraged in large structures can thwart the best laid plans.

Karl Weick (1995) observed that making sense of one's experiences involves organizing those experiences to produce a story that is recognized by other members of the organization. As an integrative application of scientific method to management problems system dynamics methodology is applied to identify and resolve issues arising in complex social systems such as health care. A feedback model simulates how related pieces work as a system to generate interesting, and often problematic, behaviors.

The application of system dynamics at a U.S. commercial managed care organization (the Company) described in this paper helps decision makers to make sense of complex health care dynamics and understand the consequences of taking one decision or another.

Background: a national-level model for forecasting

As a commercial managed care organization (MCO), the Company developed and maintains a system dynamics simulation model of the U.S. health care system (HCS) to forecast national-level utilization rates and unit costs over a three-year forecast horizon.

HCS is a system dynamics model and simulates physical characteristics, information about the state of the system, and decision rules that people use to manage their affairs in of the health care sector of the economy. As Sterman (2000) describes it, macro level dynamics emerge from the behavior of individuals and organizations. However, unlike the marketplace for most goods and services, the U.S. health care marketplace is heavily intermediated. For the most part, consumers have little if any idea of the prices paid for their health care because the payer is a third party: an employment-based pay benefit or a government-supplied social insurance.[a]

HCS integrates patient behavior; physician development and practice; planning, development and utilization of hospital facilities; research, discovery and innovation in pharmaceuticals and other medical technologies; the impact of cost control initiatives by governmental and commercial managed care organizations as third-party payers; and the influence of medical malpractice insurance organizations on physician practice and patient utilization rates.

The principal purpose of HCS is to help managers to make sense of their experiences and to predict price and consumption[b] trends over a three-year horizon. The three year forecast horizon limits the need for simulating some health care variables. For example, HCS does not include feedback from health care utilization to health status of the population because longevity is not likely to be affected in that period. The descriptions that follow provide an overview of our assumptions about principal structures that influence utilization behavior in health care.

Overview of a Health Care System simulation model

Our approach to group model building incorporated many of the features of Vennix (2001) case study as well as Morecroft (1994) and Vennix et al. (1994). However, it is difficult to gather a group to explore complex issues, and a project can span hundreds of hours. A three-part series of one-on-one meetings were held over sixty managers to elicit their views on what causes change in health care utilization and unit cost rates.

The meeting sequence described below began with a core model of physician office visits which, at the time the development began, had been increasing for several years. Hospital inpatient admissions and average length of inpatient stay were added next. As these and other sectors were built, tested and combined, sketches of how medical technologies influence consumption became more elaborate and refined (Homer (1996)).

In the first meeting, the manager was introduced to the idea of building a system dynamics model of the health care system. We reviewed graphs of measured data familiar to the manager who was asked to explain why conditions changed. The manager’s explanations were noted, and after the first meeting, a small model – a piece of the health care system – was developed to simulate the manager’s explanation.

In the second meeting, the manager reviewed simulation output and asked for his reactions and criticism. In most cases, the manager required an explanation of the small model output but, for the most part, managers agreed that small model output was as expected. The small model was adequately represented the piece of the health care system with which the manager was familiar.

For the third meeting in the series, the small models were combined into a larger model of the U.S. health care system. At first only a few pieces of the system were done, and the larger model grew slowly. The principal objection by managers was that the larger model did not contain enough details – geographic regions, individual markets, specific health conditions. While these are important details for many purposes, the purpose of HCS is to help make sense of utilization and unit costs at a national level.

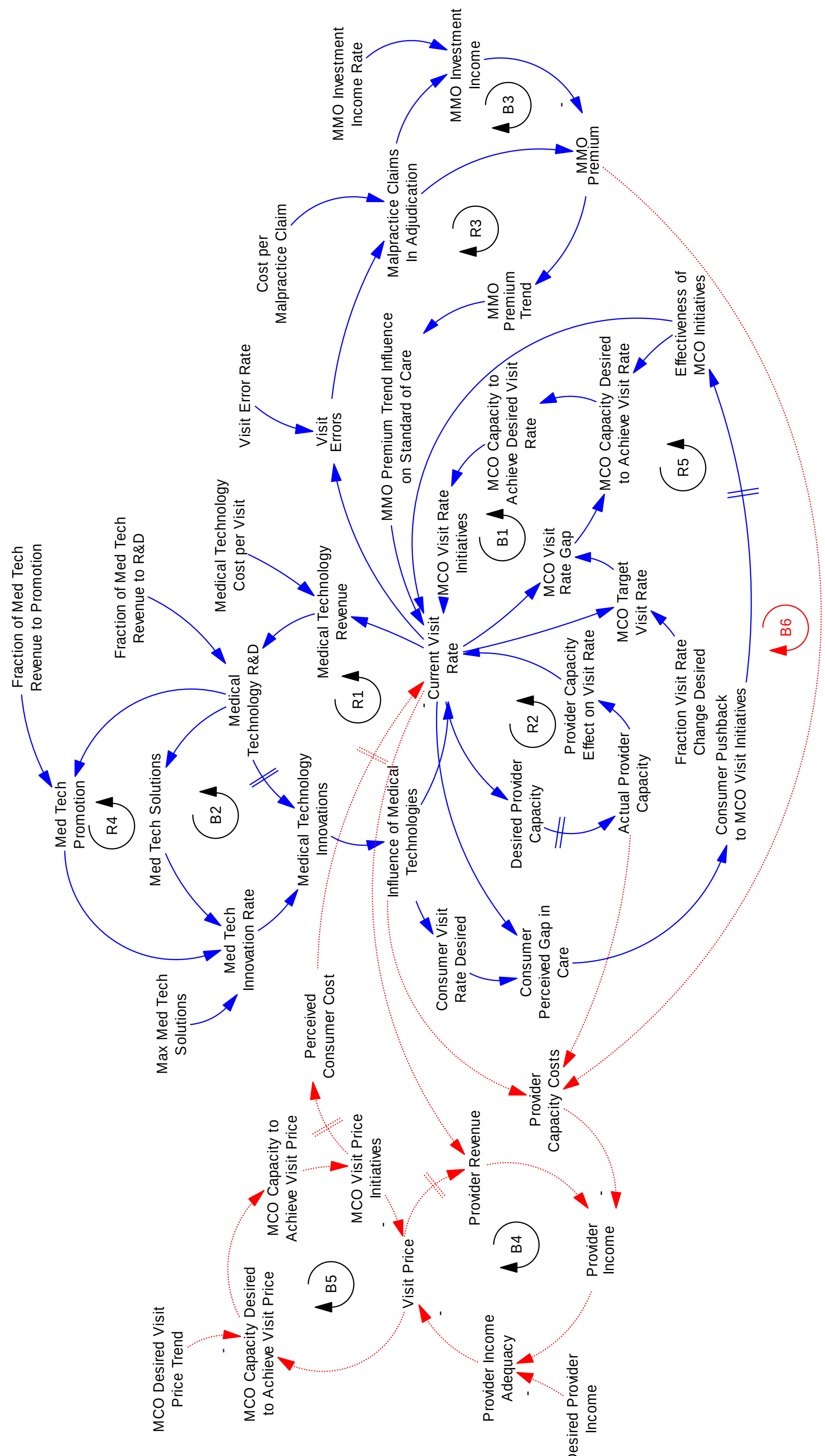

Figure 1: Overview of Health Care System model

Description of HCS

HCS is designed to simulate how consumption patterns are influenced by various forces in the health care marketplace. In essence, simulations start with the notion that consumer demand arising from disease, injury and preventive measures will not change unless influenced by changes in technology, hospital and physician capacities, standards of care and managed care initiatives. Initial hospital, physician and pharmaceutical utilization rates were developed from data measured by the U.S. Centers for Disease Control and Prevention[c] and unit prices are from publications by American Hospital Association, American Medical Association, and U.S. Department of Health and Human Services[d].

The HCS model formulation is proprietary intellectual property, and the author regrets that equations cannot be published. However, to give the reader a flavor of the model's composition, HCS comprises about a thousand equations including 165 levels, 300 constants, 30 data inputs and 10 table functions. The data inputs do not drive model variables but are used for calibration. The model is not subscripted.

As mentioned earlier, HCS is used to forecast certain aspects of consumer and provider behaviors, viz. consumption, production and prices. The three-year forecast horizon meets Company needs for understanding significant trends and their causes. However, the model is not specific to any organization and uses only publicly available data for calibration.

Figure 1 presents a high level causal loop diagram of HCS. Some of the feedback loops are identified with "B" for balancing/negative feedback and "R" for reinforcing/positive feedback and are numbered to distinguish them in the descriptions that follow in this text[e].

The initial stock of physicians[f] is affected by medical school graduations, retirements, and physician emigration rates. The initial physician visit utilization rate reflects the standard of care and implies that consumers access care for prevention and treatment at a constant rate that adjusts to reflect changes in technology, relative care capacity, and sensitivity to claims of errors. Note that the stock of physicians is not reflected explicitly in Figure 1.

The model simulates how hospital administrators plan and change treatment capacities. Facilities planning and development for emergency, nonurgent outpatient, and inpatient care are treated separately in the model but share common characteristics. We assume that hospital administrators determine average historical usage of facilities and base estimates of future use on a combination of history and projected trends. Costs are based on their 1992 construction cost adjusted for annual changes in the Construction Cost Index [g] and a simulated index that reflects the relative increase in medical technologies since 1992.

Pharmaceuticals and other medical technologies cause a portion of consumer utilization at physician offices and hospitals. Technology use generates revenue, a fraction of which is used to acquire capacity to do research to create new technology.

The pharmaceuticals and other medical technologies revenues branch into two reinforcing feedback loops: one that grows product and service choice through research and another that stimulates innovation by defining and promoting new treatments. (B2 and R4)

A portion of research resources (B2) goes to define diseases, treatable injuries, and tests of health status, which generates a stock of unmet medical needs. Another portion of research resources is allocated to invention. The fraction of the total market to which an invention applies is inversely proportional to number of inventions in active use, and an incremental inventions affect a smaller fraction of the market than inventions in use.

Innovation is the process of proliferating use of an invention. Innovation occurs when potential consumers are aware of the condition the invention is intended to test or remedy. The model allocates a portion of resources to increasing market awareness. (R4)

Governmental and commercial managed care organizations are the paying and contracting agents that develop initiatives to affect consumer and provider behavior[h]. MCO measure utilization (B5) and price trends (B1) as the basis for adjusting the number and intensity (capacity) of initiatives designed to control those trends. After determining the measures to be taken, MCO increase or decrease initiative capacity and implement the initiatives. (B1) Consumers and providers respond to unpopular initiatives with push-back, the force of consumer and provider opposition to MCO initiatives. Consumer and provider response grows with the length of time that initiatives have been effective. (R5)

HCS provides an explanation of how medical malpractice insurance organizations (MMO) adjust premiums to cushion against claims of provider error, invest surplus cash, and settle malpractice claims[i].

Medical errors and consequent malpractice claims[j] are part of a balancing feedback loop that influences physician practice standards of care. Medical malpractice insurance organizations (MMO) collect premium revenue from health care providers, invest surplus cash and cash retained for payment of future claims, and settle malpractice claims[k]. MMO investments depend on anticipated future claims, which are a function of utilization volume and historical provider error rates. (R3 and B3)

When operating results are more than adequate, MMO subsidize premiums with excess investment income. When operating or investment results are inadequate, MMO increase premiums to achieve desired operating results in the next period. (B3)

Changes in MMO premiums are linked to a controlling feedback loop in the provider sector. Kessler and McClellan (1996) note that physicians and hospitals increase prices to reflect increased premiums and increase their standard of care (i.e. practice defensive medicine) both to avoid future liability and improve their current revenue (B6).

How HCS output is validated

Validating and developing confidence in HCS is an ongoing, organic process. As audience members change, new members do not usually come with a system-wide perspective. A key part of confidence-building process is in explaining simulation results. Confidence builds with an understanding of how comprehensive the model is and how accurately the model simulates past health care system performance.

Before HCS was placed in service as a prediction tool, we calculated Theil inequality statistics to identify and guide improvements in the formulation of HCS[l]. In addition, HCS forecasts compared favorably with trend momentum, heuristic, and regression models over a three-year horizon.

Managers often develop confidence in an underlying model by comparing simulation output to measured data. (See Homer (1996), Forrester and Senge Forrester and Senge (1979) and Sterman (2000) for discussion and examples.) In essence, the model is a voice in the conversation about health care utilization and unit cost trends that earns credibility in part by simulating past systemic behavior as shown in the following graphs[m]:

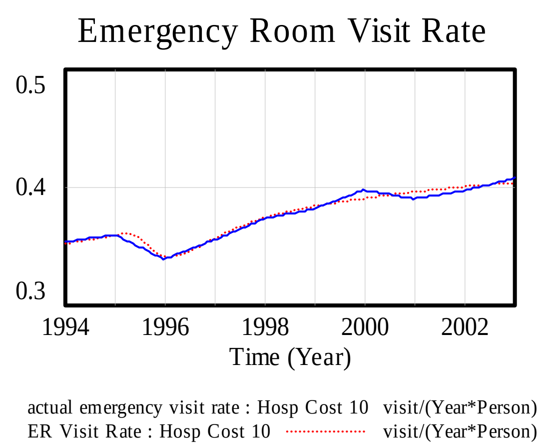

Figure 2: Annual Emergency Room Visits Per Person

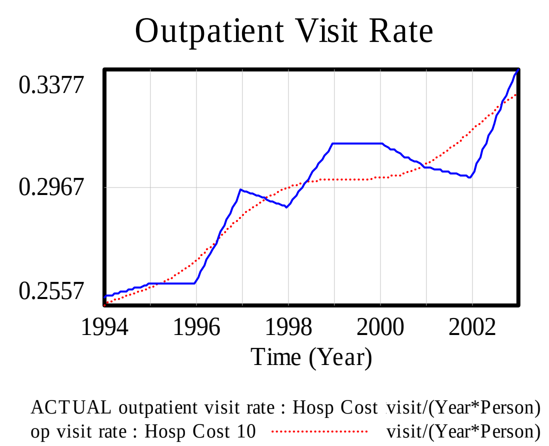

Figure 3: Annual Outpatient Visits Per Person

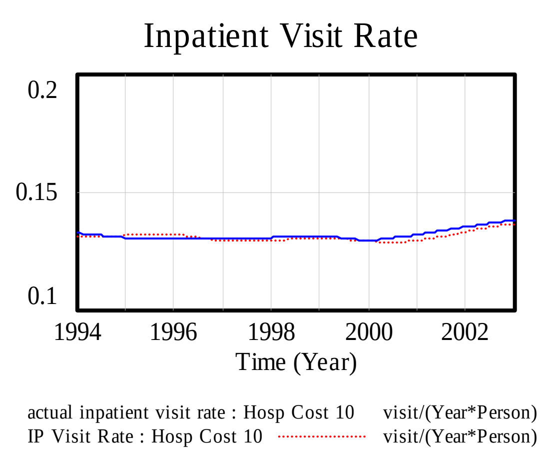

Figure 4: Annual Inpatient Admissions Per Person

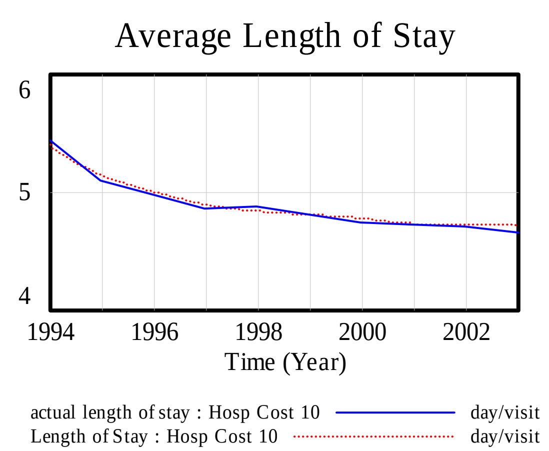

Figure 5: Average Length of Inpatient Visit

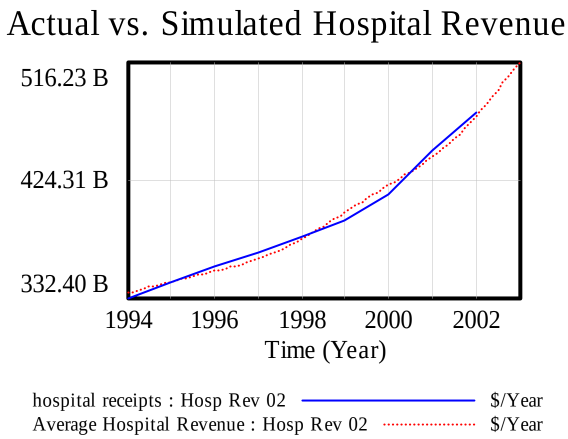

Figure 6: Annual Hospital Revenue

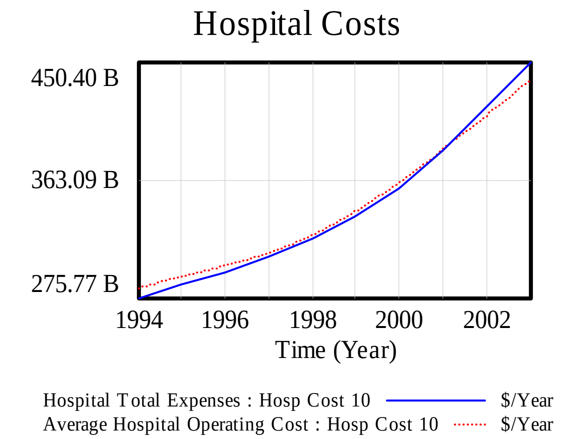

Figure 7: Annual Hospital Operating Costs

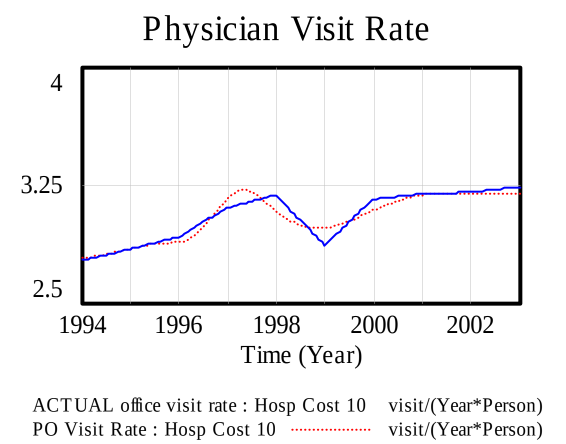

Figure 8: Annual Physician Office Visits Per Person

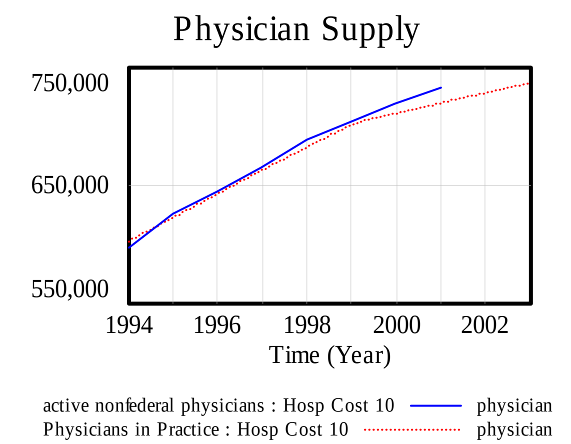

Figure 9: Physicians in Active Practice

Sensemaking with HCS

The principal audience for the output of HCS is the Company's Trend Actuaries and Trend Committee. The Trend Committee is made up of managers from functional areas including underwriting, sales, pricing, pharmacy benefits, utilization management, provider contracting, and product design. These managers are concerned with anticipating cost and utilization trends and meet regularly to develop a consensus forecast.

HCS provides a stepping-off point for predicting local unit cost and utilization trends. That is, HCS output simulates national level trends that actuaries and business analysts use as a basis for understanding how local results are affected by and fit into national market conditions.

National-level conditions influence local consumption patterns. HCS simulates physician supply, hospital capacities for inpatient, outpatient and emergency treatment, availability of pharmaceuticals and other medical technologies, medical malpractice insurance premiums, and other national market conditions that tend to influence the demand for and supplies of medical goods and services.

For example, pharmaceuticals and other medical technologies are substantial influences on utilization of medical services. HCS indicates how strong an influence these medical technologies are at a national level and thus how strong an influence they are likely to be locally. In the same way, the supply of physicians relative to consumer demand influences both utilization and prices.

In addition to serving Trend Committee needs, the logic of HCS provides a basis for analysis of and comment on current events in the health care marketplace. A quarterly health care system trends newsletter is written and distributed to over 500 managers in fields including pricing, underwriting, health plan benefits design, and medical utilization management.

The unique insights provided by a comprehensive model have proven sufficiently valuable within the organization to extend the use of HCS over four years.

Health Care System findings

Trend Committee members, actuaries and other managers frequently ask for interpretations of current events in the context provided by HCS. In some cases, HCS can be used to help them make sense of issues. In other cases, we need a separate model to simulate issues. The following lists a few of our research findings:

- The health care system is structured to increase costs. Technologies are a crucial part of a positive feedback loop that connects consumer purchasing with technology research and funding that generates still more consumption.
- Other Medical Technologies are the 21st Century economic equivalent of the pharmaceuticals industry in the last half century. Laboratory testing, diagnostic imaging and implantable electronic devices are a few prominent examples of products and services with rates of return that exceed those of the pharmaceutical industry.
- Advances in both pharmaceutical and other medical technologies have helped to reduce an inpatient’s average length of stay from about 5.4 days in 1994 to 4.3 bed-days in 2003. These advances also help to explain how inpatient capacity decreased from 228 million bed days in 1994 to 211 million in 2003 while annual non urgent outpatient visits increased from 90 million to 127 million visits.
- The decrease in investment rates of return in 2000-2001 was the principal cause of a sudden and large increase in malpractice insurance premiums. Fluctuations in investment income and consequent changes in medical malpractice premiums affect providers. When providers perceive that premiums will increase at a greater rate than their anticipated incomes, they take measures that they believe will help reduce exposure to claims.
- The annual rate of physician retirements is close to exceeding medical school graduation and physician immigration rates, a condition that does not allow for

increasing utilization rates. Rising technology-driven demand for treatment pushes patients out of the physician's office and into hospital emergency treatment capacity.

Other HCS applications: Scenario generation

With the prospect of pandemic influenza as described in the CDC report, *The Economic Impact of Pandemic Influenza in the United States: Priorities for Intervention*, Meltzer et al. (1999), HCS was modified to help make sense of health care system dynamics in the event of a new, prevalent and severe disease. The modifications included demand for vaccinations against the disease, changing capacity planning functions to allow for the extraordinary demand placed on the health care system by the disease, and a diffusion sector to account for infection, illness and mortality from the disease.

With HCS so modified, a base simulation was run with no new disease and a second simulation was done assuming an outbreak with disease parameters set to replicate morbidity and mortality rates in the CDC report. The resulting simulations were compared and an estimate of the economic impact of the new disease was estimated.

Health care system dynamics caused by the hypothetical pandemic influenza were summarized in a 'health care cost index' as shown in the following Figure 10[n].

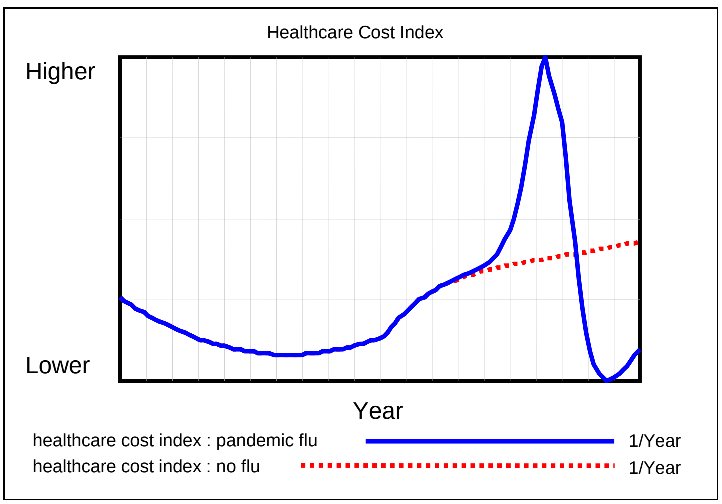

Figure 10: Healthcare Cost Index[o] from HCS With and Without Pandemic

HCS helped to explain complex interactions affecting the economic impact of the hypothetical disease that include the number of cases treated, the surge effect on provider capacity, and the demand for pharmaceuticals other than vaccinations.

Additional scenarios were run with different assumptions on the time infected persons might be contagious, transmissibility, mortality, disease severity, and effectiveness of public health measures such as quarantine and isolation.

Before HCS was used for this scenario planning, discussions about the potential impact of pandemic influenza were largely fragmented and tended toward narrow portions of the health care system. HCS provided managers with a focus and a means to consider the impact of a new disease. There was less concern about the forecastability of the triggering event and more discussion of developing robust policies to meet an uncertain future.

Other HCS applications: Strategy development

Federal legislation enacted in 2003 opened the employment-based health care finance marketplace to several new products[p]. These new plans are usually called consumer-directed healthcare plans (CDHP). In general, CDHP place more responsibility for, and control of, health care choices in the plan member's hands than traditional health care plans. CDHP are characterized by high deductible health insurance combined with a savings mechanism that allow the plan member to avoid or defer taxes on otherwise taxable income. Smaller expenditures, co-payments, and the insurance plan deductibles are made from the savings account.

The Company's principal line of business is health care finance, and CDHP generated – and continues to generate – a continuous flow of questions about the economic impact of the new CDHP finance products. The questions include who will subscribe to the new products, how will consumer spending patterns change, and how will providers respond to changes in consumption.

Our health care system dynamics model predictions established credibility for system dynamics methodology. Given the potentially large market changes suggested by CDHP, we have participated in conversations to help answer CDHP market strategy questions.

The desired answers to these strategy questions tend to fall into categories: what we need to do quickly and thoroughly, what we need to begin work on soon, and what initiatives can be deferred until more is known about the market.

Although these questions and desired answers smack of prediction, they are questions of policy choices. The desired responses lead to policies that are robust, less prone to regenerate problems in the traditional product market. Accordingly, we have constructed a suite of smaller, highly aggregated models to help answer some questions and an equilibrium[q] version of HCS in which to test economic impact of policy choices.

Path forward

System dynamics plays a key role in helping Company managers to make sense of U.S. health care system dynamics. In addition to the national level forecasts and special projects noted above, the methodology is used to make sense of the spread of infectious diseases and the uptake of medical technologies.

While this paper discusses one model in some detail, we are continuously reminded that, as Jay Forrester (1985) observed, system dynamics is not about the model. It is a complete methodology—a process for rigorously exploring problems and opportunities arising in complex interacting structures. Goals such as 'accurate forecast', 'best choice', 'right answer' and 'optimal result' are ideals to be pursued. In the process, system dynamics methods help to coalesce different perspectives, integrate specialized expertise and reach a gestalt.

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Notes:

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[a] In a population of about 290 million persons in 2003, 175 million were enrolled in employer-sponsored health care plans, 75 million were covered by government-sponsored health care plans (viz. Medicaid and Medicare) and 40 million were not currently covered by either. (Source: U.S. Census Bureau; *Statistical Abstract of the United States*, Table 142. Health Insurance Coverage Status by Selected Characteristics: 1990 to 2003, revised January 04 2006.)

[b] The health care finance field often refers to price as *unit cost*, supply as *provider* and consumption as *utilization*.

[c] Sources: U.S. Centers for Disease Control and Prevention (CDC), annually, *National Ambulatory Medical Care Survey, National Hospital Ambulatory Medical Care Survey,* and *National Hospital Discharge Survey*.

[d] The measured hospital cost and revenue time series are developed from *AHA Annual Survey* data, Copyright by Health Forum LLC, an affiliate of the American Hospital Association. The physician supply and visit price data are compiled from annual *Physician Socioeconomic Statistics*, Copyright by American Medical Association. Prescription drug prices are developed from *Report to the President: Prescription Drug Coverage, Spending, Utilization, and Prices*, Department of Health & Human Services, 2000, <http://aspe.hhs.gov/health/reports/drugstudy/>.

[e] See Richardson and Pugh (1981), Chapter 2 and Sterman (2000), Chapter 5 for detailed descriptions of causal loop diagrams and symbol conventions.

[f] Source: Active nonfederal physicians, American Medical Association, *Physician Characteristics and Distribution in the U.S.*, annually

[g] Source: McGraw Hill Engineering News-Record Construction Cost Index History (1908-2004). The Construction Cost Index is not explicitly represented in Figure 1.

[h] HCS excludes the TRICARE program administered by the Department of Defense for the military and their dependents.

[i] MMO investments earn a blended rate of return based on Ten Year Treasury Constant Maturity Rate, One Year Treasury Constant Maturity and S&P 500 Composite Total Return which are exogenous inputs to the model.

[j] Based on a informal sample of reports of medical malpractice claims settled by several state insurance regulatory authorities.

[k] MMO investments earn a blended rate of return based on Ten Year Treasury Constant Maturity Rate, One Year Treasury Constant Maturity and S&P 500 Composite Total Return which are exogenous inputs to the model. These indexes are generally available from a variety of financial publications and several sites on the Internet.

[l] See Sterman (2000), Chapter 21, for a discussion of statistical tests of model validity.

[m] Ibid. (c) and (d).

[n] The simulated values of the healthcare cost index are shown here in a range of Lower to Higher. In the version used by Company managers, numeric values were used.

[o] The Healthcare Cost Index in the above graph is model simulated output. The Index is an annualized trend in the changes in simulated consumer utilization multiplied by unit costs and weighted by contribution of the various major cost categories to total health care costs. To illustrate, the Centers for Medicare and Medicaid Services measured 2004 National Health Expenditures for pharmaceuticals, physician and clinical services and hospital services of $1.17 trillion; HCS simulates $0.9 trillion of expenditures because it excludes most long term care and behavioral health expenditures.

[p] The terms “consumer-directed” or “consumer-driven” for tax-advantaged, employment-based healthcare finance plans. In a nutshell, these plans are characterized by health care benefits over which the plan member (consumer) has significantly more control than traditional indemnity preferred provider or health maintenance organization plans. There are numerous resources available in print or on the Internet for readers who wish to learn more.

[q] See Smith and Ackere (2002) for an example of equilibrium in economic system dynamics models. See also Sterman (2000), Chapter 13, generally and Chapter 18.1.5, specifically, for a discussion of modeling of decision rules.