Systems Thinking: A Practical Application

Participant Exercises

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For AEA

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Based on Modeling and Research by Jack Homer, Andrew Jones, Joyce Essien, Bobby Milstein, Dara Murphy, and Don Seville

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For background research, see:
Milstein, Jones, Homer et al. *Finding Plausible Futures for Diabetes Prevalence: A System Dynamics Analysis of the Healthy People 2010 Objectives,* submitted to Preventing Chronic Disease. 2006

Jones, Homer, Murphy et al. *Understanding Diabetes Population Dynamics Through Simulation Modeling and Experimentation*, American Journal of Public Health, March 2006.

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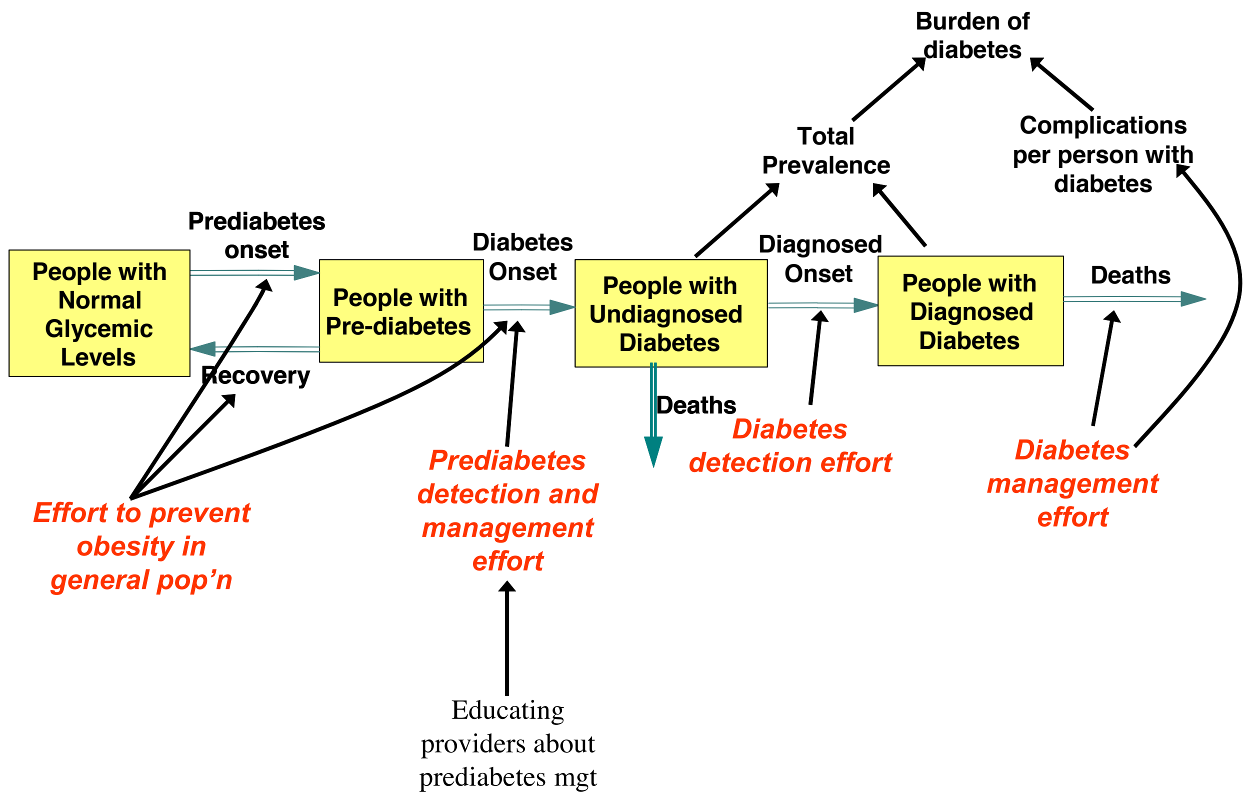
1. Connect Diabetes Interventions to Outcomes Exercise

In this exercise you will be connecting efforts to address diabetes to the system map. Look at each of the actions bulleted below. Which of these four intervention points will it affect the most? **On the following page,** write the name of the program or effort near the bottom and use arrows to link to one of the four intervention points.

- Educating healthcare providers about diabetes care
- Educating diabetes patients about managing their disease
- Organizing community groups to support people with diabetes
- Expanding insurance coverage to prediabetes management
- Promoting physical activity
- Educating providers about prediabetes management
- Getting insurance to the uninsured
- Encouraging providers to test high risk patients' blood sugar levels
- Encouraging providers to adopt the "chronic care" model
- Promoting healthy foods

If you are done, add in other efforts to address diabetes.

For example:



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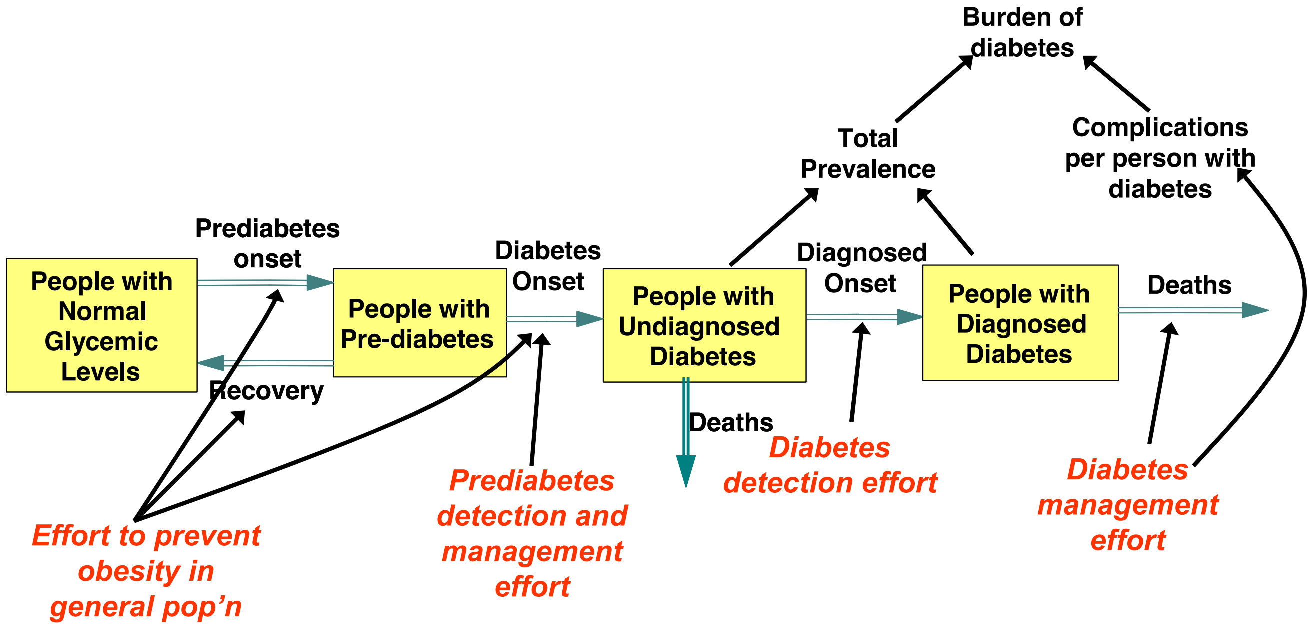
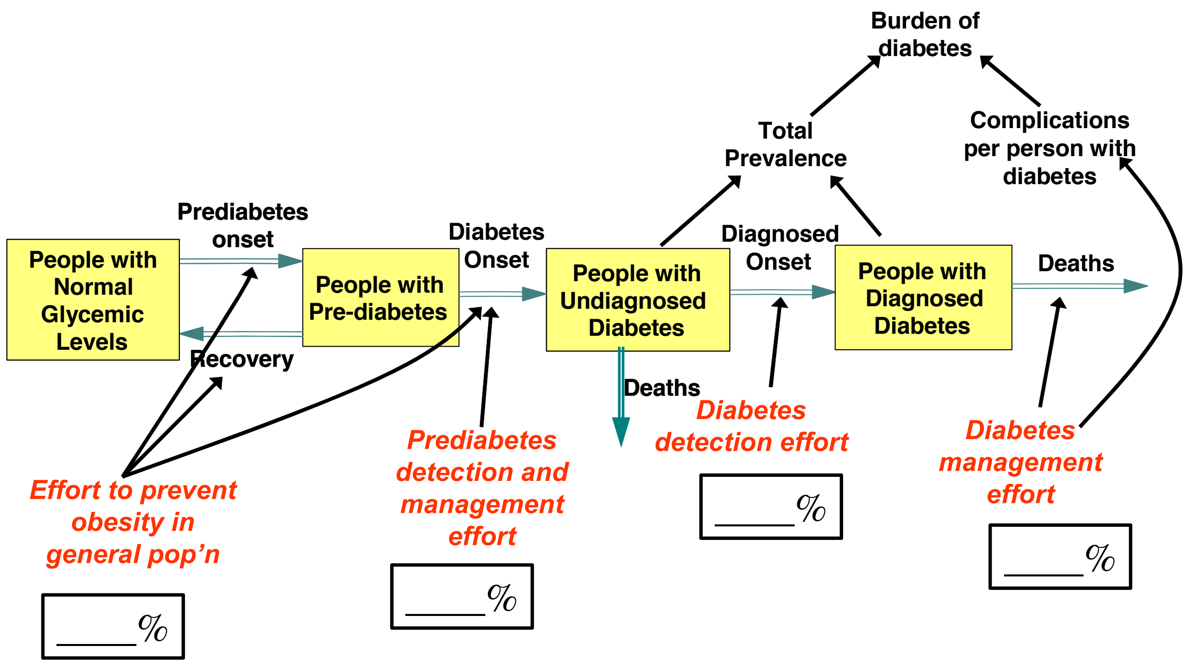
Do the Exercise on this Page



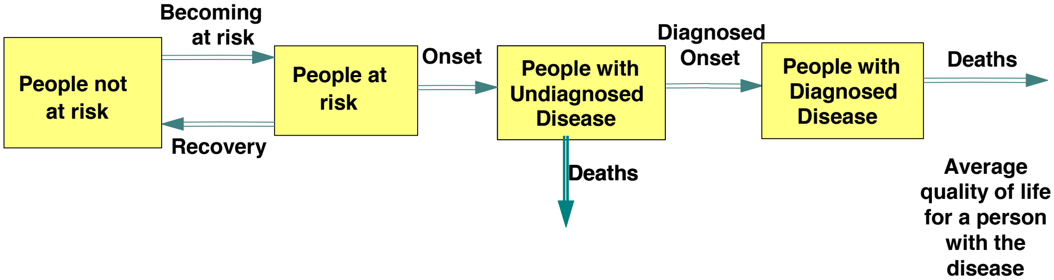
2. Allocation of Improvement Resources Exercise

Think of all the time and resources spent over the past 5 years on improving the overall diabetes system in order to reduce the burden of diabetes. What % of time and resources **do you think** has gone to each of the four interventions? (EG, 20% here, 10% there). Write the numbers down.



3. Mapping your own example

Consider the generic example below.



Create your own diagram of population flows for a disease type that concerns you – (e.g., Cardiovascular disease, HIV/AIDS, Depression). Note: a chronic disease will fit best into this form. Your diagram may include other flows such as recovery from the disease.

Similar to the diabetes case, draw "variables" to capture the various efforts that affect flows in the map (e.g., Effort to diagnose depression). Do the exercise in the space below.

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Background on System Dynamics Simulation Modeling
With a Summary of Major Public Health Studies

Summarized by

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What is System Dynamics?

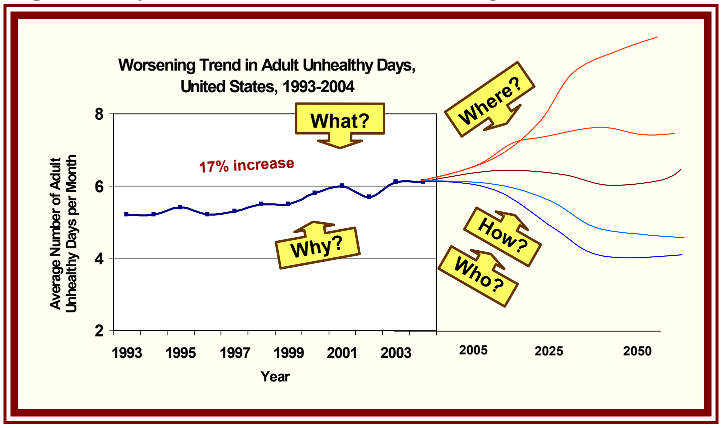
System dynamics (SD) is a methodology for mapping and then modeling the forces of change in any dynamically complex system so that their influences on one another can be better understood and the overall direction of the system can be better governed (Homer and Hirsch, 2006; Homer and Oliva, 2001; Sastry and Sterman, 1992; Sterman, 2000, 2001, 2006; Szulanski, 1997). It recognizes that our attempts to solve tough problems often fail or make matters worse due to the tendency of dynamic systems to "delay, defeat, or dilute the effects of planned interventions" (Meadows, Richardson, Bruckmann, 1982). The desire to learn how to overcome this phenomenon of *policy resistance*, which pervades most aspects of public health work, along with other areas of social endeavor, is perhaps the main motivation of those who rely on SD techniques for policy guidance.

What Questions Does it Address?

Five general lines of inquiry guide this kind of model-assisted inquiry.

- What aspects of a system's behavior are of concern?
- Why are those features changing in those ways at those times?
- Where is the system headed if no new action is taken?
- How else can the system behave, if different decisions are made?
- Who has the power to move the system in a more desirable direction?

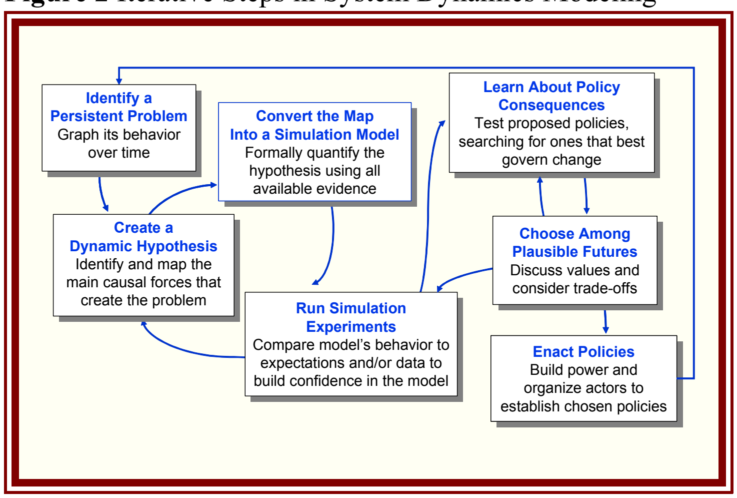
Figure 1 Dynamic Models Address Navigational Questions



What Steps are Involved?

SD methodology is iterative, evolving in response to new insights and changing conditions or goals (Homer, 1996). It enables diverse stakeholders to combine their knowledge of a problematic situation into a visible *dynamic hypothesis* and then, using computer simulation, to formally compare various scenarios for how to navigate change (Andersen, Richardson, Vennix, 1997). Often the process reveals critical leverage points that take into account a system's counterintuitive tendencies, opening new avenues for fundamental improvement (Forrester, 1971; Meadows, 1999).

Figure 2 Iterative Steps in System Dynamics Modeling



What Priorities Guide this Approach?

The primary emphasis in SD modeling is not on *forecasting* the future, but rather on *learning* how actions in the present can trigger plausible reactions both far away and over time (Morecroft and Sterman, 2000; Senge, 1990; Sterman, 1994; Sterman, 2006). With its ingenious use of simulation games as virtual worlds for interacting with an SD model, the learning that occurs is often visceral and emotional rather than purely cognitive or conceptual (Foresight and Governance Project, 2002; Maier and Grossler, 2000). As such, experiences with SD projects can both improve our intuitions about how the modern world works, and also motivate us to act more effectively and ethically in response to pressing problems (Forrester, 1971; Meadows, 2004; Meadows, Richardson, Bruckmann, 1982; Meadows and Robinson, 1985; Sterman, 2002).

Why the Emphasis on Simulation?

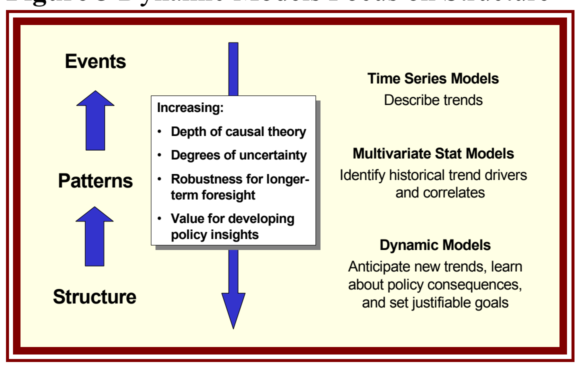
"The complexity of our mental models vastly exceeds our capacity to understand their implications without simulation. Even the best conceptual models can only be tested and improved by relying on learning feedback through the real world. This feedback is very slow and often rendered ineffective by dynamic complexity, time delays, inadequate and ambiguous feedback, poor reasoning skills, defensive reactions, and the costs of experimentation. In these circumstances simulation becomes the only reliable way to test a hypothesis and evaluate the likely effects of policies" (Sterman, 2000).

How Do Dynamic Models Relate to Other Forms of Policy Analysis?

The pragmatic emphasis on learning through action–especially simulated action–shapes how SD models are conceptualized, calibrated, and evaluated (Forrester and Senge, 1980; Graham, 1980; Meadows, 1980; Randers, 1980). SD modelers, for instance, do not automatically exclude variables from consideration if prior measurements are unavailable or imprecise (as is the case with curve-fitting techniques like regression or structural equation modeling). Most things in the world are not well measured, including many that experience tells us are important. To omit a critical parameter for lack of precise measurement is equivalent to assigning it a value of zero: the one number that is most likely to be *incorrect* (Forrester, 1980). Instead SD modelers opt to include all conceptually significant factors, quantifying them based on whatever evidence is available, and then conducting sensitivity analyses to assess the policy consequences of those estimates (Tessem and Davidsen, 1994).

Unlike time series models, which describe trends in observed events, or multivariate statistical models, which clarify patterns by identifying drivers and correlates of historical trends, SD models focus on the causal structure out of which events and patterns emerge. Such models enable analysts to anticipate new trends, learn how various policies can play out over time, and set justifiable goals for the future. Dynamic models do demand deeper causal theory, implying a greater degree of uncertainty. But they are also more robust for long-term foresight and a more valuable source of policy guidance.

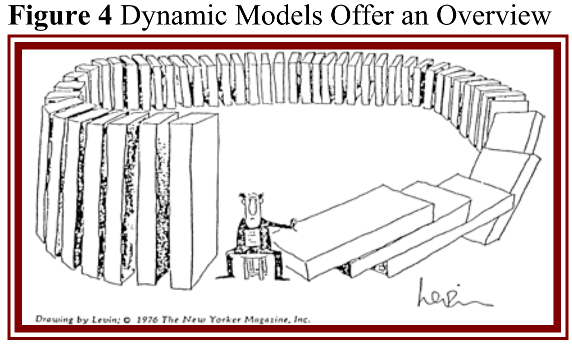
Figure 3 Dynamic Models Focus on Structure



How Broad is the Scope and How Detailed are the Representations?

If a system's overall structure–and not just a collection of external variables–is to be understood as the cause of observed events, it becomes necessary to stand back at *a very particular distance*, "not so close as to be concerned with the action of a single individual, but not so far away as to be ignorant of the internal pressures in the system" (Richardson, 1991). Some scholars refer to this special, macroscopic point of view as "the overview effect" (Richmond, 1993, 2000; Rosnay, 1997; White, 1998). SD modelers have found that a broad scope is generally needed for finding effective solutions to dynamically complex problems (Homer and Hirsch, 2006; Sterman, 1998). This wide-angle perspective also avoids blaming or scapegoating individuals for seemingly unproductive actions, recognizing that if other people were put in the same position and exposed to the same pressures, they too might behave in similar ways. Thus, one may say that SD analysts concentrate on "designing organizations in which ordinary people can achieve extraordinary results" (Sterman, 2000).

Figure 4 Dynamic Models Offer an Overview

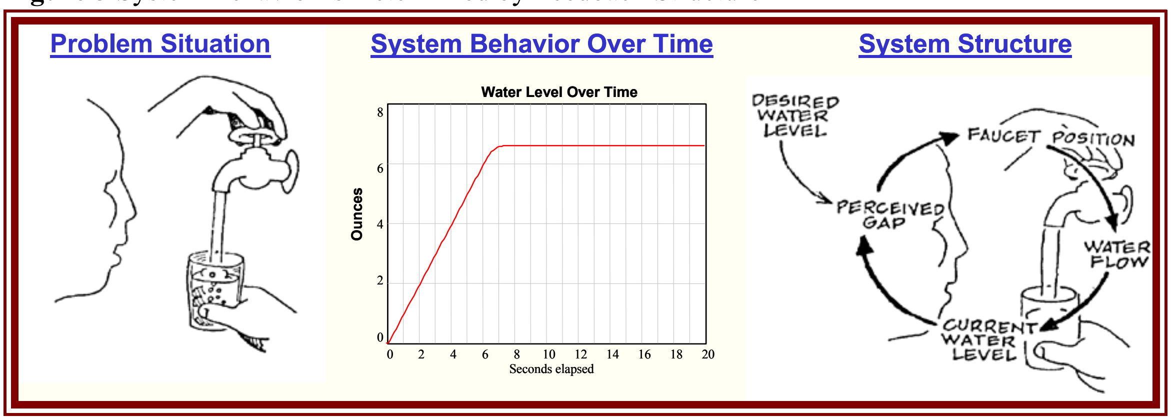


All models are simplifications of reality, and dynamic models in particular need to be kept simple enough to allow them to be easily tested, understood, and maintained–all qualities that enhance the utility of models as tools for learning. SD modelers find that the best way to achieve such parsimony, while maintaining a broad enough scope, is to limit the detail with which factors and populations are represented. A useful guideline is that a variable should be disaggregated into subcomponents only if such disaggregation contributes to an understanding of dynamics, and not simply because data may exist to support such disaggregation. Also, stakeholders and experts on the issue under study should become collaborators in the modeling process to ensure that such simplification is done in a meaningful and credible way (Sterman, 2000).

How Do Dynamic Models Connect Structure and Behavior?

The insight that system behavior is governed by causal structure–including processes like accumulation, delay, and nonlinear response–explains why the notion of *causal feedback* is central to SD modeling (Richardson, 1991). While the word system has been applied to all sorts of situations, the emphasis on analyzing dynamic feedback is both precise and relatively unique. In SD modeling, feedback refers to the situation of *X* affecting *Y* and *Y* in turn affecting *X*, perhaps through a chain of causes and effects. "One cannot study the link between *X* and *Y* and, independently, the link between *Y* and *X* and predict how the system will behave. Only the study of the whole system as a feedback system will lead to correct results" (System Dynamics Society, 2002). Accordingly, SD modelers carefully observe problem situations, study behavior-over-time graphs, and press on to reveal the feedback structures that give rise to the observed behavior.

Figure 5 System Behavior is Determined by Feedback Structure



Although change takes many forms and the variety of dynamics we observe is astonishing, in fact, most examples are instances of a fairly small number of fundamentally distinct patterns of behavior, such as exponential growth or oscillation. Each of these primary behavioral patterns can, in turn, be traced to particular combinations of reinforcing or balancing feedback structures (Sterman, 2000).

What Kinds of Problems Can System Dynamics Address?

With a nearly 50-year history since its development by Jay W. Forrester at the Massachusetts Institute of Technology (Forrester, 1961, 1969, 1989; Forrester, 1991), SD modeling today is used productively in many fields of human endeavor (Roberts, 1999; Sterman, 2000). The span of applications has grown extensively and now encompasses work in corporate management (Forrester, 1961; Repenning and Sterman, 2001); climate change (Sterman and Sweeney, 2002); urban development (Forrester, 1969); energy and global ecology (Ford, 1999; Meadows, Randers, Meadows, 2004); human service delivery (Levin and Roberts, 1976); K-12 education (Saposnick, 2004); and dozens more.

How Has it Been Used in Public Health Work?

Since the 1970s, and increasingly today, innovative investigators have used SD modeling to better understand some of the toughest problems that health leaders face, ones that would otherwise be intractable to comprehend using conventional epidemiological methods (Dangerfield and Roberts, 1999; Hargrove, 1998; Health Policy Special Interest Group, 2006; Homer and Hirsch, 2006; Sterman, 2006; Taylor and Lane, 1998). Some significant examples include studies of health problems such as

- cardiovascular disease (Hirsch and Wils, 1984; Homer, Hirsch, Minniti, *et.al.*, 2004; Luginbuhl and Hirsch, 1981);
- cervical cancer (Royston, Dost, Townshend, *et.al.*, 1999);
- chlamydia (Royston, Dost, Townshend, *et.al.*, 1999; Townshend and Turner, 2000);
- cocaine (Homer, 1993);
- dengue fever (Ritchie-Dunham and Mendez Galvan, 1999);
- diabetes (Homer, Hirsch, Minniti, *et.al.*, 2004; Homer, Jones, Seville, *et.al.*, 2004; Jones, Homer, Murphy, *et.al.*, 2006);
- dental care (Hirsch and Killingsworth, 1975; Levin and Roberts, 1976);
- drug-resistant pneumococcal infections (Homer, Ritchie-Dunham, Rabbino, *et.al.*, 2000);
- health care reform (Hirsch, Homer, McDonnell, *et.al.*, 2005);
- heroin (Levin, Roberts, Hirsch, 1975);
- HIV/AIDS (Dangerfield, Fang, Roberts, 2001; Homer and St. Clair, 1991; Roberts and Dangerfield, 1990);
- HMO planning (Hirsch and Miller, 1974);
- mammography (Fett, 2001);
- mental health (Levin and Roberts, 1976; Smith, Wolstenholme, McKelvie, *et.al.*, 2004);
- obesity (Abdel-Hamid, 2002, 2003; Homer, Milstein, Dietz, *et.al.*, 2006);
- patient flows (Lane, Monefeldt, Rosenhead, 2000; Wolstenholme, 1996, 1999);
- performance assessment (McDonnell, Heffernan, Faulkner, 2004);
- public health emergencies (Hirsch, 2004; Hoard, Homer, Manley, *et.al.*, 2005);
- public health planning (Hirsch and Immediato, 1999; Hirsch and Immediato, 1998; Homer and Milstein, 2004; Innovation Associates and New England Health Care Assembly, 1997);
- tobacco (National Cancer Institute, 2005; Roberts, Homer, Kasabian, *et.al.*, 1982; Tengs, Ahmad, Savage, *et.al.*, 2005; Tengs, Osgood, Chen, 2001; Tengs, Osgood, Lin, 2001); and
- syndemics (Homer and Milstein, 2002, 2003b, 2004)

Potential Roles for Dynamic Modeling in Public Health

Despite its past contributions, SD methodology is not routinely taught in schools of public health nor commonly used for policy analysis. Yet there are compelling reasons for doing so (Homer and Milstein, 2003a; Milstein, 2003). For instance, SD can be used productively to study

- *Individual diseases and risk factors* (e.g., by examining momentum and setting justifiable goals);
- *Mutually reinforcing afflictions (syndemics)* (e.g., by exploring interactions among related afflictions, adverse living conditions, and the public's capacity to address them both);
- *Program dynamics* (e.g., by analyzing the system-wide impacts of comprehensive programs with interacting components);
- *Regional dynamics* (e.g., by incorporating the mediating effects of local conditions, histories, capabilities, and constraints);
- *Life course dynamics* (e.g., by following health trajectories across life stages)

- *Capacities and cost-effectiveness* (e.g., by understanding how ambitious health ventures may be configured without overwhelming/depleting capacity–perhaps even strengthening it);
- *Value trade-offs* (e.g., by developing a deeper analysis of phenomena like the imbalance of upstream-downstream effort, growth of the uninsured, rising costs, declining quality, and entrenched inequalities);
- *Organizational management* (e.g., by linking balanced scorecards to a dynamic understanding of processes and goals);
- *Public deliberation and scenario planning* (e.g., by bringing more structure, evidence, and insight to public dialogue and judgment).

For Additional Information

SD Society: http://www.systemdynamics.org

SD Listserve: http://www.vensim.com/sdmail/sdmail.html

SD Bibliography: http://www.vensim.com/sdmail/sdbib.html

SD Self-study Course: http://sysdyn.clexchange.org/road-maps/home.html

SD Educational Resources: http://www.clexchange.org; http://sysdyn.clexchange.org

SD Software: http://www.vensim.com; http://www.iseesystems.com

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