5

How to Anticipate Change in Tobacco Control Systems

Systems methods represent an evolutionary step in the ability to solve complex problems, moving from simple cause-and-effect models to more realistic scenarios in which causes and effects influence each other with dynamic, evolving feedback. This chapter provides examples of the application of one systems thinking approach, system dynamics modeling, to current tobacco control issues. System dynamics has a rich research heritage, emphasizes use of simulation models for anticipating dynamic change, and has the potential to provide a more sophisticated understanding of key issues in tobacco control, especially factors that influence smoking prevalence. This chapter also presents the results of a research project by the Initiative on the Study and Implementation of Systems (ISIS) to explore the use of system dynamics to develop

- *A causal map of tobacco control variables, based on participatory input from expert stakeholders;*
- *Formal simulation models based on factors derived from these causal maps; and*
- *Simulations of tobacco use prevalence and consumption across an aging chain of smokers.*

The systems that fail are those that rely on the permanency of human nature, and not on its growth and development.

—Oscar Wilde (1854–1900)

Introduction

Today's tobacco control environment represents a complex and dynamic interrelated system of issues and stakeholders. In this dynamic environment, change is continuous and poses significant challenges for those who would anticipate change and prepare for its consequences. There is growing recognition that systems approaches need to be able to address this challenge of dynamics and to anticipate change. System dynamics modeling is one of the most prominent and promising approaches for addressing such problems and, in doing so, helping to achieve more effective integration of research knowledge and its practical implications.

ISIS developed a detailed illustration of how system dynamics modeling could be applied to tobacco control to demonstrate the potential of this approach. The goal is to encourage further interest in and exploration of the promise of systems thinking and, ultimately, to provide new insights into how to reduce tobacco use. As demonstrated in the overview of systems thinking in chapter 3 and the following chapters in this monograph, system dynamics is only one systems thinking approach to tobacco control. Other methods offer different insights, and there is considerable potential to develop new thinking about tobacco control through the skilled application of a range of systems approaches.

System dynamics facilitates an understanding of feedback processes, especially how self-reinforcing or "vicious" cycles can arise. These often are unintended negative consequences of interventions. Simple illustrative examples of such counterintuitive thinking include the following:

- Building highways to ease traffic congestion eventually fails because less congestion invites more cars and drivers, thus clogging the highways again.
- Large-scale crackdowns and violent responses to terrorist acts kill and harm innocent people. Surviving friends and family join the terrorists, so the violence escalates.
- Corporate efforts to gain advantage in the competition for executive talent lead to raises in total compensation packages. Other firms respond in kind, negating the first firm's momentary advantage and creating an overall self-reinforcing structure of raises and counterraises. Ultimately, this structure drastically increases executive compensation packages across the nation.
- Tobacco control efforts intended to reduce smoking prevalence cause market pressures that force tobacco companies to defend their interests with advertising and product promotion, strategic pricing, new product design, and target marketing, which tend to increase smoking prevalence.

At the same time, system dynamics is more than an attempt to quantify vicious cycles and unintended consequences. The conceptual and quantitative models are tools to enhance the ability to think about the dynamics of systems, leading to better decisions. The models can demonstrate effects that might not otherwise be envisioned or that might be counterintuitive. These approaches can highlight areas of uncertainty, helping to set priorities for future research or demonstrating that some things are simply unknowable. At a deeper level, they also can be used to simulate change to help in predicting what lies ahead and in shaping a more desirable future. Early system dynamics efforts have been undertaken to address different aspects of promoting or controlling tobacco use, such as

- Individual and family factors, such as genetics, personality traits, and parental role modeling
- Community-level interventions, such as smoking restrictions in public places and restrictions on advertising and promotion of tobacco products in retail stores
- State and national policies and practices, such as laws governing the purchase of tobacco products by minors, subsidies to tobacco growers, and research funding for the public health effects of active and passive smoking
- Global policies and practices, such as how multinational corporations maintain profitability by exploiting weaknesses in the policies of some countries, in trade agreements, and in the international Framework Convention on Tobacco Control, the first international health treaty[1]

Current best practices in areas ranging from prevention of smoking and smoking cessation programs to policy interventions have led to impressive short-term gains in factors such as reduced prevalence and consumption and morbidity and mortality. At the same time, these successes often carry within them the seeds of future problems, such as reduction in funding for tobacco control, shifting of public health priorities, and the counterefforts of the tobacco industry. As a result, poorly anticipated problems frequently loom, ranging from higher prevalence of smoking among groups such as young women, increased global marketing of tobacco, and fragmentation of efforts among tobacco control stakeholders—issues that ultimately could negatively affect overall public health. In areas such as these, in which traditional tools have proved insufficient, system dynamics modeling can provide a way to extend cause-and-effect models to include the dynamics of feedback and thereby provide more accurate models on which to base future policy.

System Dynamics

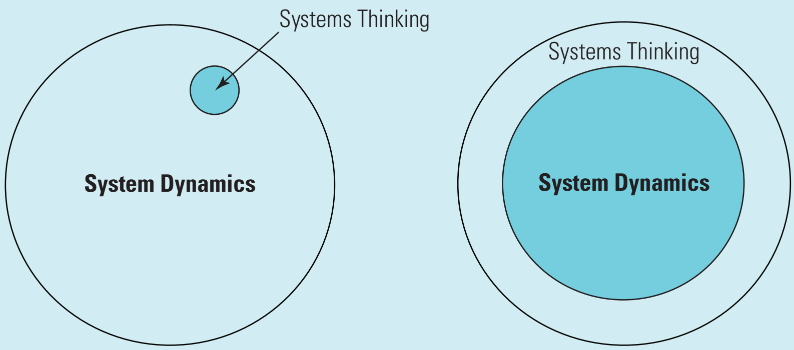
Computer simulation is used to assist thinking about complex dynamic systems. This approach grew out of (1) advances in computing technology, (2) an improved understanding of strategic decision making, and (3) developments in understanding the

Definitions: System Dynamics Versus Systems Thinking

System dynamics approaches such as those outlined here constitute one of many methods to treat behavior as a system. However, definition of the broader term *systems thinking,* which is at the core of this monograph, is the subject of considerable dispute. To some, systems thinking is the broad discipline of exploring and modeling system behavior. To others, systems thinking is more narrowly defined, constituting their essential approach to systems. Those involved in ISIS have taken a broad-based and more inclusive stance on the definition. This chapter provides background on this issue, especially as it relates to the field of system dynamics.

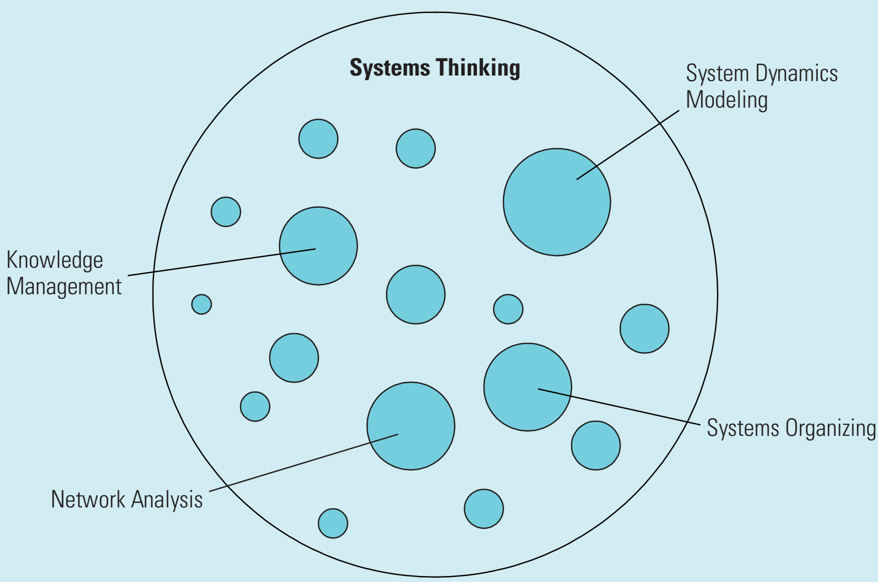
Systems investigator Barry Richmond felt strongly that systems thinking had a narrow, specific meaning (i.e., making inferences about behavior based on its underlying structure), which encompassed the modeling approach inherent in system dynamics.[a] He represents this "operational definition" of systems thinking by using a Venn diagram, arguing that system dynamics modeling forms a large part of the broader discipline of systems thinking. He contrasts this approach with other views, such as that of systems pioneer Jay Forrester of the Massachusetts Institute of Technology.[b] Forrester contends that systems thinking served as a small part of the overall system dynamics approach. The figure that follows is adapted from Richmond's paper.[a]

Forrester's View (left) versus Richmond's View (right) on System Dynamics and Systems Thinking



In comparison, many people, including those involved in ISIS, now see system dynamics modeling as one of the broad range of tools and methods encompassed by systems thinking. The best representation of this relationship may be that system dynamics modeling is one of several components within the broader context of systems thinking.

System Dynamics Modeling as One Approach to Systems Thinking



The debate about system dynamics and systems thinking terminology becomes particularly significant in light of other methodologies that adopt the "systems" label. One such methodology is Peter Checkland's soft systems methodology.[c] It counters the emphasis that systems thinking is a modeling and measurement endeavor, seeing it instead as a learning process that takes a phenomenological rather than deterministic stance. Checkland views systems thinking as an evolving process driven by the purposeful activities of its stakeholders, in which all voices are represented and boundaries between divergent views are free to shift. This approach, in turn, has become part of the critical systems thinking approach espoused by Flood and Romm[d] and Midgley,[e] in which systems thinking is seen as a stakeholder-driven process. In his classic book *Systems Thinking, Systems Practice: Includes a 30-Year Retrospective,* Checkland himself defines systems thinking as a process that "makes conscious use of the particular concept of wholeness captured in the word 'system' to order our thoughts."[c(p4)]

The argument presented here is against the parochial or narrow view of systems thinking and in favor of viewing it as a broad range of approaches that examine behavior as a system. In addition to approaches described in other chapters (systems organizing, network analysis, and knowledge management), there are other strategies that provide different lenses for examining systems. These include but are not limited to the following:

- System dynamics modeling, which seeks to create mathematical simulation models incorporating stocks, flows, and feedback, defined later in this chapter
- "Soft" systems approaches that focus on processes and people, such as Checkland's soft systems methodology,[c] Midgley's participatory stakeholder-driven approaches,[e] and Senge's concept of a learning organization.[f] Compared with traditional system dynamics, these strategies examine the evolution of a system as an ecological process, poorly or imperfectly reflected through mathematical simulation
- Chaos and complexity approaches that examine behavior as systems of autonomous agents following simple rules, such as a flock of birds that take flight by following a leader and maintaining a specific distance from their neighbors, or a tobacco control intervention modeled on agents who create effects and countereffects

A continuing part of the evolution of the systems community, which can be seen itself as a system, is an evolution over time from the modeling of simple cause-and-effect relationships, such as logic models, to complex real-world interrelationships that are depicted iteratively over time with feedback. This depiction allows examination of effects, such as side effects, edge effects, and unintended consequences. The systems community ultimately represents an evolution from the "black box"—used in an attempt to understand reality—toward more detailed and realistic models of the dynamics of reality.

This evolution mirrors trends in science and technology that in turn enable more accurate representation of reality. These trends range from simple problems that can be solved as single equations to more complex problems that must be solved adaptively with evolving feedback. Today, this evolution continues from simple feedback to broader concepts such as neural networks, cybernetics, complex adaptive systems, and other self-learning physical phenomena.

[a]Richmond, B. 1994. System dynamics/systems thinking: Let's just get on with it. Paper presented at the 1994 International Systems Dynamics Conference, Sterling, Scotland. Reprinted with permission from ISEE Systems. http://www.intraxltd.com/Downloads/Files/SystemDynamicsSystemsThinking.htm.

[b]Forrester, J. W. 1961. *Industrial dynamics.* Cambridge, MA: MIT Press.

[c]Checkland, P. B. 1999. *Systems thinking, system practice: Includes a 30-year retrospective.* Chichester, UK: John Wiley and Sons.

[d]Flood, R. L., and N. R. A. Romm, eds. 1996. *Critical systems thinking: Current research and practice.* New York: Plenum.

[e]Midgley, G. 2000. *Systemic intervention: Philosophy, methodology and practice.* Contemporary Systems Thinking series. London: Springer.

[f]Senge, P. M. 1994. *The fifth discipline: The art and practice of the learning organization.* New York: Currency.

role of information feedback in the dynamics of complex systems. System dynamics practitioners seek to frame system behavior in terms of endogenous components with definable and self-contained behaviors, which in turn interact with each other to produce an evolutionary outcome.

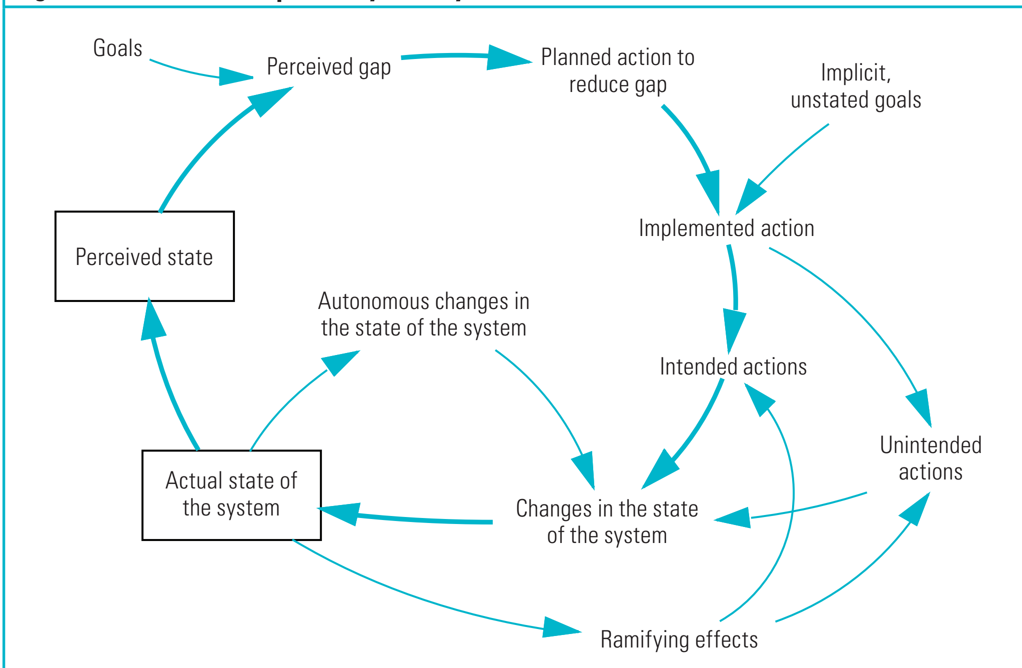
Some abbreviate this idea as the "system as cause." Explaining the behavior of a system in terms of self-contained components that interact over time can force causal influences to double back on themselves, forming feedback loops of circular causality. The feedback concept empowers this component-level point of view and gives it structure. Thus, the system dynamics approach is partly characterized by its heavy use of a feedback perspective.

This viewpoint is so important that system dynamics practitioners and others might define systems thinking succinctly as the mental effort to uncover integral sources of system behavior. Much of system dynamics can be thought of as *computer simulation in support of systems thinking*. The power of the system dynamics approach comes from this component-level, feedback-rich viewpoint, in which all purposeful action takes place in the classic cybernetic loop that includes

- Goals for the system
- Current state of the system
- Perceptions of that current state
- The gap between goals and perceptions
- Action intended to reduce the gap, resulting in a new state of the system
- Revised perceptions, leading to further actions

Unfortunately, the world that analysts attempt to simulate is more complicated than that, as figure 5.1 suggests. The

Figure 5.1 Feedback Loops in a System Dynamics Model



bold loop in the figure is the classic cybernetic loop, striving to bring the state of the system toward some set goal. However, unstated goals often intervene and unintended effects are triggered. The system changes from its own forces, and all sorts of effects feed back to alter the actions of the actors. (In a system dynamics perspective, there are no "side" effects, only effects.) Moreover, complex systems have many actors, each with personal or organizational goals, so this structure is repeated countless times in real systems. The result is that actions one group takes to reach toward its goals disturb the system and prompt other groups to implement counteraction, striving to reassert the status quo or lead to a different status quo. In contrast, the simpler cause-and-effect behavior can result when these factors are held constant. Thus, a system often will *compensate* for changes and weaken or even negate them, much as a price cut can stimulate competitive forces that negate its original goal of increasing sales. This phenomenon is referred to as *policy resistance.*[2]

In complex systems, this natural policy resistance can be seen as a pattern of dynamic behavior formed by individual events and decisions and a conscious effort to perceive in this stream of decisions the persistent policy structure producing them. System dynamics models strive to capture that policy structure as a part of system structure and produce, as output, graphs over time that represent this aggregate view of events and decisions. For example, the destruction of the World Trade Center on September 11, 2001, clearly was a significant event in the contemporary world. Without diminishing that significance, a systems view would place that event in its dynamic context, looking back in history to trace the slow accumulation of pressures that gave rise to the event itself and the extent of the nation's capacities to deal with it.

One example of system dynamics modeling can be seen in a welfare reform study[3] that was conducted in three counties in New York State. The study was an attempt to help the diverse agencies providing social services to the poor cope with the threat of persistently rising costs when some families would begin timing out of welfare benefits under reform. The mapping and modeling work was performed with groups of welfare stakeholders and social service providers in each county. This work eventually yielded a formal model of more than 600 equations used (1) to examine a number of "what if" scenarios and policy options and (2) to create an environment in which stakeholders could learn from exploring the structure and behavior of the complex system.

One key finding was a classic "better before worse" scenario commonly seen in complex dynamic systems (interventions work in the short term; compensating feedback involves a delay). As more families come off assistance, they strain employment resources intended to match job seekers with stable jobs. This increases the number of marginally employed families who may fall back into the need for assistance. The result is that fewer families make it to stable jobs and more flow back into assistance, eventually increasing the population at risk for needing assistance.

These findings suggest the need to invest more resources in areas such as job coaching, job maintenance, child care, transportation, and other interventions intended to keep people employed. These areas are not the traditional purview of social services. They rely heavily on coordinated efforts of the private sector and nongovernmental service providers. These types of insights led two of the three counties to implement strategies to increase resources for these efforts. It is noteworthy that the welfare reforms have been a huge success. While the role of such modeling in the success has not been documented, this example illustrates how such modeling influenced at least some policy makers. The system dynamics approach, particularly when used in a group context with multiple stakeholders and diverse viewpoints, has seven characteristics:

1. *Engagement*. Key stakeholders are involved as the model evolves, and their own expertise and insights drive all aspect of the analysis.
2. *Mental models*. The model-building process uses the language and concepts participants bring with them to explain the assumptions and causal mental models managers use in decision making.
3. *Alignment*. The modeling process benefits from diverse, sometimes competing, viewpoints, as stakeholders have a chance to wrestle with causal assumptions in a group context. Often these discussions realign thinking and are among the most valuable portions of the overall group modeling effort.
4. *Determination of behavior by structure*. The formal simulation models resulting from this approach show how system structure influences system behavior. This leads to insights based on familiar system stocks and flows, and reveals understandable but initially counterintuitive tendencies such as policy resistance or "better before worse" behavior.
5. *Refutability*. The formal model yields testable propositions, enabling managers to determine how well their implicit theories match available data about overall system performance.
6. *Empowerment*. By using the formal model, participants can envision how actions under their control can change the future of the system.
7. *Estimation of parameters*. The model can help to estimate useful parameters that are not otherwise available, such as model factors that lack an empirical base of values.

System Dynamics Application to Tobacco Control

A demonstration project to illustrate the modeling of factors in tobacco prevalence and consumption by using a system dynamics approach was undertaken as part of ISIS, incorporating heuristic data from participants in the ISIS innovation team. This model was designed both as a proof-of-concept project for system dynamics simulations of macrolevel tobacco issues and as a starting point for discussions on integration of such methods with other transdisciplinary aspects of a systems thinking environment.

Brainstorming Components of Tobacco Control Systems

During initial ISIS workshops in Washington, DC, participants helped form the concepts for the model presented here through a group brainstorming exercise. Workshop participants listed ideas, one per sheet, and then ideas were arranged on a wall, as a base for facilitated discussions on clusters of model issues. Building on the insights and data gained through these workshops, the facilitator constructed a causal map and simulation model based on factors in tobacco prevalence and consumption. The primary purpose of this model was to use it as a learning tool to attempt to create a simulation environment in which tobacco control stakeholders can experiment and theorize. Although the model was based on heuristic input from ISIS participants, its concepts serve as a prototype for future analyses using validated models and accurate data sources.

Path to System Dynamics Approaches to Tobacco Control

The system dynamics simulation model in this chapter, examining tobacco consumption and prevalence, is part of a growing tradition of efforts to use systems methods for policy simulation to address issues in tobacco control and public health. Initial projects in this area range from a 1980s systems study at the Massachusetts Institute of Technology projecting an accelerated decline in tobacco use[a] to the comprehensive tobacco policy model developed at the University of California at Irvine,[b] as well as proof-of-concept work undertaken at the National Cancer Institute before the efforts of ISIS.[c] More recent efforts detailed by Levy and associates[d] include the following:

- SimSmoke, funded by the Substance Abuse and Mental Health Services Administration's Center for Substance Abuse Prevention and the Robert Wood Johnson Foundation, models smoking rates and smoking mortality over a 40-year period. This model bases its projections from historical data on factors such as smoking prevalence, consumption, initiation, cessation, and mortality, as well as the influence of policy factors such as laws, taxes, and tobacco control activities. SimSmoke's projections range from a status quo scenario gradually reducing prevalence from 18.5% to 15.4% by 2040, with rising annual mortality during much of the period because of population trends, to proportionately lower prevalence based on the impact of specific policy interventions.
- A system model funded by the Substance Abuse Policy Research Program of the Robert Wood Johnson Foundation used age-specific rates for initiation and cessation of smoking. It demonstrated that smoking prevalence will continue to fall under current trends. However, it also established the implausibility of the goals for prevalence set for the *Healthy People 2010* initiative.
- GlaxoSmithKline sponsored a dynamic model for smoking control designed to project demand for its products for nicotine replacement therapy. The model focuses on the decision to stop smoking based on the "stages of change" model and uses empirical data about population demographics and behavior involved in quitting smoking. Its findings include the observation that lowering barriers to aids for smoking cessation, such as nicotine replacement therapy, increased cessation rates.

[a]Roberts, E. B., J. Homer, A. Kasabian, and M. Varrell. 1982. A systems view of the smoking problem: Perspective and limitations of the role of science in decision-making. *International Journal of Biomedical Computing* 13 (1): 69–86.

[b]Tengs, T. O., N. D. Osgood, and L. L. Chen. 2001. The cost-effectiveness of intensive national school-based anti-tobacco education: Results from the tobacco policy model. *Preventive Medicine* 33 (6): 558–70.

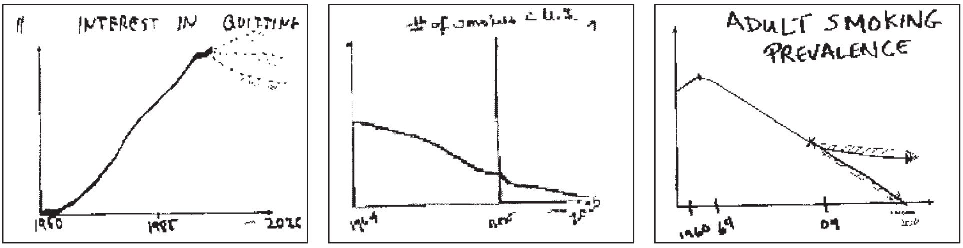
[c]Leischow, S. 2003. Social network analysis in tobacco control. Presentation at the National Cancer Institute, Bethesda, MD.

[d]Levy, D. T., F. Chaloupka, J. Gitchell, D. Mendez, and K. E. Warner. 2002. The use of simulation models for the surveillance, justification and understanding of tobacco control policies. *Health Care Management Science* 5 (2): 113–20.

Grouping Components into Sectors

The initial data used to form this model were derived from discussions, exercises, and a series of graphs created by ISIS conference participants (figure 5.2). Participants were asked to draw rough sketches or graphs showing how they thought the brainstormed components evolved over the past few decades and how they might be projected into the future. The graphs from these experts were grouped

Figure 5.2 Sample of Graphs on Tobacco Use Factors from Expert Participants at 2003 Conference on ISIS



Note. These images were hand-drafted by participants in the exercise.

into substantive sectors to create a series of composite pictures, collapse the issues to a more manageable size, and provide useful talking points as the team progressed to modeling. Examples of sectors resulting from this exercise included the following:

Tobacco use. The sector on tobacco use examined the relationship between people and tobacco—whether they smoke and rates for starting, stopping, or resuming tobacco use. For this sector, participant graphs were supplemented with compiled data showing the fractions of the U.S. population who were current or former smokers or who never smoked during 1965–2000.[4] Some of the original hand-drawn graphs were generated by the experts for the sector on tobacco use. As part of the exercise, participants drew a graph to show changes for each key variable over time. Dotted or shaded lines represent alternative future scenarios.

Tobacco industry. The sector on the tobacco industry examined the influence and lobbying efforts of the industry, combining participant graphs of these factors with data from the Economic Research Service of the U.S. Department of Agriculture showing variations in the tobacco supply from 1950 through 2000.

Tobacco control and government intervention. The sector on tobacco control and government intervention examined trends in tobacco control efforts over time. These included the measure for strength of tobacco control that was developed to measure state-level tobacco control resources, capacity, and efforts, as well as factors such as resources and funding, regulation of tobacco by the U.S. Food and Drug Administration, and percentage of restaurants with a smoking ban in place over time.[5] The data compiled from these ISIS participants, supplemented with historical data on tobacco-related factors from official sources, contained many observed trends, such as a clear plateau in the historical decline in tobacco use, increasing near-term tobacco sales, and a rise and fall of tobacco control efforts over time, tied to recent decreases in funding for tobacco control.

Developing a Causal Model

A causal map typically consists of the following elements:

- *Stocks* are accumulated or integrated quantities with values or levels (e.g., number or proportion) that do not change instantaneously. Stocks accumulate in response to flows. Stocks are the written words on a causal map (e.g., tobacco revenues or people smoking), and stocks that are central to specific causal loops are highlighted in boxes.

- *Flows* are varying quantities that create the dynamics in the system by increasing or decreasing stocks. Flows (e.g., production of tax revenues by smokers) are represented by the arrows on a map.
- *Loops* are linked, directional relationships between model parameters.
- *Delays* are built-in characteristics of any system, providing more realistic linkages of cause and effect that may be difficult to observe. For example, it takes time to introduce new legislation or develop a new marketing campaign. A delay can be seen as a property of a stock.

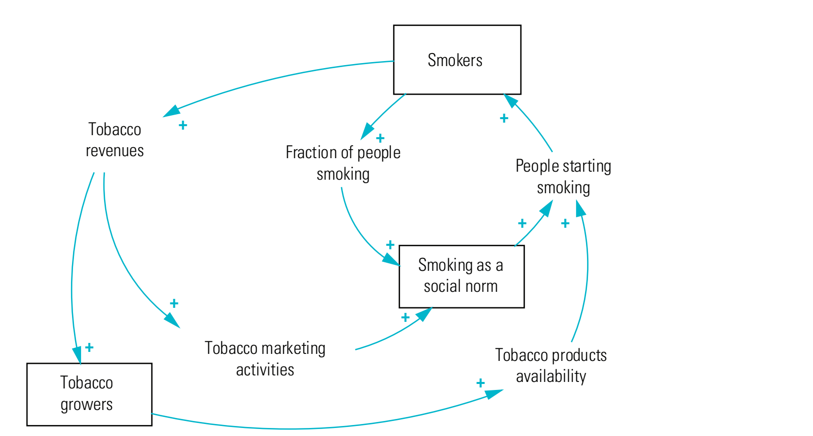
These brainstormed components, organized by sector, formed the basis for construction by the project facilitator of an overall causal loop model of factors in tobacco prevalence and consumption, as a precursor to the development of a formal system dynamics model. A causal loop model (presented later in this chapter) was built step-by-step as outlined in this section.

Causal loop diagrams are an integral part of system dynamics modeling, helping to foster group knowledge and understanding and providing a concise view of an enormous amount of complexity and a starting point for simulation. In ISIS, such diagrams act as a bridge, drawing information from participants and data sources, and resulting in a “map” that helps stakeholders define and, more important, discuss the fundamental hypotheses and connections leading to more formal modeling. (The final causal map shown later in this chapter was developed heuristically and is meant to be illustrative rather than authoritative.)

One group of participants created the causal map and used the brainstormed components organized by sector and the graphs of functions over time to draft the initial flow diagram. To better explain development of the overall causal model, the model is examined a section at a time and the logic is described. The final causal loop model shown later in this chapter presents the full map, and figure 5.3 shows the segment examining social norm and tobacco growing issues.

In the diagram, “smokers” represent the pool of people who smoke. As the number of smokers increases, the revenue generated

Figure 5.3 Causal Map Segment, Incorporating Social Norm and Tobacco Grower Factors

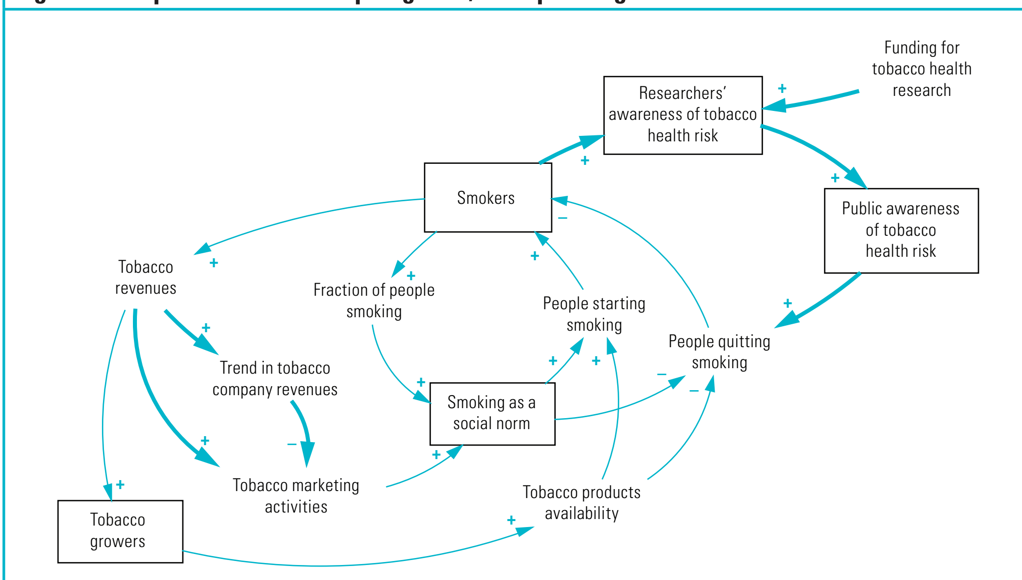


by their purchase of tobacco products also increases, which is indicated by the plus sign next to the line that connects "smokers" and "tobacco revenues." This increase has two effects: it enables the tobacco industry to increase tobacco production (tobacco growers) to meet the demand of increased smoking, and it generates more money for "tobacco marketing activities."

Following the inside loop, the increase in "tobacco marketing activities" creates greater acceptance of smoking and tobacco use. Marketing activities tend to normalize smoking as a behavior rather than simply capture more market share. Marketing, for the tobacco industry, is a source of new smokers. Following the outside causal loop, as the capacity for tobacco production increases, there is an increased availability (e.g., discounted cost) of tobacco products. The establishment of "smoking as a social norm," complemented by the increased availability of tobacco products, results in an increase in the number of "people starting to smoke," and consequently, an increase in the "fraction of people smoking."

If this initial model segment is expanded to a slightly larger segment (figure 5.4), it becomes apparent that research on the health effects of smoking leads to growing awareness of health risks from tobacco use, which eventually disseminates to the general public and helps build pressures and motivations for people to stop smoking. As the "fraction of people smoking" increases, the "researchers' awareness of tobacco as a health risk" becomes clearer. This increased awareness prompts researchers to formulate new questions and apply for "funding for research on tobacco as a health risk." Their work eventually finds its way to "public awareness of tobacco as a health risk." Reports on the negative effects of smoking and exposure to secondhand smoke filter from research to a broader awareness. As individuals process this information, they choose to stop smoking in greater numbers.

Figure 5.4 Expanded Causal Map Segment, Incorporating Awareness of Tobacco Health Risk



The new causal path captures the idea that the "trend in tobacco company revenues" is a decrease because as the number of smokers decreased, tobacco companies would increase spending on "tobacco marketing activities." The minus sign next to the line between "trend in tobacco company revenues" and "tobacco marketing activities" depicts the negative relationship that as tobacco revenues *decrease,* marketing is *increased.* By an increase in marketing, tobacco companies would try to compensate for the successes of the research community in prompting people to try to stop smoking.

"Antitobacco constituencies" represent those who advocate against support for the tobacco industry. As both "researchers' awareness" and "public awareness of tobacco as a health risk" increase, the number of people and organizations opposing tobacco use tends to grow. The map expanded as shown in figure 5.5 suggests that these antitobacco constituencies can move more funding to tobacco research and control, leading to further growth (1) in awareness of tobacco as a health risk and (2) in efforts to control or reverse the growth of tobacco production and use.

The outside loop highlights some of the effects of tobacco control programs. As "funding for tobacco control programs" increases, "pressure on tobacco companies to reduce marketing activities" increases (e.g., via legislated bans on certain forms of advertising). This pressure is an additional factor but only one of many that determine levels of tobacco company marketing.

A segment on government awareness of tobacco as a health risk is added in figure 5.6. The government draws from three sources of information to understand the risk posed by tobacco use. First, government depends on "researchers' awareness of tobacco as a health risk" to provide information on the health risks of tobacco. Second, government relies on "public awareness of tobacco as a health risk" to gain a better understanding of the degree to which tobacco use is an issue among its constituents. The higher the public awareness of tobacco risks, the

Figure 5.5 Causal Map Adding Impact of Antitobacco Constituencies

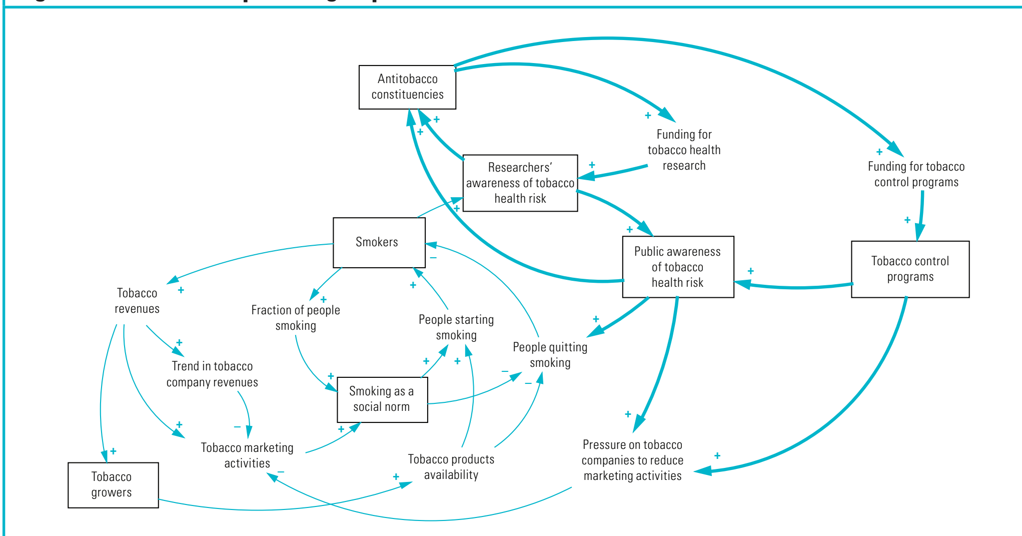


Figure 5.6 Causal Map Adding Government Awareness of Tobacco as a Health Risk

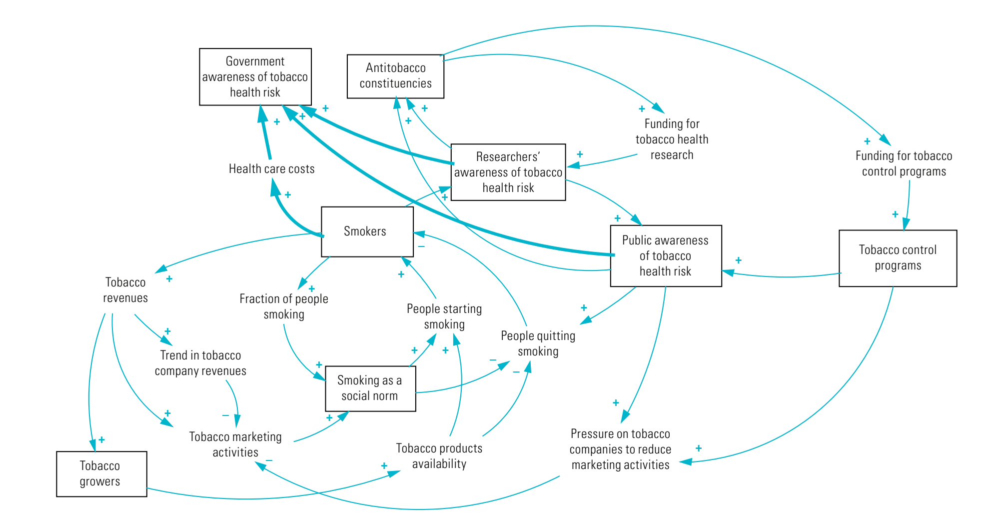
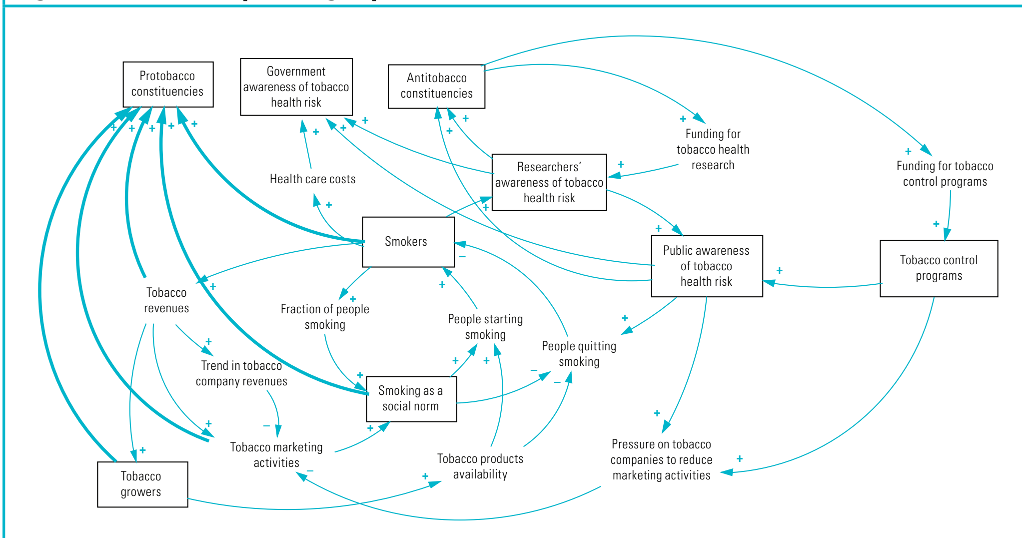


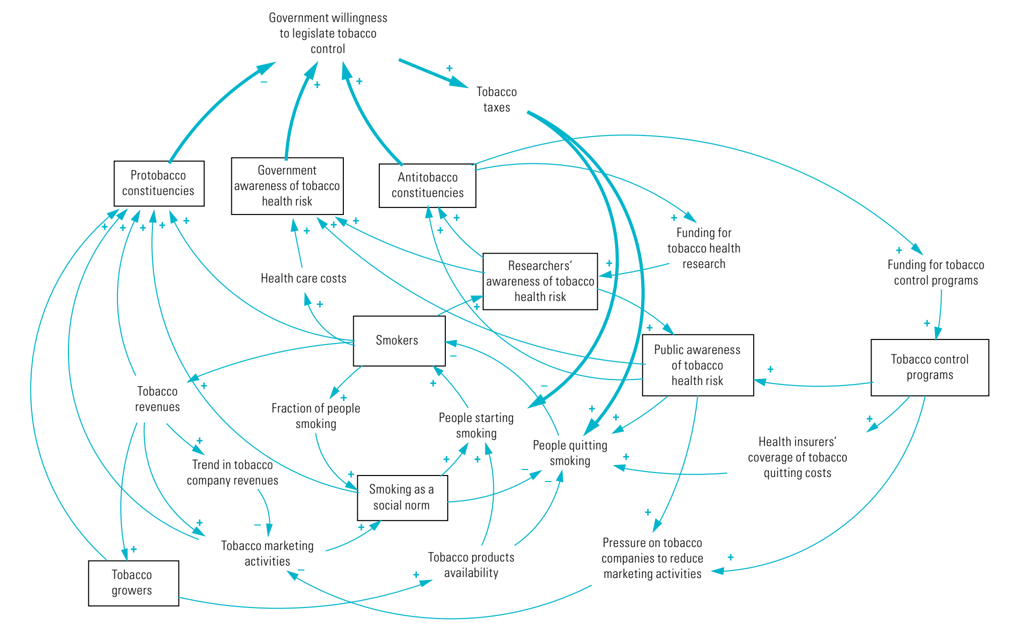
Figure 5.7 Causal Map Adding Impact of Protobacco Constituencies



more motivated people are to pressure their legislators to act. Finally, government experiences a direct feedback loop in the "health care costs" associated with tobacco use. As the number of smokers increases, the health care costs associated with smoking also increase. The government directly bears many of these costs through Medicare. However, such costs also are indirectly affected by the public debate over the general cost of health insurance.

The influence of protobacco constituencies is added in figure 5.7. Protobacco constituencies represent those who advocate in favor of tobacco products and their increased availability. Tobacco companies, smokers, and those who

Figure 5.8 Causal Map Adding Impact of Greater Willingness to Legislate Tobacco Control



accept smoking as a social norm generate the ability to provoke action against tobacco control measures. From a social and psychological perspective, smokers play an important role in the protobacco constituency, because they often are interested in ease of availability and few limitations on smoking behavior.

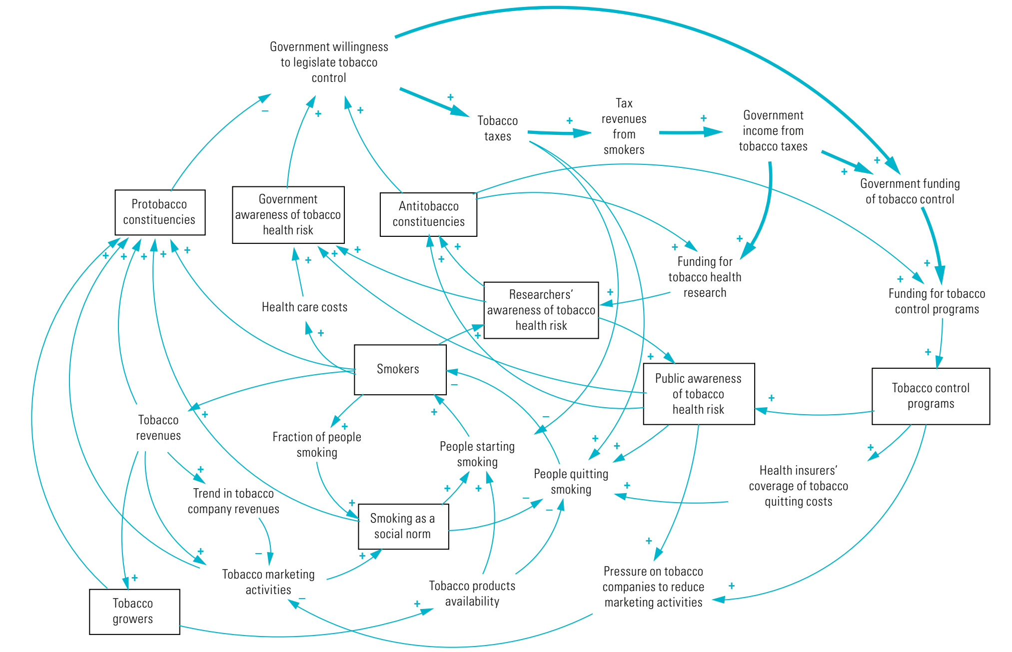
Tobacco revenues create an obvious incentive for people to protect tobacco. Shareholders in tobacco companies desire increased revenue, and companies have a vested interest in the success of their product. Consequently, the tobacco industry takes steps to protect their investment.

The willingness of government to take actions against tobacco interests depends on the balance of forces created by the protobacco and antitobacco constituencies and the government's perceptions of health risks associated with tobacco use. Segments showing the forces influencing willingness to legislate are added in figure 5.8. Increased taxes on tobacco are an early result of this growing government willingness to act against tobacco interests. The impacts of taxes on individual motivation to start or stop smoking create a number of feedback loops in the system, counteracting the growth of the population of smokers and contributing to its eventual decline.

Some effects of government legislation to control tobacco use are added to the model in figure 5.9. For example, as government receives more money from tobacco taxes, it is more willing to increase that revenue stream. However, this loop also works in reverse. As government revenues from tobacco taxes decrease, the government may actually become less willing to act against tobacco interests because it would be threatening its own revenue stream.

Tobacco tax revenue is dependent on the taxes associated with tobacco use, as well as the number of people who smoke (figure 5.9). As either increases, one would expect

Figure 5.9 Causal Map Adding Impact of Government Tax Revenues and Funding for Tobacco Control



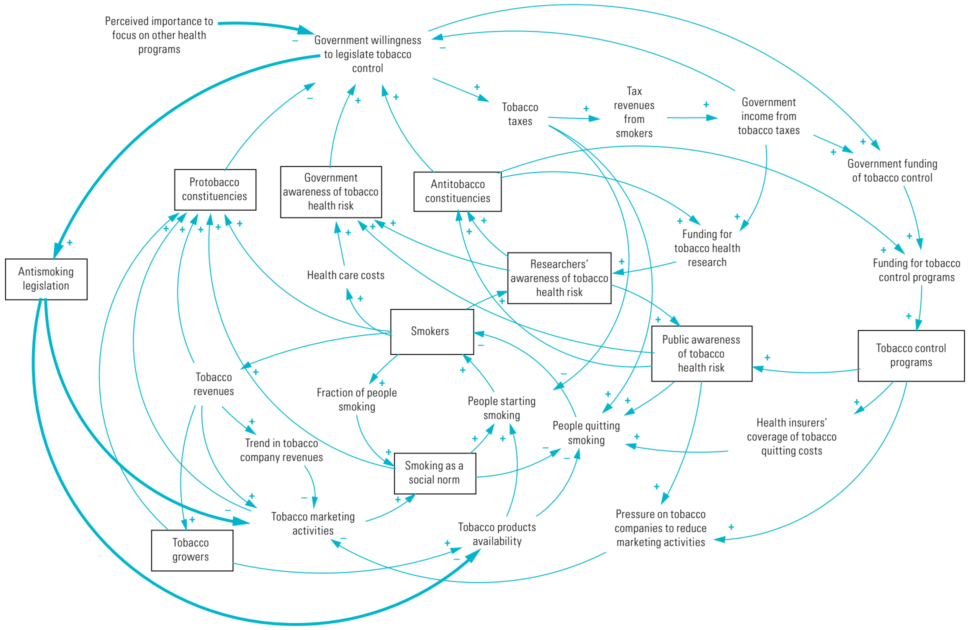
that tax revenue would also increase. These increased revenue streams increase government income. The model suggests that more money moving into the system from tobacco taxes results in increased funding of both basic research and tobacco control.

Finally, government willingness to legislate tobacco control ultimately leads to policy interventions such as antismoking legislation, which in turn has effects on the marketing of tobacco products and their availability. Both of these factors are affected directly by legislative restrictions, as well as by side effects such as counterefforts by the tobacco industry. Adding the impact of these factors leads to the final causal map (figure 5.10) drafted for this pilot project.

The building of this map, as outlined in figures 5.3 through 5.10, was based on participant identification of components, grouping of these components into sectors, and descriptions of the dynamic patterns of the variables over time. The facilitator used this information to construct the causal map and provided it to the participant group for feedback and potential revision. The causal map would doubtless benefit from input from a broader range of stakeholders, such as tobacco growers. This would likely add additional stocks and flows and open some current model elements to debate. The causal map, in turn, was used to inform the development of segments of the formal system dynamics model discussed in the next section.

The tobacco system articulated by this causal map is but a system within a larger system. For example, there have always been competing public health priorities, most recently exemplified by the focus on obesity. In many ways, playing tobacco against obesity competitively is a zero-sum game. With finite

Figure 5.10 Final Causal Map of System Dynamics Model for Tobacco Control in the Initiative on the Study and Implementation of Systems



Note. An earlier version of this figure was published as Figure 1 in A. Best et al. 2006. Systemic transformational change in tobacco control: An overview of the Initiative for the Study and Implementation of Systems (ISIS). In *Innovations in health care: A reality check,* ed. A. L. Casebeer, A. Harrison, and A. L. Mark, 189–205. New York: Palgrave Macmillan. Reproduced with permission of Palgrave Macmillan.

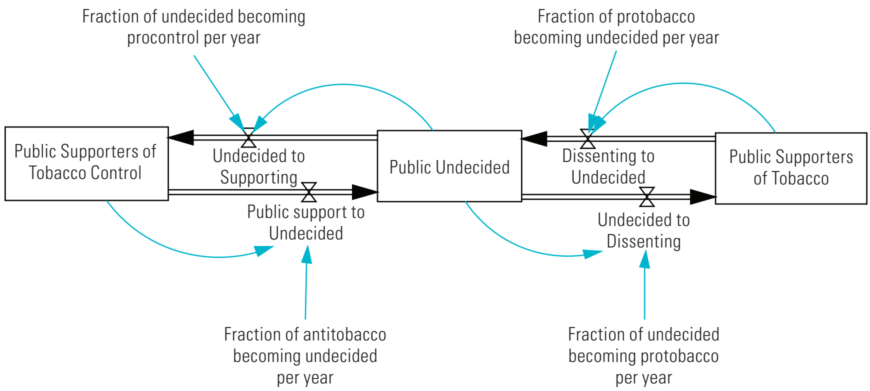
resources, the public health community must set priorities. If the importance of obesity as a health risk increases relative to that of tobacco use, the government's willingness to act and the direction of funding for tobacco control and research may be affected. Issues such as these point to the importance of continuing the use of system dynamics models and the evolution of these models from original assumptions based on changes in the environment.

Developing System Dynamics Models

How does a system dynamics modeler move from hand-drawn graphs, empirical data, and the causal map to a formal system dynamics model? This section presents selected model segments that were used in a larger formal simulation of factors in tobacco use over time.

Compared with the earlier causal maps showing relationships among model factors, these "shards" of system dynamics models form the detailed basis for the estimated parameters used for simulation. They constitute the basic structure of the formal model, showing how causal elements discussed here were translated into a simulation. However, there is not a one-to-one correspondence between segments of the causal map described previously and these model shards. For the purposes of this demonstration project, the simulation model was informed by the overall content of the causal map, and adaptations were made according to the judgment of the analyst and feedback from participants. Only some of the

Figure 5.11 Model of Public Opinion Factors



formal model shards are described here to illustrate how this part of the modeling process works in the context of this example. (The figures shown for these shards are taken from program output from the VENSIM software used for this simulation.)

Public Opinion Sector

The model shown in figure 5.11 relates to the "smoking as a social norm" portion of the causal maps shown in figures 5.3–5.10. That segment of the maps was translated into part of the simulation model by building a closed set of stocks, linked by inflows and outflows in which it is assumed that opinion moves through this closed chain in response to pressure. For example, every year, some fraction of the undecided population moves from the undecided stock to public support of tobacco use or public support of control of tobacco use.

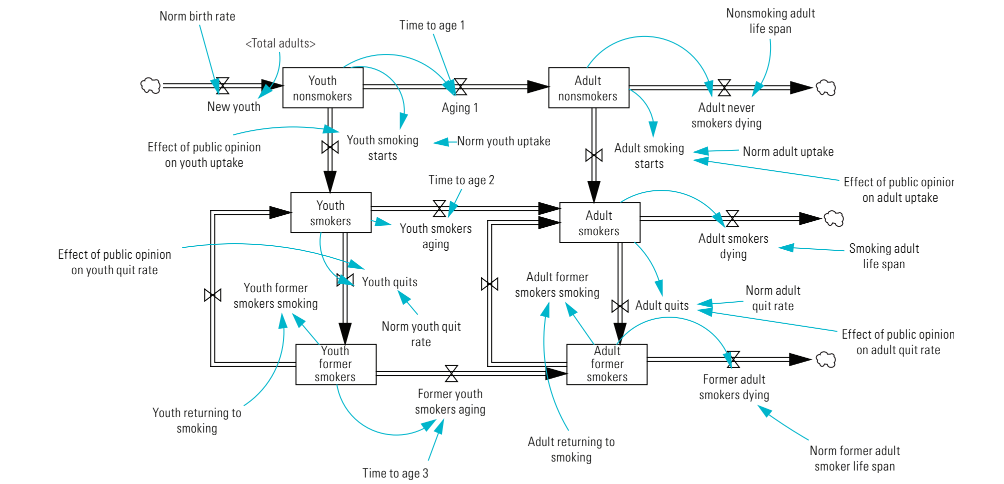
Tobacco Use Sector

Figure 5.12 depicts several "aging chains" used in the formal model to track the inflows and outflows of current and former smokers and people who never smoked, from birth to death. Formulation in this manner is consistent with historical monitoring of tobacco use and enables substantial comparison. If it is assumed that all people are born nonsmokers, one of five behavior scenarios takes place:

1. Youths start to smoke tobacco products or age into adulthood as nonsmokers.
2. Adult nonsmokers start to smoke or continue as nonsmokers until they die.
3. Youths who smoke stop smoking, becoming former youth smokers, age into adulthood as former smokers, or resume smoking after stopping.
4. Youths who age into adulthood as smokers die as smokers or stop smoking and become former adult smokers.
5. Former adult smokers resume smoking or remain former smokers.

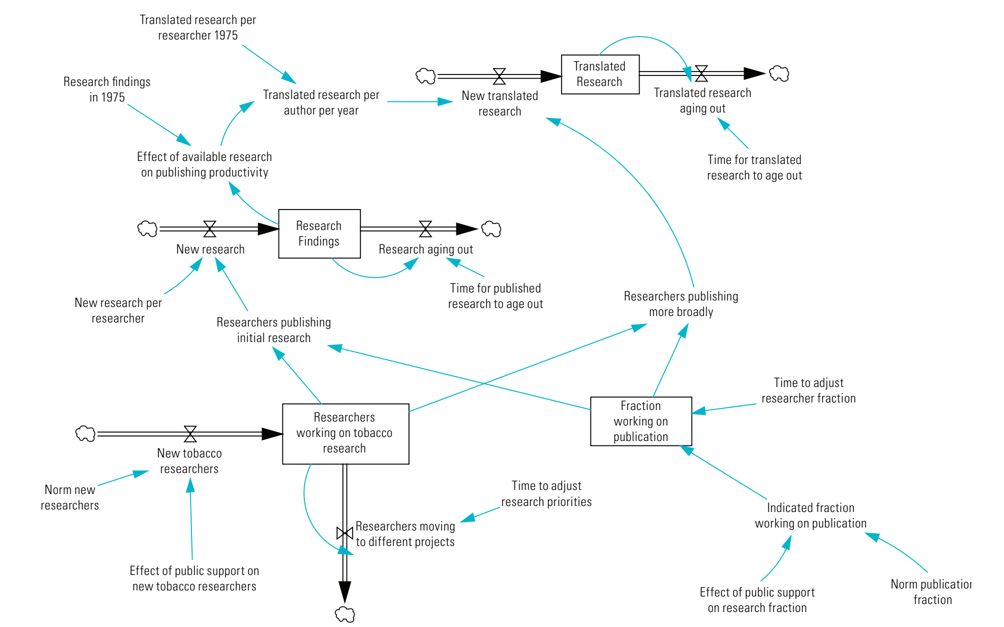
Proximate drivers of flows are built into the formal model in figure 5.12. As shown earlier in this chapter, the state of current opinion affects the rates at which adults and youths begin and stop tobacco use. For example, as public opinion builds in support of tobacco control, rates of initiation of smoking decline. As public opinion builds in support of tobacco use, rates of initiation increase.

Figure 5.12 Model of Aging Chains of Smokers (Birth to Death)



Note. Years are the unit of age.

Figure 5.13 Model of Research and Dissemination Factors



Research and Dissemination Sector

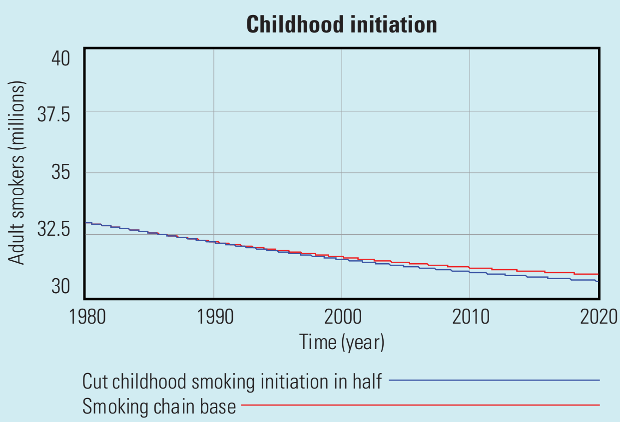
The simulation model in figure 5.13 illustrates research and dissemination (education) factors. These factors play an important role in influencing public health awareness, as described in figure 5.5. This model assumes there are *x* numbers of researchers performing research on tobacco use and control who create initial research (e.g., published in peer-reviewed journals) or translate initial research into information

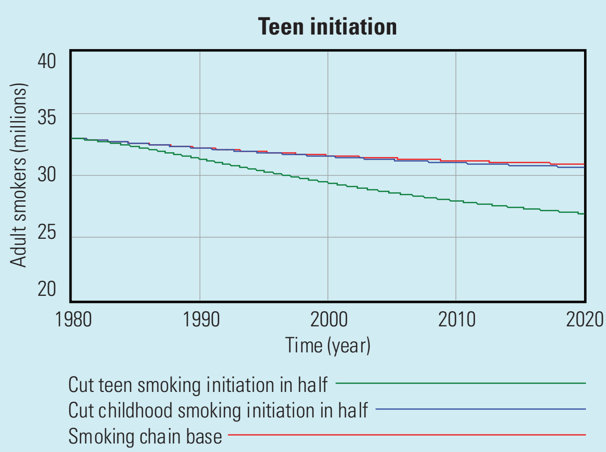
Playing "What If" Games with Smoking Prevalence

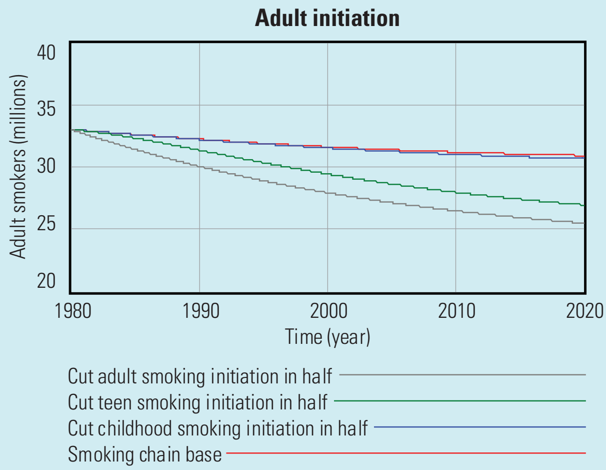
If the number of children who start smoking were suddenly cut in half, how would it affect the number of smokers 40 years from now? As part of the ISIS system dynamics model described in this section, a simulation was performed by using the model for the aging chain of smokers (birth to death) that shows the impact of rates for smoking initiation and cessation at specific ages on the prevalence of tobacco use. This model was then used to test the effect of dramatic changes in these initiation rates, in different age groups, on prevalence over a 40-year period.

The simulation results show that cutting smoking initiation in children under age 12 years in half had minimal impact downstream. However, similar decreases in adolescent (ages 12–20 years) and adult smoking initiation produced much greater declines. Factors behind these results ranged from the relatively small number of child smokers to the cascading effects of each group on subsequent rates for smoking initiation and cessation.

Effect of 50% Declines in Child, Adolescent, and Adult Smoking Initiation in Longitudinal Studies of Smoking Prevalence







Perhaps an even more important outcome from this simulation was the reaction of other tobacco control stakeholders, many of whom felt that this simulation would not necessarily reflect long-term outcomes in real life. Some people, particularly those involved with tobacco use issues among young people, thought that a sharp decline in youth smoking could become a powerful agent in other factors. These include social and culture change, which could in turn create conditions for much greater reduction in prevalence.

Although this simulation was designed only as a proof of concept project with limited data, it brought two important points to life for ISIS participants: that system dynamics models often can reveal unexpected outcomes and that the results depend strongly on the assumptions behind the model. These factors highlight a key limitation in system dynamics modeling, which is that the modeling cannot easily be validated. When surprising results occur, it is not clear whether they have arisen from one or more unwarranted assumptions. The second key limitation is the great difficulty in parameterizing system dynamics models. These limitations reinforce the point that system dynamics models are aids to thinking about complex issues, not tools for delivering "truth."

available for dissemination to the public (e.g., tobacco fact sheets available for download on many public health Web sites or television news pieces on recent tobacco-related health warnings).

Several effects of public opinion are built into this model. The model assumes that the rising tide of public support may increase the demand for researchers engaged in tobacco-related projects and, likewise, increase the demand for materials on awareness of risk for dissemination to the public.

Not all of the causal map has been explicitly included in the model. Sometimes factors in the causal map are handled differently in formal modeling. This was the case for factors related to the tobacco industry. Instead of separately modeling the influence of these factors, this model considers the rate at which research translated for dissemination reaches the population as a net gain, after subtracting for an effect of counterresearch and propaganda from the tobacco industry.

Government Sector

Figure 5.14 examines government intervention. The hypothesis is that government intervention grows in response to public support for tobacco control. This segment of the formal model illustrates the idea of a delay, labeled "time to change government intervention." This is interpreted as the time it takes to create new legislation or repeal existing legislation, as the support for tobacco control rises and falls.

Public Opinion Revisited

With the assumption of basic understanding of the tobacco use, research and dissemination, and government sectors, figure 5.15 shows the effects of the public opinion sector on tobacco control.

Changes in public opinion are influenced by the number of smokers and nonsmokers in a population. This hypothesis is based on the assumption that, for example, a firmly established social norm in favor of smoking tends to produce more smokers, who tend to support the existence of the social norm.

Translated research will tend to "push" public opinion toward control of tobacco use, because the assumption is that a more informed population chooses reduction of tobacco use. The model indicates a weak "backlash" effect in response to increasing government intervention. This is based on the presumption that government constraints on personal behavior may draw some opinion away from support.

These segments of simulation models illustrate how causal maps and other factors such as experience and expertise in subject matter are translated into more formal simulations. Such simulations enable researchers and practitioners to change different parameters in efforts to explore the likely effects of these changes throughout the dynamic system. Based on those trials and how appropriate the results appear, the simulation itself might be revised. In this manner, the act of simulation constitutes

Figure 5.14 Model of Government Sector

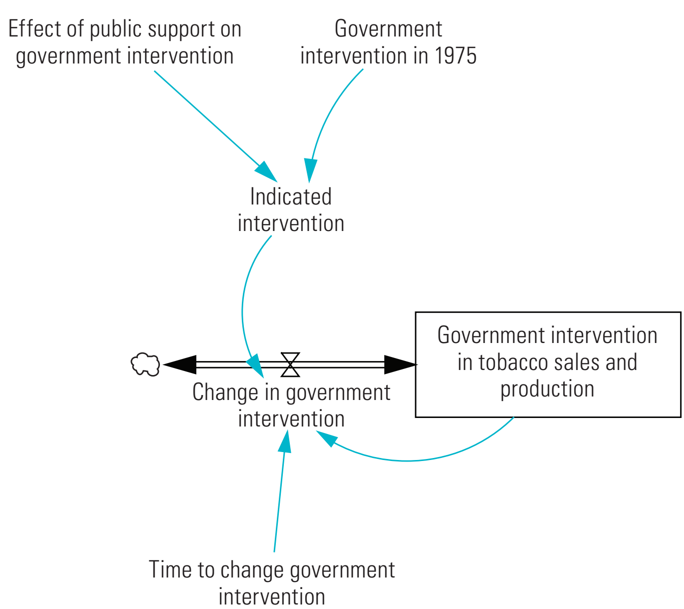
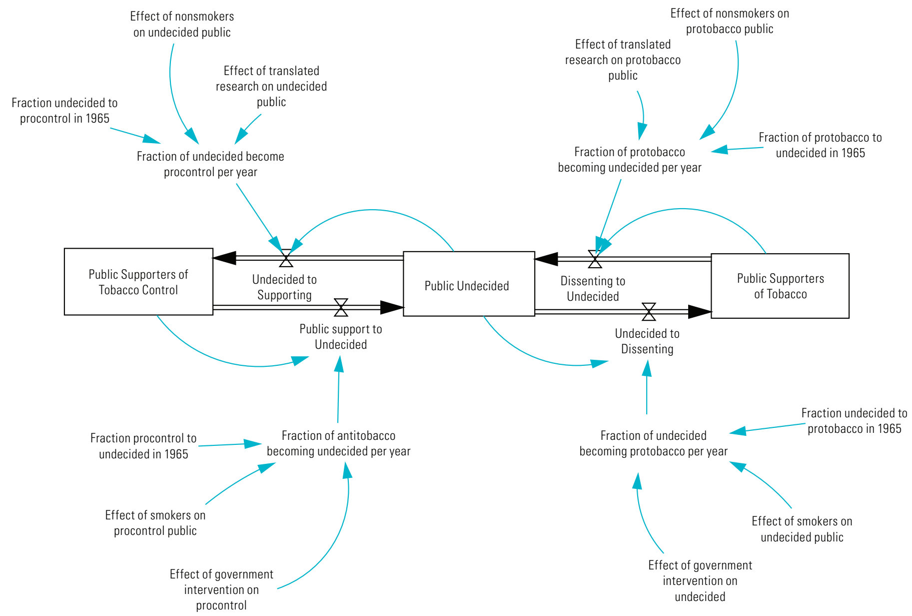


Figure 5.15 Expanded Model of Public Opinion Factors



a type of dynamic laboratory for trial-and-error efforts to better anticipate the effects of different conditions.

Validating Simulation of System Dynamics Models

Simulation of system dynamics models means allocating numbers to the "stocks" in the model and activating the "flows" so that changes in behavior over time are simulated. An example of the behavior of the model is presented here through text description and graphical representation. This section highlights causal loops to provide supplementary explanations for important model dynamics and shows how simulation models are set against real-world data in an ongoing process of revising and validating the models.

The results in the initial simulation model are compared with outcome data in figure 5.16. Data from the Centers for Disease Control and Prevention,[6] represented by the short lines in the model, are compared with the simulation projections, represented by the long lines. The test model fits existing data well over time. However, the simulation model has the advantage of allowing projections into the future, represented by the extension of the long line over the short line.

System dynamics modeling does not simply assume that projections into the future are accurate or valid because of a correspondence of simulation estimates with historical data. A multitude of simulation models might correspond just as closely with historical estimates. Modeling is done primarily for its probative value, as a tool for exploring possible effects, but modeling of this type can be a basis for more confident projections. For instance, multiple models that predict similar longer term outcomes, all making differing assumptions, form a stronger basis for validity than any one model alone would.

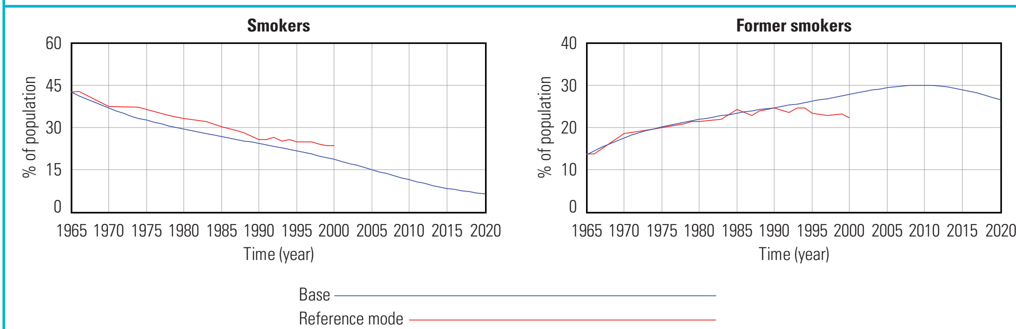
The historical data progressively diverge from the simulation data during 1990–2000 (figure 5.16, graph on right). This finding suggests that important parameters influencing more recent projections were either not included or were not properly weighted in the simulation. This finding might be used to start a series of trial-and-error revisions to the simulation model to explore possible reasons for such a discrepancy.

Estimating Parameters

An additional advantage of the model is that it allows exploration of sectors for which no data exist. Modelers use intuition to decide whether the model "makes sense." For example, the stocks for public opinion are visible in figure 5.17. The initial parameters for the public opinion stocks are a function of the smoking rates in a population. For example, those who smoke are assumed to be proponents of tobacco use. Those who have used tobacco and stopped smoking are assumed to be supporters of tobacco control. These assumptions are open to challenge, but they are useful for illustrative and probative purposes.

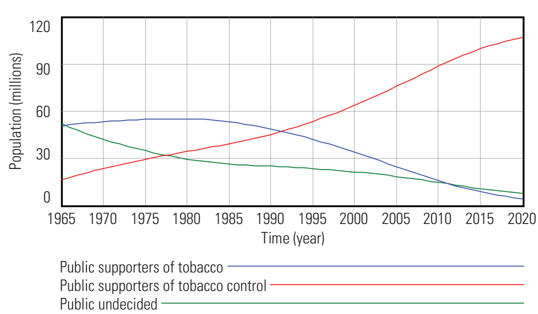
Support for tobacco control has been increasing, although not necessarily at a predictable or constant rate. In this model, the reason public support fails to establish a linear positive trajectory at its end point is

Figure 5.16 Model Data Versus Actual Data on Population Fractions of Current and Former Smokers



Note. Model data are indicated by the long line. Actual data are indicated by the short line.

Figure 5.17 Stock Values for Public Opinion over Time (Baseline)



based on several important feedback loops, shown in figure 5.18.

Because the model begins in 1965 with a substantial number of current smokers, the size of the smoking population allows support of tobacco use to continue to grow for several years. It is bolstered slightly by the effect of government intervention in the wake of the 1964 Report of the Advisory Committee of the Surgeon General on smoking and health.[7] Until regulations on tobacco product warnings became institutionalized by the Federal Cigarette Labeling and Advertising Act in 1965,[8] the government warning about tobacco use as a health risk had an effect opposite to that intended on the tobacco-using population.[9] This result was in keeping with the modeling assumptions discussed earlier on the effects of this intervention on public opinion (figure 5.19).

Momentum to control tobacco use builds slowly, as rates of the decline in smoking and public interest in intervention and research grow. Eventually, the stock of support for control overtakes the stock of tobacco use.

Simulation Results

Examination of the effects of changing various model parameters and their effects can lead to a better understanding of the system. These effects are grouped by model sectors. For each grouping, the most relevant scenarios are discussed, although they represent only a small fraction of all possible scenarios.

Tobacco Use Sector

An informative initial test is to evaluate the following proposition: the effect of public support for tobacco control on tobacco use has been underestimated. The blue baseline in figure 5.20 represents the original effect of public opinion on the adult rate of starting to smoke. The x axis indicates the input, that is, the level of public support for tobacco control. The y axis indicates the impact of this support on the current adult rate for smoking initiation. The shape of the blue baseline changes with changes in the

Figure 5.18 Feedback Loops Affecting Public Opinion

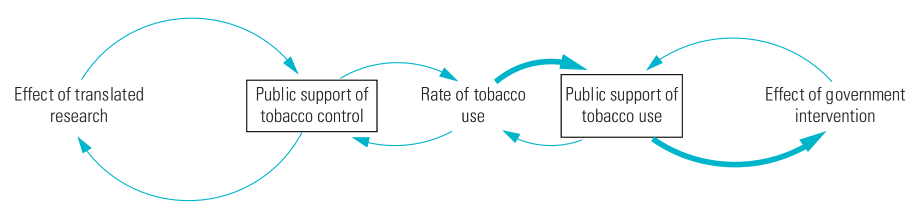


Figure 5.19 Feedback Loops with Change in Feedback Levels

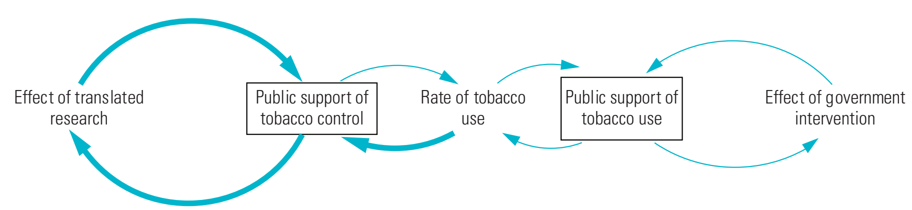
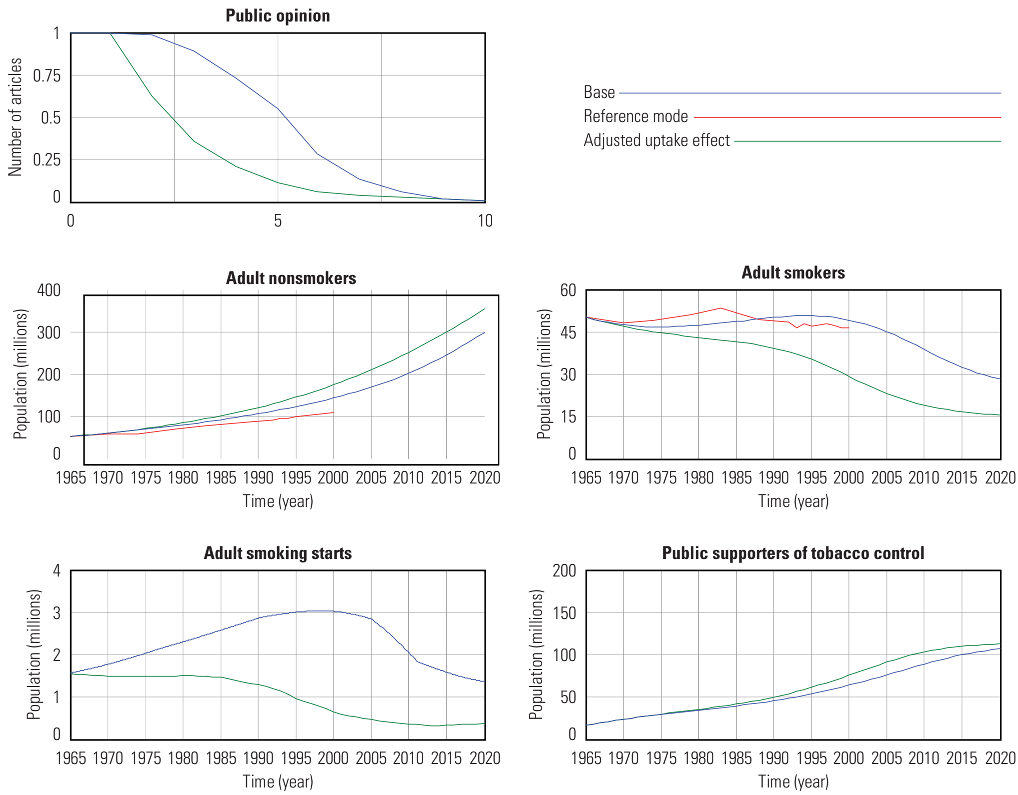


Figure 5.20 Effect of Public Opinion on Adult Uptake



parameter of public opinion. The graph of new data shown by the green line suggests that a change in public opinion yields a much greater change in the rate of smoking initiation among adults.

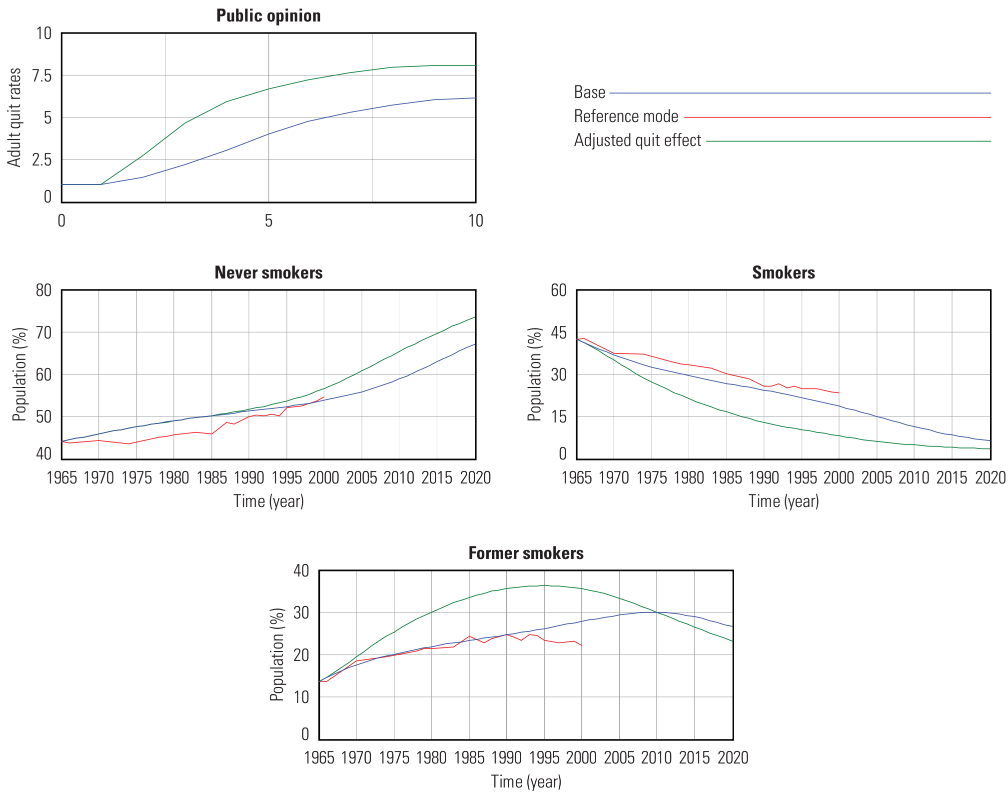
The largest impact of the change is indicated in the graphs for adult smokers, because the rate of smoking initiation declines much more quickly than in the baseline simulation, which consequently reduces the number of former smokers. The number of supporters of tobacco control also is slightly higher, but this effect moderates quickly.

The effect of public opinion on the rate for smoking cessation among adults also may be different from that at baseline. The original base assumption and an altered assumption are both expressed in figure 5.21. The altered assumption suggests that public opinion has a more significant impact on smoking cessation than the original assumption.

When the effect of public opinion is amplified, predictably, fewer people are smoking, and a much higher percentage of people have stopped using tobacco. After 1995, the percentage of people who never smoked also is significantly higher. As shown in the causal loops in figure 5.22, this increase is due to the feedback effect of public opinion on the rate of smoking initiation.

Change in the smoking cessation rate directly affects the numbers of smokers and former smokers. This model shows that the growing

Figure 5.21 Effect of Public Opinion on Rate of Smoking Cessation among Adults



contingent of nonsmokers also has an effect on the number of adults who never smoked (figure 5.22). As public opinion grows, the rate at which adults initiate smoking declines. In this way, the model captures what might be hypothesized as an elusive shifting of the social norm regarding tobacco use. These effects have only begun to become visible during the more recent decades. Should the model capture the dynamics of the system accurately, it can provide useful details about its behavior in coming years.

Research and Dissemination Sector

Additional tests can be designed to explore the dynamic effects of public opinion in the research and dissemination sector. For example, figure 5.23 shows the results of simulation of the effect that public support for tobacco control has on altering the research fraction. This is the proportion of researchers conducting basic research versus the proportion translating research into information that can be disseminated to the public. Based on the assumptions of the model, the greater the public support for tobacco control is, the more emphasis is placed on funding basic research (figure 5.23, top). Paradoxically, more public support may mean less translational research. The amount of funds for all research (basic plus translational) is growing because of public support. However, it does not grow as rapidly as the proportion for basic research that appears to be responsive to the public. The

Figure 5.22 Causal Loops for Public Opinion and Support of Tobacco Control

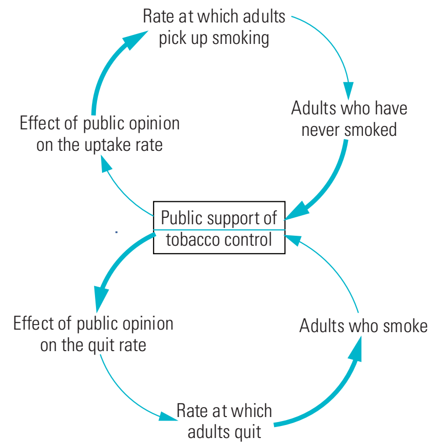
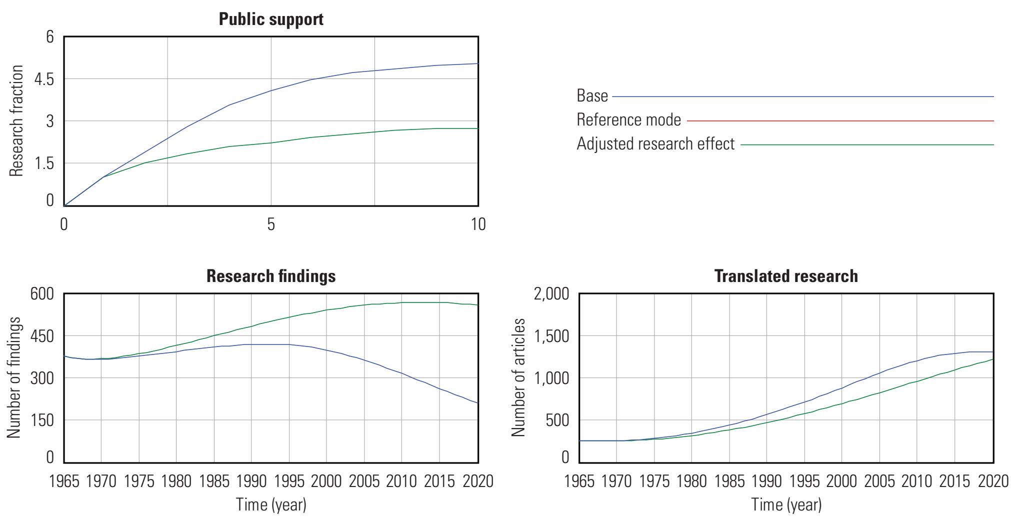


Figure 5.23 Effect of Public Support for Tobacco Control on Research Fraction



model suggests that the effect of public support is weaker than it was at baseline (figure 5.23, graph at lower left). Despite the shift to more initial research, the simulation shows that the amount of translated research does not decline as much as might be expected (figure 5.23, graph at lower right).

A compensating loop in this model addresses the publishing productivity of those who translate research. With more public support for tobacco control, the research fraction is altered to favor more basic research, a higher volume of such research is accumulated, and consequently, the publishing productivity of researchers working on translational research is affected negatively (figure 5.24). The change in translated research is significant enough to alter the stock of tobacco use (figure 5.25).

Figure 5.24 Causal Map for Research and Public Support for Tobacco Control

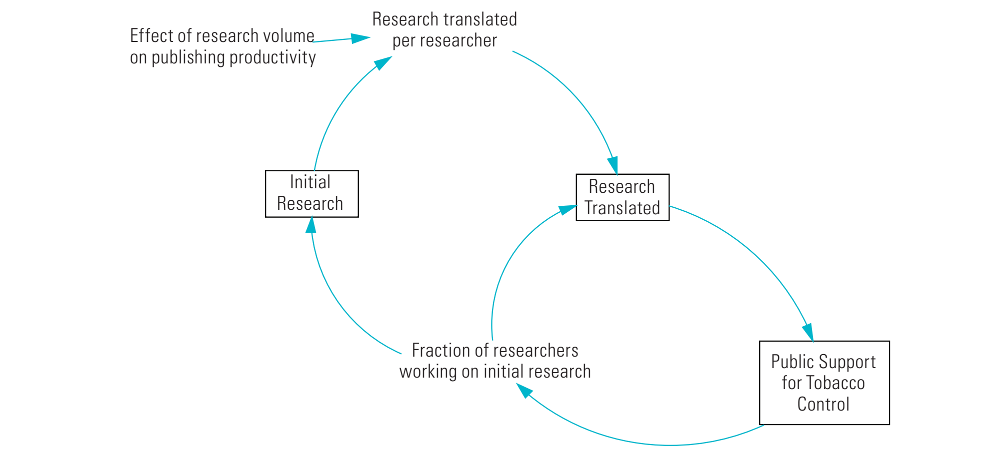
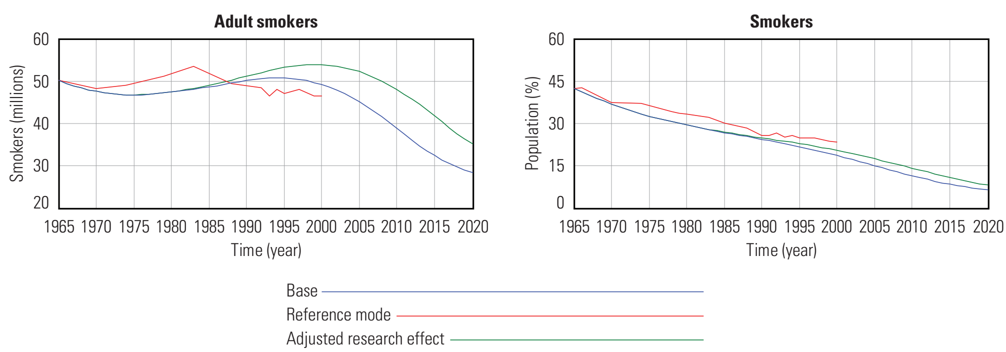


Figure 5.25 Effect of Research on Tobacco Use



However, the effect moderates toward the end of the simulation, and one suspects that this effect would disappear over time.

Public Opinion Sector

Previously, a test was performed to determine how significantly public opinion affects the amount of research being performed. For the next test here, this assumption is reversed and the impact of relevant and timely research on public opinion is explored. As has been mentioned during ISIS workshops, providing such data to the general public is a vital component of a tobacco control policy.

A simple test explores the sensitivity of translated research by changing the time it takes to “age out” of the public’s awareness. The baseline assumption is that the public’s memory of awareness about tobacco use as a health risk is fairly long; the time until the research ages out is set at 25 years. The results of changing that parameter to 15 years are shown in the graphs in figure 5.26.

Because translated research flows through this stock more quickly and thus remains in the public’s mind for a shorter period, less of it accumulates. Less accumulation of research directly and negatively affects

Figure 5.26 Effects of Translated Research on Public Opinion

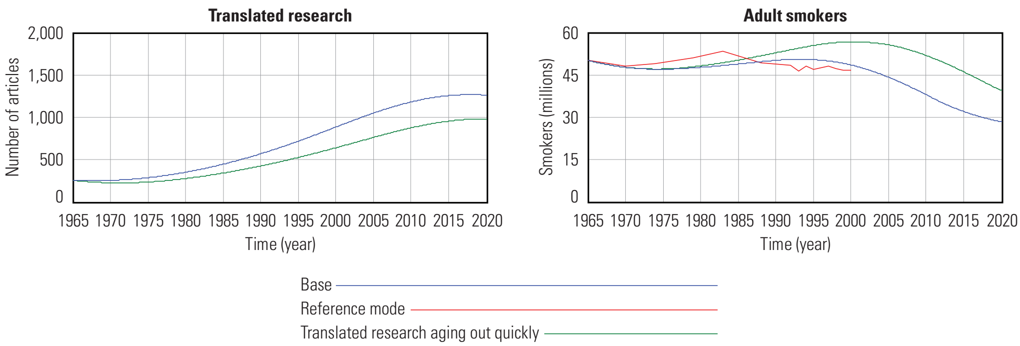
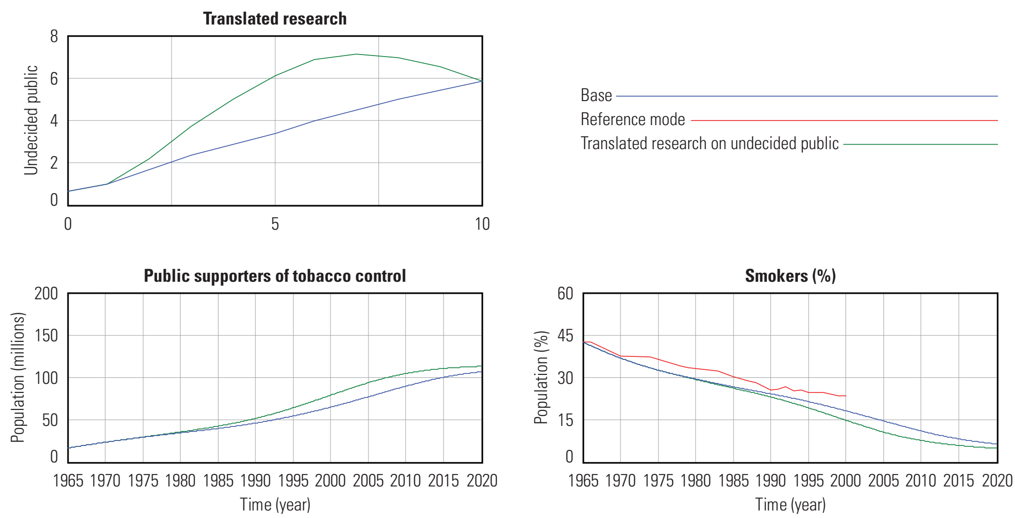


Figure 5.27 Effects of Translated Research on Undecided Public



the shifting social norm, and a higher stock of current smokers results. The life span of relevant tobacco research is an important concept, even though it may be difficult to accurately measure. Although it is beyond the scope of this simple model, it is clearly worthwhile to consider the quality of translated material. This is because quality undoubtedly affects the durability of tobacco research and education.

This simulation environment offers other ways to explore the effects of research. A new assumption suggests that, as in the baseline run, more translated research yields a greater effect (figure 5.27). In this new run, however, the model also reveals that there is a point at which more research does not yield greater impact but leads to less movement into the stock for tobacco control. Practically speaking, if the volume of antitobacco information available far exceeds the public's ability to integrate it into the current social consciousness, it will likely be filtered out. A slight gain in support for tobacco control and, consequently, a decline

Figure 5.28 Percentage of Undecided Public over Time

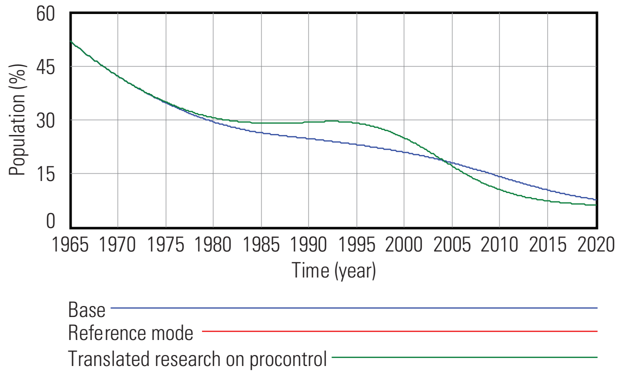
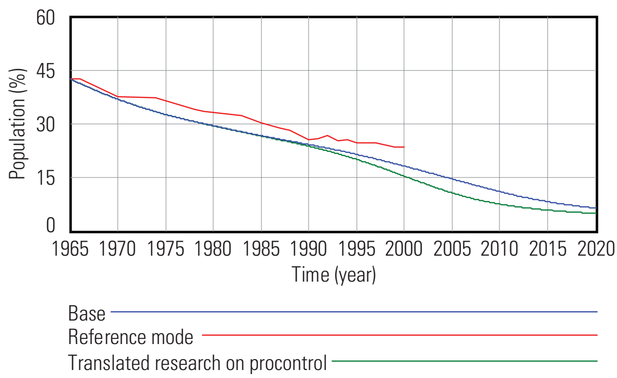


Figure 5.29 Effect of Research on Population Fraction of Smokers



in the fraction of people using tobacco are shown in figure 5.27 (lower graphs). If translated research has a greater effect than that in the baseline run, the simulations result in a predictable gain for the stock for the undecided public (figure 5.28).

The "gain" illustrated in figure 5.28, practically, means that 30% of the public has been undecided on the issue of tobacco control for more than two decades. Those without a keen eye on the long-term behavior of the system may be tempted to consider this finding as something other than progress. Based on this model, the absence of a dramatic gain for tobacco control could be interpreted as the natural evolution of the system. As the undecided public begins to shift toward support of tobacco control, a drop in rates of tobacco use will become apparent, as shown in figure 5.29.

Government Sector

A final example simulation experiment toggles the impact of government intervention. This model includes an assumption that government intervention may have the unintended effect of producing a backlash against tobacco control. In New York State, for example, laws regulating smoke-free restaurants and bars have produced a solid and well-funded campaign against tobacco regulation. This campaign threatens to weaken not only the law but also the movement to protect nonsmokers from the health effects of tobacco use.

The effects of government intervention on the shift from support for tobacco control to an undecided position and from undecided to a protobacco position are shown in figure 5.30 (top left and top right, respectively).

As expected, the decreased strength of the effect leads to more tobacco control advocates and fewer supporters of tobacco. Over a longer period, the impact of the

Figure 5.30 Effects of Government Intervention on Shift from Support for Tobacco Control to Undecided and from Undecided to Support for Tobacco Use

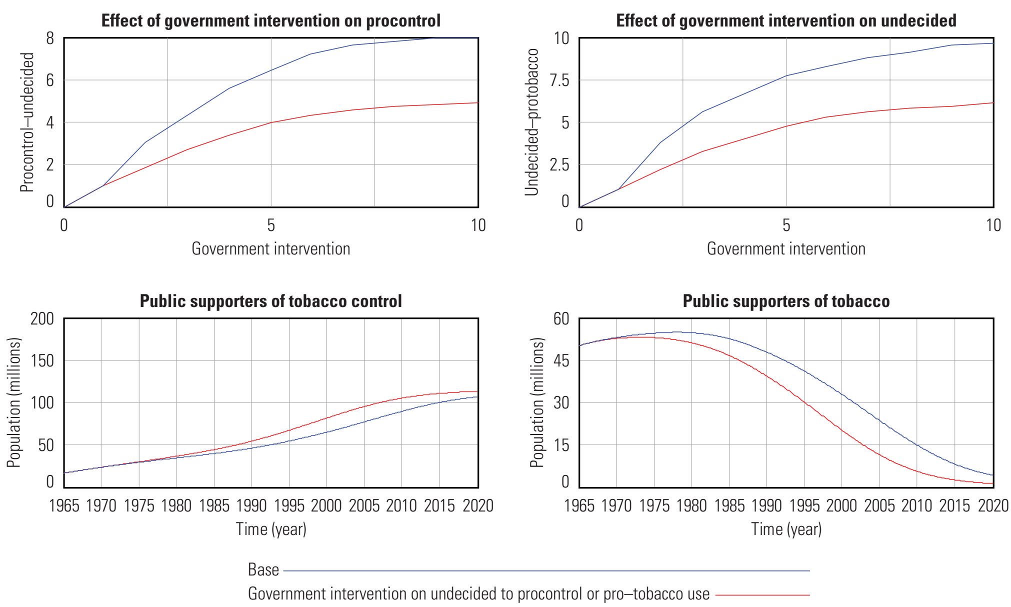
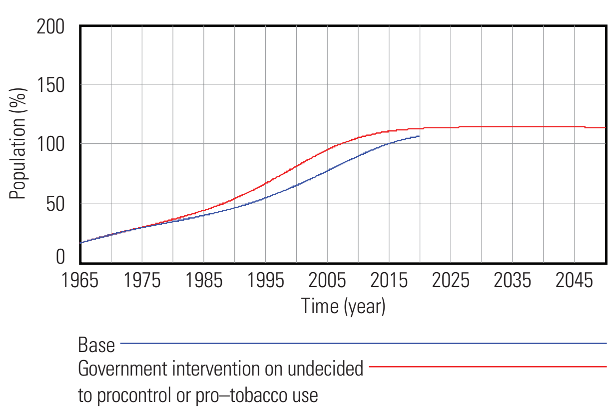


Figure 5.31 Effect of Government Intervention on Public Supporters of Tobacco Control



effect does not yield a significant change in behavior. The reaction of a population to a series of government regulations, all else being held constant, does not have a long-standing influence on the changing social norm (figure 5.31).

This model presents a simplified view of factors in tobacco prevalence and consumption, which were developed for illustrative purposes. Although the model represents only one iteration, it provides a base from which further modeling work, corrections, additions or subtractions, and enhancements could be easily accomplished as part of a more accurate simulation. Meanwhile, it serves as a mechanism for raising questions, provoking discussion, and gaining a deeper understanding of the complexity of this dynamic system. It also opens a valuable dialogue among stakeholders in tobacco control and other disciplines in the ISIS project.

Summary

This chapter examines the potential for using system dynamics modeling in tobacco control and public health and presents a case study of developing and using a system dynamics model to explore trends in tobacco use over time. It demonstrates use of a modeling approach to represent the interrelationships among key factors in tobacco use and their evolution over time. The project developed here can be considered a heuristic and preliminary model, but many of the results compare well with actual outcome data. Overall, this project serves as a valuable proof of concept for future systems-level modeling efforts.

This case study project was designed to develop clearer ideas about system dynamics and about the range of approaches that can contribute to more effective tobacco control and public health in general. The system dynamics approach arose, at least partly, from dissatisfaction with the limitations of simple cause-and-effect approaches that have no feedback for tackling the challenges of tobacco control. These approaches are effective in improving understanding of individual causal mechanisms or small clusters of mechanisms. However, they cannot provide much assistance in addressing the dynamic complexity of tobacco control.

The ISIS project used the rubric of systems thinking to establish a starting point for investigating the world of dynamic modeling and its application to tobacco control. Many approaches to systems thinking exist, sometimes with tensions evident among them. Nonetheless, the research outlined in this chapter provides a clear sense of how one systems approach, system dynamics, can help the tobacco control community to understand, model, and react to the complexities of the current tobacco control environment. System dynamics is an aid to thinking differently about the tobacco control world—to characterizing it in terms of feedback, stocks and flows, and structure and behavior. System dynamics elucidates the role of feedback, which keeps the system in balance and leads to change that may or may not be advantageous. System dynamics modeling also has the potential to work in concert with the other areas under study in ISIS, including the following:

- Management of organizations as a system, with an understanding of the macrodynamics of planning, implementation, and evaluation and how these constitute a feedback mechanism that is both driven by system forces and drives them (chapter 4)
- Network methods, encompassing the development and management of stakeholder groups that define the system of interest and its dynamics (chapter 6)
- Knowledge management and knowledge transfer, which facilitate the use and management of explicit and tacit

knowledge (in the form of both data and people) that helps to describe and evolve system models (chapter 7)

System dynamics methods, in conjunction with other systems thinking approaches, are a useful tool for probing, exploring, understanding, simulating, and interacting with future issues in tobacco control. Many issues remain to be investigated to build on the foundations established here. At the same time, the concepts presented in this chapter represent a starting point toward developing a more systemic approach. This new approach would underpin the ability to work with increasingly complex, multifaceted tobacco control issues. It also would provide the foundation for transforming knowledge about a range of public health issues into effective policy and practice.

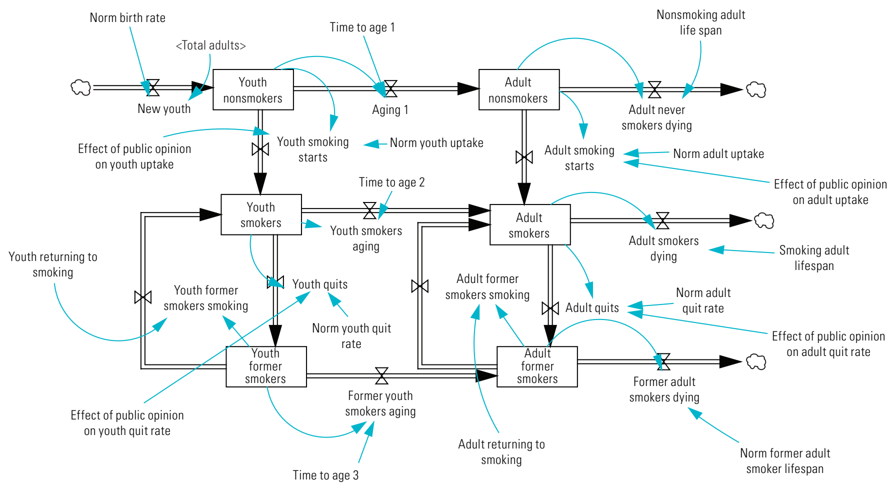
Conclusions

1. Tobacco control consists of dynamic relationships over time and requires approaches, such as system dynamics modeling, that can address such dynamics.
2. Understanding of tobacco control and public health issues has evolved from simple cause-and-effect studies and logic models to more complex, ecological problems that involve feedback and evolving behavior.
3. System dynamics uses mathematical simulation approaches based on stocks, flows, and feedback loops, which can model system structures and simulate future system behavior, including possible unintended consequences and long-term effects.
4. Demonstration projects, such as the system dynamics simulation of tobacco prevalence and consumption developed for the Initiative on the Study and Implementation of Systems, show the potential to model and simulate future tobacco issues to design more effective interventions.
5. Opportunities are likely to surface for integrating system dynamics modeling and other systems thinking approaches at epistemological and methodological levels. Systems approaches can and should integrate within a larger systems thinking environment encompassing components such as systems organizing, networks, and knowledge management.

Appendix 5A. Detailed Development of a System Dynamics Model

This section outlines the specific system dynamics model sectors created for a demonstration model of tobacco prevalence and consumption from 1965 to the present. This model was designed to simulate the effects of specific changes to model variables on prevalence and consumption of tobacco over time. Specific model segments are shown in detail in this appendix.

Figure 5A.1 Tobacco Use Sector



Note. Years are the unit of age.

Figure 5A.2 Tobacco Research and Education Sector

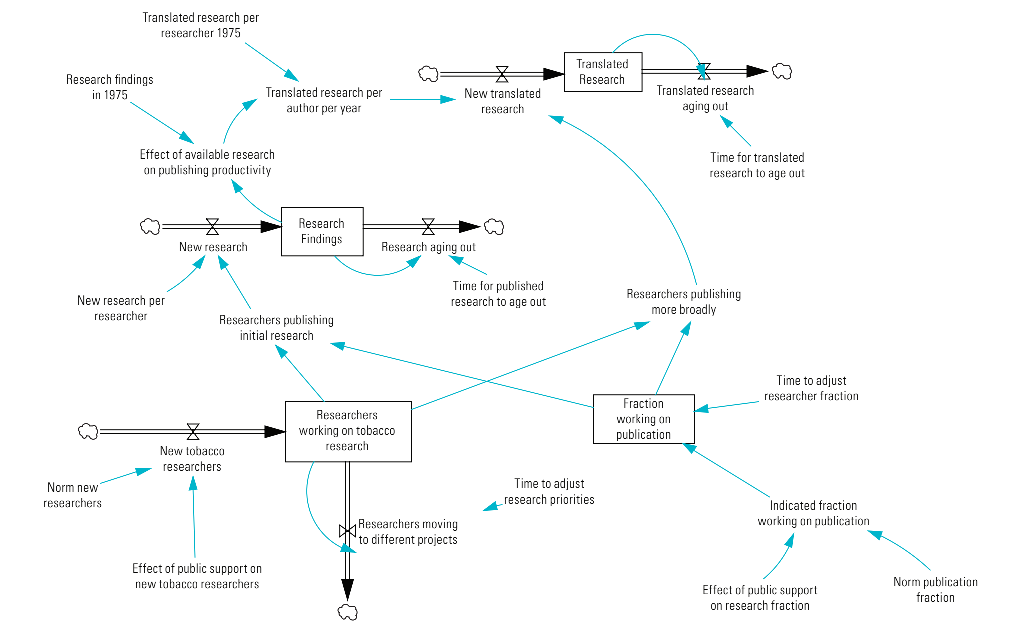


Figure 5A.3 Government Sector

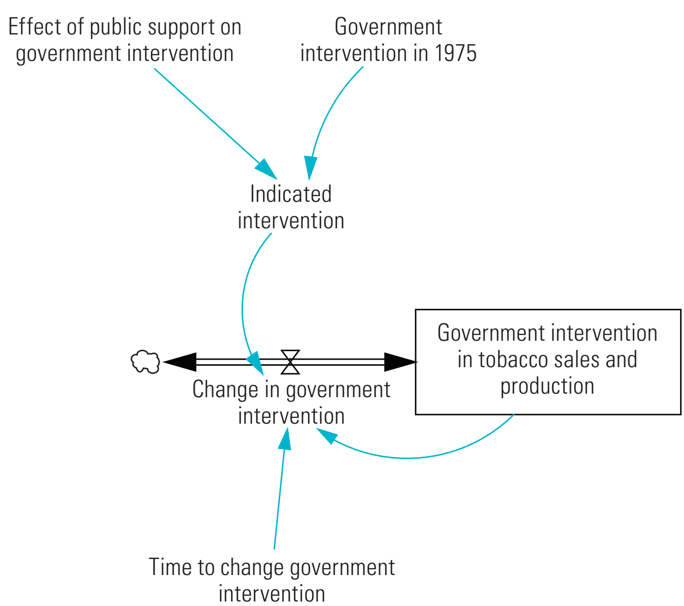
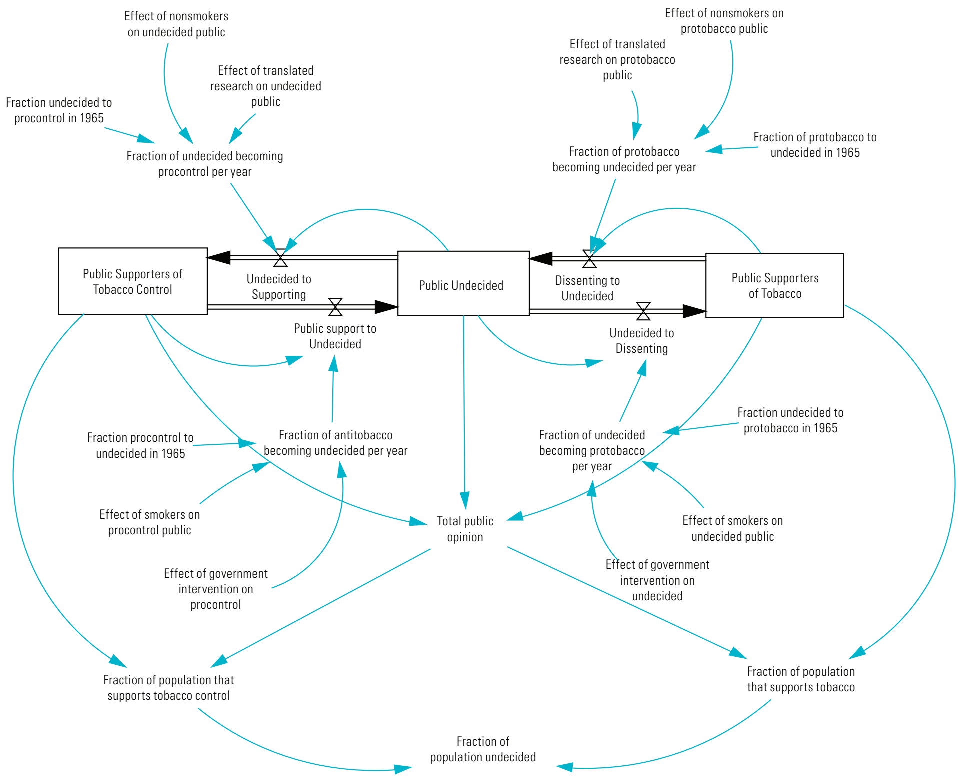


Figure 5A.4 Public Opinion Sector



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