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Systems Thinking: Potential to Transform Tobacco Control

The preceding chapter explored contemporary challenges faced by proponents of tobacco control, particularly with respect to improving public health outcomes. This chapter presents a view of systems thinking as an endeavor that encompasses a broad and rich historical tradition of systems fields that could help address the increasingly complex challenges that tobacco control faces. The chapter addresses the application of systems approaches to tobacco control by examining

- *Current systems thinking approaches, including theories and issues encompassed by or closely allied to systems thinking*
- *Four promising systems approaches under study in the Initiative on the Study and Implementation of Systems (ISIS) project, which are explored in detail in subsequent chapters within the broader context of an integrated systems environment*
- *Key questions of tobacco control practitioners, researchers, and policy makers that are addressed by systems thinking*

The goals of this chapter are to describe several frameworks for understanding what is meant by systems thinking, present a brief overview of the vast terrain of systems concepts, suggest an integrated view of the idea of systems thinking that is emerging in part from the work conducted in this project, and outline some of the implications of systems thinking for three key stakeholder groups in tobacco control—practitioners, policy makers, and researchers.

First come hints, then fragments of systems, then defective systems, then complete and harmonious systems. [And] thus, the great progress goes on.

—Thomas Babington Macaulay (1800–59)

Introduction

This chapter begins to frame the process of applying systems thinking to key issues in tobacco control as a prelude to more detailed examinations of individual systems approaches and their synthesis in subsequent chapters. The first section offers a brief overview of the idea of systems thinking and the many systems concepts that help inform it. The next section suggests the contours of an integrated framework for systems thinking. It does so by introducing the four systems approaches that were the specific focus of the ISIS project (systems organization, system dynamics, network analysis, and knowledge management and transfer). The central role of participatory approaches to human systems is described, and suggestions are offered about how these might be integrated within a new field of study. The chapter concludes with specific questions these systems approaches might help answer for several groups of tobacco control stakeholders: practitioners, researchers, and policy makers.

Public health issues such as tobacco control are not simple, linear cause-and-effect problems. They are systems bound together by a network of factors that influence and react with each other, much like a living organism. The prevalence of tobacco use and tobacco product consumption has decreased substantially in the United States in the past few decades in response to interventions such as consumer education, telephone quitlines for smoking cessation, advertising restrictions, increased taxation, clean indoor air restrictions, and health warnings. Nevertheless, tobacco use remains responsible for hundreds of thousands of preventable deaths each year. Moving past the current plateau in tobacco control outcomes requires dealing with a complex interplay of evolving actors and factors that must be addressed as a system. The purpose of ISIS has been to explore the potential of key systems approaches that address challenges in tobacco control, including

- Disparate communities of interest and frequent duplication of effort
- Limited integration of research and practice, so that the best science frequently sits unread and unimplemented
- A paucity of organized dissemination and collaboration methods
- Competition from a well-financed and well-organized tobacco industry that has integrated dissemination and networking efforts
- The need for more experience in evaluating (1) the interconnected dynamics of the tobacco control system and efforts of the tobacco industry and (2) the effects of these dynamics on key outcomes such as tobacco cessation and morbidity and mortality due to tobacco use

Successful program development in any field requires both effective strategy and powerful implementation—sometimes characterized as "doing the right thing right." The ultimate primary goal of these systems approaches in tobacco control is to improve performance. Documentation of improvement requires direct measures of outputs and outcomes, such as (1) decreases in smoking prevalence; (2) greater efficiency in terms of the number of smokers served by direct contact programs (e.g., clinics, Web sites, and hotlines) per dollar invested and over time; and (3) higher proportions of programs and policies meeting standards for "evidence-based" interventions. The promise of systems approaches, backed by a growing body of evidence, is increased facilitation of progress toward such desired outcomes.

Systems approaches may help cast new light on issues that affect program delivery in the real world: staff turnover, the glut of information and directives, isolation, multiple demands on programs, and multiple roles for managers. The world does not stand still as proponents of tobacco control attempt to manage this environment. A well-funded tobacco industry has the resources to anticipate and thwart novel initiatives. Even well-intentioned, beneficial efforts can have unintended negative-feedback effects. Therefore, flexible strategies based on widely accepted philosophy and best practices are essential. However, these strategies also must enable response to emerging science and systemic feedback.

At the broadest level, a fresh, trans-disciplinary approach to thinking about intervention systems is likely needed, one that integrates a balanced and comprehensive blend of program and policy tools. Program, policy, budgetary, and legislative issues all arise from the identification and implementation of strategies for best practice, which are themselves often in flux. Moreover, the underlying philosophy of public health continues to evolve. As stated in an overview of the syndemics initiative of the Centers for Disease Control and Prevention,[1] "The medical model of disease specialization, once praised for its utility and versatility, is proving inadequate for confronting. . . contemporary public health challenges." The statement echoes a growing move toward researching public health problems as both multidimensional population-level issues and individual issues. Unless these crosscutting factors are viewed from a systems perspective, it is likely that progress on any initiative can become mired in the many interacting and competing forces. Developing capacity for integrated strategies to tackle the complexity of these issues is a major focus of ISIS.

Already, developments in tobacco control and in public health in general are starting to move in this direction. As outlined in chapter 2, tobacco control strategy has mirrored the shift in emphasis from individual behavior change to population-level and policy-level change. There is a concomitant shift from controlled studies of individuals to population-level efforts involving logic models, networks, and collaborations among multiple stakeholders—all historical precursors to the systems approaches described here. The ISIS project springs from a clear trend that these approaches—and more important, their synthesis—hold a potential key to solving more complex issues in the prevalence of tobacco use and tobacco product consumption and, in turn, making further substantive positive changes in public health.

Systems and Systems Thinking

The *Merriam-Webster Dictionary* offers 12 distinct definitions of "system."[2] The principal definition is "a regularly interacting or interdependent group of items forming a unified whole."[2] In the field of systems theory, system is defined as "a set of elements standing in interrelation among themselves and with the environment."[3(p159)] Hidden within these simple definitions is considerable complexity, a history of ideas spanning centuries, and the basis of a new scientific and philosophical paradigm.

In this monograph, *systems methods* are considered specialized techniques or procedures for researching and understanding systems (e.g., system dynamics modeling, structured conceptualization, or network analysis). *Systems approaches* are broader theories or traditions that use systems methods within an organizing framework to address systems (e.g., general systems theory, chaos theory, and complexity theory). *Systems thinking* is the use of systems approaches and the general logic that underlies them to view the world.

The modern idea of systems theory is credited to the biologist Ludwig von Bertalanffy, who wrote *General System Theory: Foundations, Development, Applications*[4] in 1968. However, thinking about systems has a much longer history. The relationship between part and whole that serves as a foundation for systems-based approaches[5–7] is as old as European philosophy.[3] Aristotle's hypothesis that formal nature (e.g., the whole form) is of greater importance than material nature—more commonly known today as the principle that "the whole is more than the sum of its parts"—still is an accurate description of one of the central premises of systems theory.[8] In the 15th century, Nicholas of Cusa linked medieval mysticism with the origins of modern science through the idea of *coincidentia oppositorum*—the "fight" between part and whole.[3]

Systems thinking spans 2,600 years to the time of Lao Tzu and the first formal description of a complex system in the yin and yang of the Tao. Systems thinking was not "born yesterday."[3] However, its modern incarnation has risen simultaneously from several fields, including quantum physics, biology, ecology, cybernetics, psychology, and sociology.[3,6] It can be found in the physical, natural, and social sciences and is common in business[9–11] and education.[9,12–18] Depending on how wide one casts the net, systems thinking approaches span centuries, hundreds of fields, and thousands of scholars.[19] A family tree of systemic thought[20] includes in its "genealogy" ancient and contemporary scholars in a wide range of fields[19] and illustrates the variety of traditions in systems thinking.

The reader who is new to systems thinking may be daunted by the complexity and volume of literature. However, these variations and distinct traditions of systems thinking have some common themes. These themes include the notions of holism, integration, interconnectedness, organization, perspective taking, nonlinearity, and constructivism. Biological, ecological, and organismic metaphors are widely used to describe these themes.[4,6,7,21–29]

Common misconceptions are (1) that systems thinking rejects traditional scientific views[3,4,6,28–30] that emphasize linear, reductionist, mechanistic, and atomistic thinking; and (2) that systems thinking is framed by mechanical metaphors.[31] These are not correct. Although systems thinking does emphasize holistic thinking,[3,4,6,28–30] it complements traditional reductionist science rather than rejecting it. Von Bertalanffy wrote that it "is apparent that [systems epistemology] is profoundly different from the epistemology of logical positivism or empiricism even though it shares their scientific attitude."[4(pxxii)]

Another misconception is that systems thinking superficially emphasizes holistic thinking and lacks the rigor of traditional science. To the contrary, systems thinking uses differential equations and other more complex mathematics to describe system dynamics,[3,32,33] formalized qualitative systems methods,[34] and well-reasoned systems metaphors,[3,24,28,30,35,36] along with specific applications in virtually every field.[6,10,11,37]

The roots of systems theory[4,19] have grown into what is sometimes described as the "new sciences": general systems theory;[4] complexity science;[33,38–41] chaos theory and nonlinear dynamics;[42,43] cybernetics;[44,45] control theory, information theory, and computational simulation;[46] relational mathematics, game theory, decision theory, and system dynamics;[11,32] and ecology and set, graph, and network theory.[47–50] Systems thinking is used to better understand system behaviors and to identify systems principles such as feedback loops, stocks and flows, open versus closed systems, decentralized versus hierarchical systems, self-organization,[33,40] autopoiesis,[35,51] nonlinear systems,[43] complex adaptive systems (CAS),[33,38,40,41,45,52] boundary conditions, scaling and power laws, silo effects, small-world phenomena,[47,48] emergence,[53] cellular automata,[45] and fractal self-similarity.[54]

Many examples of systems thinking contribute to an understanding of the world. From the systems thinking of chaos theory, one can learn that minuscule changes in initial conditions can lead to dramatic emergent effects and that resistant systems can be directed to change. From complexity science, one can see that complexity emerges from simple rules acting locally on independent variables. That is, biological and social systems often do not have hierarchical controls that coordinate their behavior but are instead self-organizing. From system dynamics one can learn that, as systems thinker Senge puts it, "cause and effect are not closely related in time and space"[9(p63)] and that feedback can lead to unintended and unforeseen outcomes. Understanding of control systems has been expanded from an "input-blackbox-output" paradigm[3] to one that includes inputs, outputs, feedback, processes, flows, and control. These are just a few examples of systems thinking concepts from a broad range of disciplines.

Frameworks for Systems Thinking

There is no single and correct method of systems thinking. Borrowing an idea from Collins and Porras,[55] systems thinking rejects the "tyranny of either/or" and embraces the "genius of and/both." Systems thinking is a worldview that balances part and whole and focuses on complex interrelationships and patterns from multiple perspectives.[28,37] An inherently transdisciplinary approach that blends many perspectives, it has been characterized as an Odyssean thinking style that combines Apollonian and Dionysian perspectives.[56,57] Systems thinking is an epistemological stance transcending reductionist, critical realist, and constructivist perspectives. As an applied science, it bridges theory and practice. It is a conceptual revolution that has led to an emerging understanding of the complexities of the systems that make up the world. Systems thinking provides new tools to address practical, complex problems in much the same way mechanical thinking enabled previous generations to build agricultural or industrial structures.

A number of scholars have developed frameworks for systems thinking—sets of principles, rules, skills, or ideas that they claim underlie systems thinking. Each framework has advantages and disadvantages and was developed in the context of a particular purpose. Each was created from a different perspective or systems tradition. The summaries of some of the frameworks presented here are not meant to be exhaustive or definitive. However, each one gives a glimpse of systems thinking, and collectively they help to convey the essence of systems thinking.

Some scholars see system dynamics as a branch of systems theory. Others see systems theory as a branch of system dynamics. Scholars of system dynamics often use the term "systems thinking" to refer to system *dynamics* thinking,[9,58–64] dropping the word "dynamics" as a descriptor. For example, "systems thinking" is defined by one source as follows:

> Systems thinking is an approach for studying and managing complex feedback systems, such as one finds in business and other social systems. In fact, it has been used to address practically every sort of feedback system. System dynamics is more or less the same as systems thinking, but [it] emphasizes the usage of computer-simulation tools. System dynamics is based

> on systems thinking, but [it] takes the additional steps of constructing and testing a computer-simulation model.[65]

Richmond offers an example of a framework for system dynamics thinking in his book *The "Thinking" in Systems Thinking: Seven Essential Skills.*[59] He compares seven skills of systems thinking that are derived from system dynamics with skills of traditional styles of thinking (table 3.1).[59] Richmond's framework illustrates some of the key notions of systems (dynamics), including the ideas of causal linkages and feedback loops. Chapter 5 in this monograph explores system dynamics in greater depth.

System dynamics is a type of systems thinking that has gained popularity in business settings such as organizational learning. In *The Fifth Discipline: The Art and Practice of the Learning Organization,*[9] Senge lays out five disciplines for building a "learning organization." According to Senge, learning organizations are adaptive and generative and are necessary for survival and competition. His five disciplines[66] are as follows:

1. **Systems thinking:** The integrative [fifth] discipline that fuses the other four into a coherent body of theory and practice
2. **Personal mastery:** Approaching life and work "as an artist would approach a work of art"
3. **Mental models:** Deeply ingrained assumptions or mental images "that influence how we understand the world and how we take action"
4. **Shared vision:** With genuine vision "people excel and learn, not because they are told to, but because they want to"

Table 3.1 Richmond's Seven Skills of Systems Thinking

Traditional skill	Systems thinking skill
Static thinking Focusing on particular events	**Dynamic thinking** Framing a problem in terms of a pattern of behavior over time
System-as-effect thinking Viewing behavior generated by a system as driven by external forces	**System-as-cause thinking** Placing responsibility for a behavior on internal actors who manage the policies and plumbing of the system
Tree-by-tree thinking Believing that really knowing something means focusing on the details	**Forest thinking** Believing that to know something requires understanding the context of relationships
Factors thinking Listing factors that influence or are correlated with some result	**Operational thinking** Concentrating on causality and understanding how a behavior is generated
Straight-line thinking Viewing causality as running in one direction, with each cause independent from other causes	**Closed-loop thinking** Viewing causality as an ongoing process, not a one-time event, with effect feeding back to influence the causes and the causes affecting each other
Measurement thinking Searching for perfectly measured data	**Quantitative thinking** Accepting that one can always quantify, even though one cannot always measure
Proving-truth thinking Seeking to prove models to be true by validating them with historical data	**Scientific thinking** Recognizing that all models are working hypotheses with limited applicability

Note. From Richmond, B. 2000. *The "thinking" in systems thinking: Seven essential skills.* Toolbox Reprint series. Waltham, MA: Pegasus Communications. Used with permission.

5. **Team learning:** Engagement of team members in true dialogue, with assumptions suspended

Senge[9] outlines 11 laws of the fifth discipline, which he derives from lessons in fields as diverse as chaos theory, complexity theory, organizational theory, management theory, and system dynamics:

1. Today's problems come from yesterday's solutions.
2. The harder you push, the harder the system pushes back.
3. Behavior grows better before it grows worse.
4. The easy way out usually leads back in.
5. The cure can be worse than the disease.
6. Faster is slower.
7. Cause and effect are not closely related in time and space.
8. Small changes can produce big results, but the areas of highest leverage often are the least obvious.
9. You can have your cake and eat it too, but not all at once.
10. Dividing an elephant in half does not produce two small elephants.
11. There is no blame.

Similarly, Gelb sees systems thinking as the glue that binds his seven principles of effective thinking. Gelb proposes that effective thinking in today's world can be framed by seven principles[67,68] he claims are characteristic of Leonardo da Vinci's genius:

1. An insatiable quest for knowledge and continuous improvement
2. Learning from experience
3. Sharpening the senses
4. Managing ambiguity and change
5. Whole-brain thinking
6. Body–mind fitness
7. Systems thinking

Gelb believes[68] that da Vinci's principles will help people to cultivate creativity every day, balance analysis with imagination, sustain continuous learning, embrace ambiguity and uncertainty, nurture creativity and innovation in the workplace, and apply systems thinking to problem solving.

Capra, a physicist and systems thinker, proposed ecological thinking, a systems thinking model he defines as "core concepts in ecology that describe the patterns and processes by which nature sustains life."[6(p231)] Table 3.2 illustrates his six principles of ecology. Like system dynamics thinking, ecological thinking emphasizes cyclic thinking, processes over time, and feedback. However, it also gives more salience to networks, being nested, and development.

Checkland developed soft systems methodology in the 1960s. In the classic form of these methods,[69,70] a researcher or an observer experiencing a problem makes as few presumptions about the nature of the problem as possible. A "rich picture" then is developed by attempting to capture in detail the logic, relationships, value judgments, and feel (tone) of the problem situation. Essential features of the system (root definition) are then characterized. The mnemonic device CATWOE is used in this step: customers, who are beneficiaries of the system; actors, who transform inputs to outputs; transformation of input to output; weltanshauung (relevant worldviews); owners, who have veto power over the system; and environmental constraints. CATWOE is used to construct the root definition, which takes the following form: "A system that does P (what) by Q (how) to contribute to achieving R (why)." Then a "cultural analysis" is undertaken to explore the roles, norms, values, and politics

Table 3.2 Capra's Six Principles of Ecology

Networks	At all scales of nature, we find living systems nesting within other living systems—networks within networks. Their boundaries are not boundaries of separation but boundaries of identity. All living systems communicate with one another and share resources across their boundaries.
Cycles	All living organisms must feed on continual flows of matter and energy from their environment to stay alive, and all living organisms continually produce waste. However, an ecosystem generates no net waste, one species' waste being another species' food. Thus, matter cycles continually through the web of life.
Solar Energy	Solar energy, transformed into chemical energy by the photosynthesis of green plants, drives the ecological cycles.
Partnership	The exchanges of energy and resources in an ecosystem are sustained by pervasive cooperation. Life did not take over the planet by combat but by cooperation, partnership, and networking.
Diversity	Ecosystems achieve stability and resilience through the richness and complexity of their ecological webs. The greater their biodiversity, the more resilient they will be.
Dynamic Balance	An ecosystem is a flexible, ever-fluctuating network. Its flexibility is a consequence of multiple feedback loops that keep the system in a state of dynamic balance. No single variable is maximized; all variables fluctuate around their optimal values.

Note. From Capra, F. 2002. *The hidden connections: Integrating the biological, cognitive, and social dimensions of life into a science of sustainability,* 231. New York: Doubleday.

relevant to the root definition. A systems model is developed by using only the elements of the root definition and cultural analysis in a way that flows logically from the two elements. The focus of this step is to limit the number of possible components to the six or fewer CATWOE elements, while demonstrating all the properties of the system. Thus, the focus is to balance the simplicity of few components with the complexity of system properties. Different root definitions and CATWOE elements are used to construct several models illustrating how multiple perspectives relate to the problem. Finally, these models are discussed, compared, and contrasted by using the problem situation and insight from this process to identify ways to improve the problem situation.

In his book *Hidden Order: How Adaptation Builds Complexity,*[71] Holland details a framework for studying CAS, proposing seven basics.[71(p10)] "We *aggregate* similar things into categories (and) then treat them as equivalent."[71(p10)] Aggregations are reusable and recombinable and, once formed, can act as agents or meta-agents. "*Tagging* facilitates the formation of aggregates."[71(p12)] Holland gives the example of a banner or flag that "is used to rally members of an army or people of similar political persuasion."[71(p13)] He explains that CAS use tagging to "manipulate symmetries" and to "ignore certain details while directing our attention to others."[71(p12)] Another property of CAS is *nonlinearities,* which "almost always make the behavior of the aggregate more complicated than would be predicted by summing or averaging."[71(p23)] A property Holland calls *flows* includes two types of effects: multiplier and recycling. The property of flows explains how resources move and change as they proceed through the system. In describing the property of *diversity,* Holland writes, "it should be evident then that we will not find CAS settling to a few highly adapted types that exploit all opportunities. Perpetual novelty is the hallmark of CAS."[71(p31)] Anticipation is a critical capability for CAS. CAS anticipate or make predictions by using *internal models.* For example, "insectivorous birds anticipate the bitter taste of butterflies with a particular orange and black wing pattern."[71(p31)] One paradox CAS must solve is how to use internal models based on repetition in constantly changing and novel situations. How can CAS use an internal model based on a repeating pattern if each situation is slightly different or totally novel? Holland proposes that *building blocks* are used and reused, allowing CAS to decompose novel situations into parts, as a child's building blocks are used to create novel structures.

Systems Concepts

Important systems concepts are relevant to different types of systems and constitute a unique lexicon of systems thinking. Here, several major systems concepts that inform systems thinking are introduced. Rather than being comprehensive, the intent is to present notable systems concepts within this rich historical tradition. Each concept may represent an entire specialized field of study, networks of scholars and researchers, scientific journals, conferences, and societies.

CAS self-organize, adapt, and evolve over time. In a CAS, semiautonomous agents interact on the basis of simple local rules. The term "complex adaptive system" often is used interchangeably with the term "complexity theory," which proposes that higher level complexity emerges from lower level simplicity. In an example highlighted in this chapter (see sidebar, this page), the boids, sporting fans, fish, or birds are *adaptive agents* because they adapt to their environments. The environment of an adaptive agent includes other adaptive agents.

Interaction between adaptive agents or systems often is called *feedback,* which refers to the mutual causality of the relationship (e.g., positive/exciting or negative/dampening). In a similar vein, the term *cellular automata,* originally developed

Simple Rules and Superorganisms

In 1986, Reynolds made a computer model of coordinated animal motion such as bird flocks and fish schools, calling the simulated flocking creatures "boids."[a] The basic flocking model consisted of three simple "steering behaviors":

- Separation: Steer to avoid crowding local "flockmates."
- Alignment: Steer toward the average heading of local flockmates.
- Cohesion: Steer to move toward the average position of local flockmates.

Each boid reacts "only to flockmates within a small neighborhood," so the boids are interacting only with neighbors. Flockmates that lie outside the individual boid's neighborhood are ignored.

Reynolds's computational experiment models the complex flocking behavior of boids, fish, and birds by using simple local rules acting on independent variables. The result is emergent complexity—a collection of individual organisms that act like a single superorganism.

An even simpler example of the complex behavior of superorganisms that is based on simple rules can be found at national sporting events. The stadium wave, in which fans simulate an undulating elliptical blanket around the stadium, is based on a single, simple, local rule: if your left neighbor stands up, then stand up. The initial starting condition for this complex phenomenon is a single line of standing people.

Note. Adapted from Cabrera, D. 2002. Patterns of knowledge: Knowledge as a complex, evolutionary system; An educational imperative. In *Creating learning communities,* ed. R. Miller. Brandon, VT: Solomon Press.

[a]Reynolds, C. 2006. Boids: Background and update. http://www.red3d.com/cwr/boids.

by von Neumann[72] in the computing arena, also refers to the idea of modeling biological or artificial self-reproduction by using simple interacting "cells" that follow simple, local rules.[72] Computational cellular automata models are popular and useful because they explicate many of the essential patterns found in more complex, self-organizing, real-world systems. *Self-organization* occurs in CAS as spontaneous patterns or features of a system that emerge at macro levels resulting from the collective interactions of microscale independent agents and local rules. These features are often called *dissipative structures,* because they persist as stable structures for longer durations, even though, internally, there is a continuous and dynamic flow of matter or energy. The concept of *emergence* is related because it refers to the existence of properties at a higher level (e.g., the level of the whole) that cannot be found at a lower level (e.g., the level of the parts).

The concept of *autopoiesis* (literally, self-production), which refers to self-producing systems, also is related. Two Chilean biologists, Maturana and Varela,[51] developed the concept of autopoiesis. Autopoiesis is similar to Kauffman's autocatalytic theory of sets in which the origin of life occurs when a collection of molecules catalyze each other. Kauffman writes, "Whenever a collection of chemicals contains enough different kinds of molecules, a metabolism will crystallize from the broth."[33(p43),40]

Nonlinear systems are systems in which the whole does not equal the sum of its parts or, more technically, systems that can be represented by a curvilinear pattern, rather than a linear pattern. Nonlinear systems are capable of self-organization and chaos. There are many implications of chaos. Chief among them is the understanding that small changes in initial conditions can result in large, systemwide effects (sensitivity to initial conditions). The popularized story of Lorenz's butterfly—an insect that by flapping its wings causes a chain of events leading to a hurricane on the other side of the world—often is used as an anecdote for understanding chaos theory.

Both linear and nonlinear systems are attracted to a subset of their phase space called an *attractor.* Attractors are modes or phases of system behavior. Attractors (e.g., fixed-point, periodic, or strange) determine the behavior of a system within a particular space. A marble tossed into a salad bowl will, over time, settle into an attractor at the bottom of the bowl (the basin of attraction). A chaotic (strange) attractor is fractal. *Fractals* are geometric patterns, a set of points, or structures that are self-similar across different levels of scale. Fractals, discovered by Mandelbrot, have become popular in science and art; many fractal patterns are strikingly beautiful. When a system exhibits fractal geometry, the parts appear to be similar to the whole, even though they belong to different scales. The branching pattern of trees is fractal, as are the coastline of England and the branching alveoli of the lung.[54] All systems evolve in some way. *Evolution* can be defined in Darwinian terms as natural selection and the descent of species, or in more general terms, as behavior over time.

Finally, *network theory* is a general theory used throughout physics, biology, and the social sciences that explores the behaviors, structure, and function of an interacting set of items (e.g., objects, people, concepts, or points).[47,48,50,54,73,74] Networks are made up of *vertices* (a set of items) and *edges* (connections among the items). Vertices and edges are called sites and bonds in physics, nodes and links in computer science, and actors and bonds in sociology.[50] Chapter 6, "Understanding and Managing Stakeholder Networks," in this monograph, presents network approaches to systems thinking.

Systems thinking can be simple and complex, theoretical and practical, scientifically rigorous and philosophically grounded. In the context of tobacco control, it is important to consider the types of systems questions that people with different roles in tobacco control need to address. Chapters 4 through 7 address in depth four broad systems approaches—systems organizing and management, system dynamics modeling, network analysis, and knowledge management—and their implications for tobacco control.

Systems Thinking: Toward an Integrated View

As understanding of systems thinking, systems approaches, and systems methods increases, it becomes apparent that there is a need to integrate the diverse and myriad traditions into a more coherent whole. The ISIS project is an initial and somewhat limited foray into such an endeavor. Nevertheless, one can begin to sketch some of the central components of a more integrated view of systems for tobacco control and public health, based on the work done to date. In addition to consideration of the construct of systems thinking, an integrated approach to systems thinking would include the following components (and likely much more):

- **Case studies of systems approaches.** This would include studies of the variety of systems approaches and the methods that are associated with them. The ISIS project has begun studies in four systems approaches: systems organizing, system dynamics, network analysis, and knowledge management.
- **Participatory methods for systems thinking.** In human systems like tobacco control and public health, better participatory methods for modeling systems and for thinking from a systems perspective need to be developed.
- **Evolution of systems studies.** As more studies of systems approaches and methods are developed, the evolution of a "field" of systems studies that integrates across diverse traditions will be encouraged.

Case Studies of Systems Approaches

An integrated approach to systems thinking should involve trial-and-error experimenting with a variety of potentially promising systems approaches and methods to learn how they work and what their potential advantages and costs are in real-world contexts. A central purpose of ISIS has been to identify several promising approaches and apply them to help "navigate" current problems in tobacco control.

The four core systems approaches examined by ISIS are outlined in table 3.3 along with brief descriptions of the goals of each approach and the case studies conducted in the ISIS project. Many of these approaches are newly developing. Other approaches, such as system dynamics, have been available for years but have rarely been applied in this area. Because the application of systems thinking to tobacco control is in its early stages, the excitement and the promise of this undertaking are just beginning to be realized.

These approaches all serve as parts of a broad, systems-based view of the world that can be applied specifically to tobacco control and more generally to public health. More important, these approaches reflect more general trends of using systems approaches to understand and manage increasingly complex phenomena in all walks of life, ranging from organizational behavior[9] to national defense.[75] These four approaches were chosen because of their promise in key areas of tobacco control. They are not the only systems approaches, nor are they necessarily the best. They are part of a much

Table 3.3 Core Areas Examined by ISIS and Goals

Core area	Long-term goals	ISIS case studies
How we organize: Systems organizing	Participatory, stakeholder-based approaches to systems organizing	Concept-mapping studies of local strength of tobacco control factors and of designing for research dissemination
How we understand dynamic complexity: System dynamics modeling	▪ Development of systems models for tobacco control factors and processes for analyzing and evaluating them ▪ Telling the tobacco control "story" in qualitative as well as quantitative terms, so it can reach a wider audience	▪ Causal model for tobacco cessation based on data in clinical and community guides ▪ Quantitative simulation of intervention impacts in different age groups
Who we are: Network analysis	Network-based structures for future collaborative tobacco control efforts	▪ Examination of network issues in the Global Tobacco Research Network ▪ Case study of network analysis in ongoing multistate tobacco control evaluation project
What we know: Knowledge management and knowledge transfer	Infrastructure for knowledge management and transfer in tobacco control efforts, incorporating both explicit and tacit knowledge	Review of current dissemination efforts (e.g., NCI's Cancer Control PLANET initiative)[a] and analysis of knowledge management needs

Note. ISIS = Initiative on the Study and Implementation of Systems; NCI = National Cancer Institute; PLANET = Plan, Link, Act, Network with Evidence-based Tools.

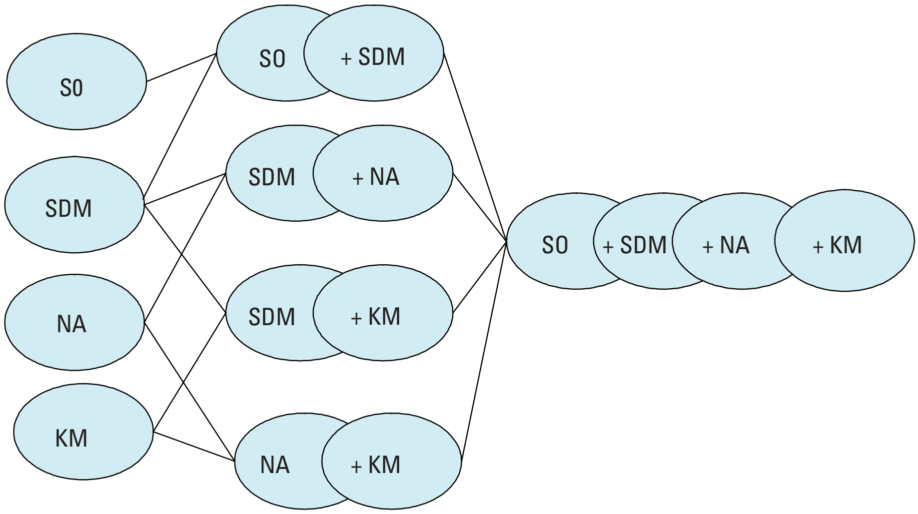
[a]Cancer Control PLANET is an NCI-funded portal providing on-line access to research results, partner organizations, and evidence-based programs and products for cancer control, available at http://cancercontrolplanet.cancer.gov.

larger diverse mosaic of potential systems approaches hinted at in the review earlier in this chapter.

The methods described here as part of the ISIS project have the potential to deliver incremental improvements in tobacco control and public health outcomes. However, each method also complements the others. Together, these methods provide a fundamentally new way to address the complex root causes of current tobacco use. Frameworks that enable integration of a number of systems-based approaches also would be useful.

An integrated approach to systems thinking will likely result in the evolution of one or more fields of study that enable researchers and practitioners to learn about the construct of systems thinking, and the history and variety of approaches and methods, and to begin to develop crosscutting and cross-disciplinary perspectives on systems thinking. Such fields already are emerging. For example, frameworks such as Integration and Implementation Sciences[76] (described in table 3.4 and in the sidebar in Appendix B, p. 272) propose a core theoretical base from which systems methodologies may be developed and applied to specific areas. They provide a potential transdisciplinary base for studying system-level problems faced in tobacco control efforts and may help fill important gaps in methodologies between complementary disciplines. For example, chaos and complexity theory often takes an exploratory approach to the behavior of a system based on simulations of interactions of individual agents who follow simple rules, whereas traditional system dynamics seeks to identify relationships and optimize

Figure 3.1 Combining ISIS Approaches for Applications



Note. ISIS = Initiative on the Study and Implementation of Systems; SO = systems organizing; SDM = system dynamics modeling; NA = network analysis; KM = knowledge management.

Table 3.4 Framework of Integration and Implementation Sciences

Integration and Implementation Sciences framework	ISIS case studies
Systems thinking and complexity science	System dynamics simulation
Participatory methods	System dynamics simulation; concept-mapping projects with multiple stakeholders
Knowledge management, exchange, and implementation	Network analysis Knowledge management and knowledge transfer

outcomes.[77] An integrated systems study field can enhance understanding of the advantages of these different approaches and suggest how new hybrid approaches might be formed by combining or integrating features of each. For example, figure 3.1 illustrates how the four systems approaches studies in the ISIS project can potentially be coupled in various pairings and even integrated as a set. The framework of Integration and Implementation Sciences (table 3.4) serves as one example of using an integrative approach to link these disciplines to address core problems in public health (e.g., the paradox of society's inability to implement known cost-effective solutions to the 10 leading causes of preventable death worldwide, as identified by the World Health Organization).[78] The ISIS project sought to apply key components from this framework to existing problems in tobacco control, as a proof of concept for how they can integrate to form a new approach to complex public health issues.

ISIS is only a first step in applying systems approaches to tobacco control. An aim of this monograph is to show the potential value of these approaches individually and in combination and to point to broader frameworks for further development of these approaches. In this sense, ISIS attempts both to encourage and model how an emergent field of systems studies might approach its task. It is not clear at this point whether such a field eventually will be a formal academic discipline, a transdisciplinary specialization, or some other form. But however the field evolves, the idea of systems studies is one whose time has come.

Participatory Methods for Systems Thinking

An integrated approach to systems thinking needs to include the recognition that participatory methods are integral to human systems approaches. All four of the systems approaches studied in the ISIS project integrate participatory methods into how they address systems. An integrated approach would have the study and evolution of participatory methods as a major focus.

Brown and colleagues[79] outline a framework for stakeholder inclusion that views participatory methods as forms of structured engagement among researchers, community representatives, business groups, and policy makers to accomplish the collective solution of problems as a system. They recognize the importance of individuals, societies, and cultures as aspects of complexity.

Participatory methods encompass a wide range of engagements, including action research, Delphi methods, consensus building, and numerous intuitive unnamed methods.[80] These methods involve two or more parties and a range of disciplines and sectors, can be short- or long-term, can challenge elites or be controlled by them, and can vary in the degree to which they empower marginalized groups. Participatory methods enable practitioners and researchers to learn together about problems of mutual interest in a way that provides reciprocal benefits. They can combine perspectives to build new concepts, insights, and/or practical innovations that they could not produce alone.

The four key elements in contemporary thinking about participatory methods are (1) paradigms, goals, and interests; (2) relationships and organization; (3) methods and technologies; and (4) contextual forces and institutions. Engagement between researchers and practitioners must take into account different social, political, and ethical paradigms; different engagement goals and interests; and different expectations about accountability. Furthermore, the relationships and organization must be able to accommodate power differences; build trust; and develop effective control, ownership, division of work, and decision-making processes. The methods and technologies used within this framework can be divided into four types:

1. **Participatory, focused, puzzle-solving methods** are appropriate when answers to well-defined problems are needed. Such methods make efficient use of the comparative advantages of each party and do not require expensive ongoing relationships.
2. **Exploration of issues and agenda setting** are appropriate when multiple views are needed for understanding complex, ill-structured problems. These methods allow many voices to be involved in identifying issue patterns and implications and set the stage for wide participation in problem solving.
3. **Participatory intervention and assessment methods** document, analyze, and improve the quality of interventions and best practices. They focus on existing programs and activities and are particularly useful for identifying the costs and benefits of possible solutions.
4. **Participatory methods for long-term development** of domains involve ongoing co-inquiry to build perspectives, theory, and practice in new domains. These methods are particularly useful in providing in-depth analysis of poorly understood problems over the longer term. They can produce new paradigms for understanding intractable problems

and lead to fundamental changes in theory and/or practice.

Contextual forces and institutions are the final element of the framework. They take into account the broad range of factors such as political, social, and economic forces on global, national, and local levels that are at play at the time of engagement. This element also allows for the impact of the auspices under which the participatory methods are conducted and of the institutional bases of the researchers and practitioners.

Participatory methods are central to bringing stakeholders into the consideration of complex problems. Ideally, their use enables those affected to have a say in the management of uncertainties and of the inability to find perfect solutions. However, strategies for guiding researchers on which methods to use still are being created, and experience with key issues (such as how to build trust) is limited. This scenario underscores the need for continuous evolution of closer links between systems thinking and participatory methods. Chapter 4 of this monograph considers participatory methods in greater detail and describes their critical role in systems organization and management.

Application of Systems Thinking in Tobacco Control

Systems thinking approaches are by their very nature context dependent. Public health issues such as tobacco control provide an ideal laboratory for their implementation. The next section describes several frameworks for understanding systems thinking and presents a brief overview of the vast terrain of systems concepts, suggests an integrated view of the idea of systems thinking that is emerging in part from the work conducted in this project, and outlines some of the implications of systems thinking for three key stakeholder groups in tobacco control—practitioners, policy makers, and researchers.

Case Studies of Systems Approaches

On a practical level, stakeholders certainly will question how systems thinking and systems approaches apply to real-life situations they regularly encounter. Each of the approaches, either in part or in combination, provides promising methods for tackling the sometimes disparate problems faced by various stakeholder groups. The next three subsections present some of the "real-world" questions several groups of tobacco control stakeholders might pose about their most pressing issues. Here, three stakeholder groups that are especially important for early implementation of systems thinking and approaches in tobacco control are considered:

1. **Practitioners:** Stakeholders and managers of "agencies" that deliver state or local programs for prevention and cessation of tobacco use.
2. **Researchers:** Scientists and analysts who develop the evidence base for effective tobacco control, such as heads of research institutes or those working at the interface of tobacco control programs and research.
3. **Policy makers:** Politicians and national agency executives who make decisions about policy and strategy.

ISIS and the Practitioner

Practitioners often represent the front line in delivering tobacco control interventions to individuals and populations. The following questions suggest practitioner issues that could be addressed via systems approaches.

- **How can I cope with competition from other organizations for scarce resources?** Funding is almost always a concern for practitioners. The changing political climate and the previous successes of tobacco control efforts make it difficult for practitioners to argue effectively for resources that often are scarce. Practitioners frequently are faced with competition from similar organizations and must find a balance between effectively stating a need for funding and presenting their organization and previous accomplishments positively.
- **How do I communicate the positive outcomes my organization has achieved while arguing for continued/additional funding?** When applying for a continuation of funds, practitioner organizations face a dilemma. The program must appear to be effective, yet justify the need for continued work. This is a common issue in which practitioners and policy makers interface. It is particularly salient in the evidence-based environment of tobacco control efforts.
- **How can I maintain trust with my clients when changes in funding levels alter the services I am able to provide?** Practitioners committed to tobacco control and to their clientele may find it difficult to reduce or restrict services they view as necessary. Frequently, little notice is given when changes occur. Practitioners must be prepared to communicate "bad news" to smokers and other clients who rely on their services and who may feel unimportant, frustrated, and angry. Decisions about the changing nature of services often are made outside the organization, and practitioners may feel as though they are voiceless in the policy arena.
- **How can I spend more time in the field and less time with administrative details?** The effects of top-down decision making also are evident in the amount of bureaucratic paperwork that requires increasingly more of the practitioner's time. In an attempt to ensure that money is being spent only on high-quality, effective programs, policy makers frequently require increased reporting from funded agencies. These requirements often take valuable time away from the "real work" that needs to be accomplished. Moreover, it may seem as though more time is spent reporting on what is being done than on doing anything to help smokers. This situation is especially frustrating when funding levels are reduced or when increased reporting responsibilities accompany reductions in funding.
- **Where can I find succinct, clear, and practical information on best practices?** Because of the limited time practitioners often have to accomplish their goals, keeping abreast of the latest research discoveries and finding information relevant to the practitioner's organization can be particularly difficult. Research journals are designed for researchers rather than practitioners and often are not organized for simple access to knowledge.

ISIS and the Researcher

Researchers play a key role in developing the evidence base and underlying science behind tobacco control efforts. The following questions present researcher issues that could be addressed via systems approaches.

- **How do we keep our research from sitting unread in journals?** Academic institutions place a high value on publications in peer-reviewed journals and frequently discount writing that is geared toward practitioners. Taking the time to write for a more general audience is not highly valued, and researchers often are pressed for time. Research discoveries are shared with other researchers from similar fields in journals or at conferences, but the ideas are rarely put into practice.

- **Why don't more people use the science that we develop?** Researchers often work in isolated groups and do not have access to practitioners and others who might put their work into practice. Although dissemination often is a goal, the existing pathways of dissemination are not highly effective. Moreover, as described here, practitioners frequently have trouble finding time to keep abreast of research. At a deeper level, research may not connect with the immediate goals and priorities of practitioners.

- **Where can we connect with other researchers who have common or complementary interests but are in different departments or fields?** In addition to dealing with weak networks between researchers and practitioners, researchers often struggle to make connections with other researchers outside their primary disciplines. Although tobacco control is a transdisciplinary field that relies on knowledge from a wide variety of areas, it often is difficult to identify appropriate collaborators with different backgrounds.

  At another level, even though funding agencies are increasingly interested in transdisciplinary collaborations, partnerships are difficult to form in an environment in which research silos are the predominant force. Collaborations traditionally have been formed by researchers who work in the same field, read the same journals, and attend the same conferences. The changing environment makes the development of extended, well-funded networks a challenge for ongoing research.

- **How can we streamline the process of approval and funding for our work?** Large funding bodies make it more difficult for individual researchers and laboratories to obtain funding, because their focus increasingly shifts toward funding large-scale projects involving multiple principal investigators. Such projects require (1) a great deal of logistical support, not only to conduct the project, but also to organize proposals and apply for funding; (2) a high level of understanding of the needs of the target population; and (3) the ability to adequately articulate practical implications of the research to the funding organizations.

ISIS and the Policy Maker

Policy makers not only provide leadership among tobacco control stakeholders groups, but also play a key role in the funding decisions and policy interventions that are increasingly becoming central to tobacco control efforts. The following questions focus on policy maker issues that could be addressed via systems approaches.

- **What priorities dictated past resource allocation, and what priorities does the future dictate?** Policy makers, as the primary source of funding for both research and tobacco control programs, have the unique role of bridging both research and practice. Financial implications are at the forefront of many decisions and are a critical concern for most policy makers.

- **How can we get more "bang for our buck" in research expenditures?** The changing tobacco control environment alters the amount of funding available and places limitations on how available funds can be spent. Lessons learned must be considered when decisions about future allocations are made, and the available money must be stretched to cover many pressing needs.

- **How can we synthesize all of the "silos" of information out there?** To accomplish more for less, research endeavors need to be more streamlined and collaboration across disciplines must increase. There is a constant struggle between the desire to fund short-term projects with immediate results versus longitudinal projects that explore long-term health outcomes.
- **How can we reduce or eliminate duplication of effort among stakeholder organizations?** Coordinating the sharing of resources and information also is a struggle for practitioners. Policy makers have the responsibility to ensure that efforts are not duplicated and that ineffective practices are not implemented.
- **How can we persuade more professionals to make use of evidence-based practices?** Holding organizations accountable and requiring reporting are the tools policy makers use to address these concerns. However, organizations frequently complain that they do not have the time or resources to conduct complex evaluations that will provide the necessary information. Without proper evaluations, policy makers cannot determine whether funds are wisely spent, whether organizations are achieving desired outcomes, or whether best practices are being used.

From Stakeholders to Synthesis

Questions such as those discussed previously highlight issues of concern to specific stakeholders in tobacco control. Systems approaches hold the potential to address these issues. However, they also speak to a much broader area, moving from an environment of "What's in it for me?" to one in which professionals have sufficient understanding of their own systems to ask, "What's in it for all of us?" With improved linkage, visibility, and participation—driven by approaches such as systems models, networks, and knowledge bases—stakeholders such as those discussed here have the potential to address broader questions:

- How can we engage the public generally and people at risk from smoking to build a consensus agenda for how best to reduce smoking prevalence and tobacco consumption?
- How can we link our efforts to work more efficiently?
- How can we learn from each other's knowledge to forge better solutions to the problems we address?
- How can we better integrate research and practice?

Within the answers to such questions are the keys to realizing the potential of systems approaches to make substantive change in tobacco control, while at the same time addressing individual stakeholder issues such as those outlined here. The lesson of many systems, whether they are successful organizations or natural ecosystems, is that fundamental interconnectedness is, unto itself, critical to achieving successful outcomes. A major aim in the ISIS project was to combine systems approaches that address specific needs by setting a much broader goal, namely, the linkage of these approaches and their communities of interest into a new tobacco control environment that holds a much greater benefit for all parties.

Summary

The current tobacco control environment consists of a broad mosaic of individuals and organizations with a common goal of reducing smoking prevalence and tobacco consumption and associated morbidity and mortality. The path to this goal still suffers from a gap in the linkage between current science and clinical and public health practice. The general premise offered here is that integrated systems thinking, approaches, and methods can help fill this gap. The application of systems thinking to tobacco control holds the promise of an integrated, dynamic process with several potential benefits, including the following:

- Development of clearer, collaborative relationships within the tobacco control community
- Improved alignment of resources and networks toward effective, evidence-based practices
- More efficient, nonduplicating use of resources
- Better understanding of the impact of tobacco control activities on public health outcomes

One goal of ISIS was to examine and explore the integration of four key approaches to systems thinking—systems organizing, system dynamics modeling, network analysis, and knowledge management. Such an effort, while potentially useful for many issues, may be especially apt for helping to create an integrated framework that will facilitate efficient and effective dissemination and implementation of evidence-based tobacco control practices. One hope is that efforts of ISIS will contribute to the foundation extant in the *Guide to Clinical Preventive Services*[81] and *Guide to Community Preventive Services*[82] and existing dissemination efforts to create a new, scientific, integrated systems approach to evidence-based public health practice. This would involve a shift in approach—one that seeks to transform a profession, not just to integrate methodologies. With this in mind, the role of ISIS could be framed with the following arguments:

- Tobacco control is at a crossroads, with many tasks accomplished, but difficult and complex challenges lie ahead.
- Approaches that are known to work are not being adopted in practice,[83] despite significant efforts. One hypothesis is that tobacco control efforts have not succeeded because the systems of research and the systems of practice do not intersect effectively.
- To reach the next level of outcomes, professionals in the system have to work more effectively and efficiently as a system. The most significant challenges today are systems challenges.
- Therefore, a goal of ISIS was to transform tobacco control by addressing systems issues to encourage more effective integration of research and practice and dramatically improve health outcomes.

Applying systems thinking to more effectively integrate the systems of research and practice is key to achieving more effective use of science in tobacco control initiatives and, more important, within public health as a whole. The chapters that follow outline in detail the specific systems approaches and methodologies studied in the ISIS project. Collectively, they point to a new and more comprehensive view of the field—as a systems problem that can be addressed by using systems approaches to achieve dramatic improvements in outcomes.

Conclusions

1. The key challenges in tobacco control and public health today are fundamentally systems problems, involving multiple forces and stakeholders. Systems thinking is an innovative approach to address these challenges and improve health outcomes.
2. Numerous frameworks exist for systems thinking, a concept that encompasses a

broad synthesis of systems approaches. These approaches provide a theoretical basis for applying specific systems methods, such as system dynamics modeling, structured conceptualization, and network analysis.

3. The Initiative on the Study and Implementation of Systems encompassed four key areas of systems thinking, and their integration: how people organize (managing and organizing as a system); how people understand dynamic complexity (system dynamics modeling); who people are (network analysis); and what people know (knowledge management and knowledge transfer).

4. Examination of systems approaches has the potential to address key questions and problems faced by the various stakeholder groups involved in tobacco control.

5. Potential benefits of systems thinking in tobacco control include improving collaboration among stakeholders; harnessing resources toward evidence-based practice; eliminating duplication of effort; and gaining deeper knowledge about the impact of tobacco control activities.

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