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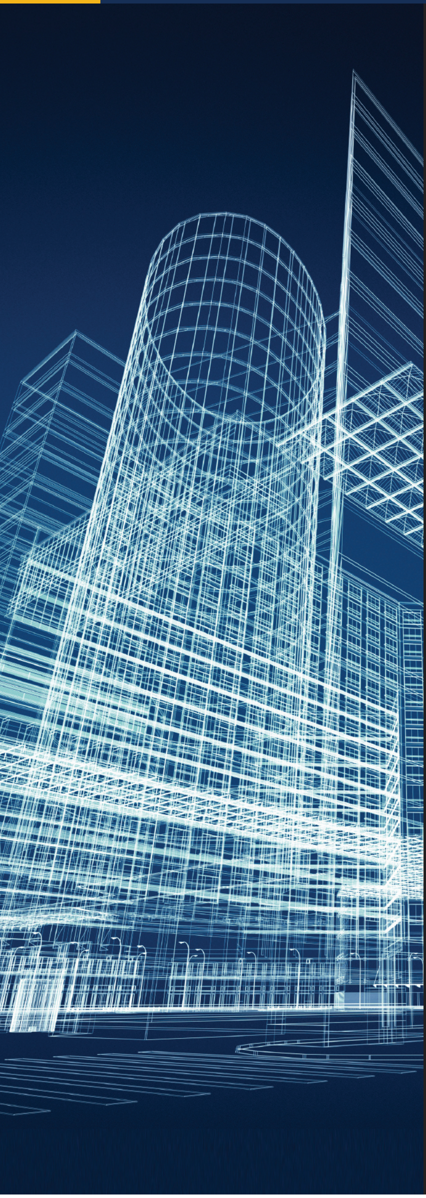

A Systems Approach to Modeling Community Development Projects

Bernard Amadei

MOMENTUM PRESS ENGINEERING

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Abstract

This book makes the case for a systems approach to small-scale community development projects. It looks more specifically at the application of one branch of systems science, called system dynamics, to develop conceptual models of small-scale communities and address specific issues they might be facing at different scales. A systems approach recognizes that, by definition, communities are complex adaptive systems consisting of multiple subsystems and parts (e.g., individuals, institutions, and infrastructure) that are interconnected, are driven by some purpose, follow certain rules, and interact with each other and with their surrounding environment. In order to address community issues and problems, complexity and uncertainty must be embraced and dealt with. This book emphasizes and shows how to include a system- and complexity-aware approach in the different phases of small-scale community project management. Adopting this approach comes with unique challenges such as dealing with ill-defined problems, considering uncertainty, recognizing that no unique and best solutions to complex problems exist, and accepting satisficing (i.e., good enough) solutions. This book emphasizes the need for community development practitioners to integrate in all stages of their projects: participation, systems thinking, continuous reflection-in-action, and a combination of critical and creative tools. At the same time, practitioners must ensure that they deliver solutions that are sound from a technical point of view (i.e., done right), adaptable to the cultural, economic, and social context in which they work (i.e., rightly done), and developed for the right reasons.

Keywords

complexity, system dynamics, systems approach, systems thinking, adaptive, community, participation, development projects, reflective practice, behavior patterns, structure, context, satisficing.

CONTENTS

Preface

This book is about systems thinking, system dynamics modeling, and community development projects. It is a follow-up to my first book on the topic of engineering and development, published in 2014 through ASCE Press, in which I looked more specifically at the role of engineering in poverty reduction and human development in general. After writing *Engineering for Sustainable Human Development: A Guide to Successful Small-Scale Development Projects*, it was not my original intent to start a new book project. But in writing that book, I became interested in exploring further the field of systems thinking and its possible applications in small-scale community development projects, mostly engineering projects in rural communities in the developing world. This interest originated from the observation that communities are systems of systems consisting of multiple parts (e.g., individuals, institutions, and infrastructure) that are interconnected, are driven by some purpose, follow certain rules, and interact with each other and with their surrounding environment. Simply put, communities cannot be analyzed in a deterministic and reductionist way by assuming that they consist of an assembly of static and independent elements and that the assembly is nothing more than the sum of its parts.

Following my participation in a workshop on system dynamics modeling taught by Corey Peck in Colorado in 2011, I became captivated by that methodology and started exploring its applications to development projects. I began using it in some of the courses that I taught at the University of Colorado (CU) at Boulder. In the meantime, my own field experience in the developing world with Engineers Without Borders – USA and the Mortenson Center in Engineering for Developing Communities at CU made me realize that there ought to be a better approach to addressing community needs than the traditional one used by development agencies. Their methodology is to look at communities as consisting of separate units, with separate issues, and which can only be addressed by specific experts who do not usually talk to each other. In a nutshell, these experts are supposed to come up with well-defined solutions to poorly specified problems and are expected to do it right, in a rational way, on time, and within a specific budget. I believe that this compartmentalized and myopic approach has been responsible, at least in part, for the limited success of development projects over the past 50 years.

Any community—whether a household, a village, a city, or a megacity—consists of a network of agents in which human beings play an active role. In communities, human systems interact with socioeconomic, environmental, infrastructure, and financial systems. They are by far the most complex of all systems, the least understood, and the most difficult ones to model. When interacting with other systems, human beings bring with them a limited potential for perceiving and processing information toward making decisions. They have limited cognitive capabilities (i.e., bounded rationality) for responding to changes and demands from the environment they face, especially when that environment is characterized by complexity and uncertainty.

As we manage our daily lives, we must be aware that we interact with multiple systems (social, economic, environmental, infrastructure, etc.) all the time. In fact, we cannot avoid systems whether we are awake or asleep. We encounter systems when interacting with each other, with institutions, and with natural systems, among others. Our own bodies are also remarkable systems. These systems are adaptive and often seem to be beyond our control. The problem with us, human beings, is that we would like the problems we encounter in these systems to be simple or complicated but not *complex*: problems for which we "don't know the unknowns." The bad news (or the good news, depending on how we look at it) is that very few problems we face are *simple* where we "know the knowns." Such problems are usually found in controlled environments or at the end of chapters in university textbooks. Over time, we have been able to handle *complicated* problems for which we "know the unknowns" and for which solutions are possible albeit they require the input of experts. Many structures and technologies designed by engineers belong to that category.

As wholes, communities are neither simple nor complicated. They are complex, with some components that may behave in a simple or complicated manner. Assuming communities to be not complex and approaching their issues accordingly can lead to projects with limited success or failed projects altogether; the developing world is littered with such projects that have been designed, planned, and implemented in a compartmentalized manner. Instead, embracing the complexity of communities and carrying out development projects within a complex context is one of the many recommendations developed in this book.

In this book, I consider small-scale communities as complex adaptive systems and acknowledge, as a starting point, all the associated characteristics of such systems, such as feedback mechanisms, emergence, nonlinearities, self-organization, uncertainty, etc. Communities consist of systems, subsystems, and other components in an overall hierarchy of complexity. The value proposition made herein is that systems thinking represents a better mindset than deterministic and reductionist thinking when addressing the various stages of community development projects. Systems thinking overcomes the limitations of deterministic and reductionist thinking by looking not just at the components of communities as separate parts but also by considering not only how these parts interact, their common purpose or function, the rules they have adopted, and how the parts interact with their environment.

A systems approach to community development projects implies adopting a system- and complexity-aware project management approach when considering project initiating, planning, executing, monitoring and controlling, and closing. These processes need to be managed by system- and complexity-aware individuals and groups, in a nonrigid way, and with core practices, leading to satisficing (good enough) solutions.

In addition, I look more specifically in this book at the application of one branch of systems science, called system dynamics, to develop conceptual models of small-scale communities and/or address specific issues they might be facing at different scales. System dynamics was originally developed by Dr. Jay Forrester at MIT in the 1950s and

1960s and has gained popularity in many fields of science and engineering. Interestingly, there are a limited number of instances where system dynamics has been used in the different aspects of international development and aid, especially at the project scale. However, as reviewed in this book, over the past 10 years some development practitioners have demonstrated a growing interest in addressing the applications of systems thinking in development. This book is about showing the *potential* of using systems thinking and system dynamics in development projects. System dynamics modeling—sometimes referred to as dynamic modeling in the literature—can provide a better understanding of the multiple issues that are at play in a community.

A unique feature of the systems approach presented in this book is that it combines system dynamics tools with traditional tools used in small-scale community development projects. As a result, the proposed framework encourages development practitioners to use a more flexible and adaptive approach in the appraisal, problem identification, design of solutions, and implementation phases of projects, compared to that used in traditional project management. The book emphasizes the importance of a *continuous reflection-in-action* through monitoring and evaluation in *all* stages of project management and not as an afterthought as projects unfold.

The writing of this book became my major professional occupation (other than other nonnegligible academic commitments) after Drs. Michael Ben-Eli and Markus Schwaninger invited me to co-teach a course on sustainability, systems, and development in July 2014 at Earth University in Costa Rica. The course was offered through the *Sustainability Laboratory* based in New York and brought about 20 international fellows interested in spending three weeks understanding the relationship between the aforementioned topics. The course gave me the impetus to write this book and to plunge into the field of systems thinking. It also gave me an opportunity to embrace a different and more hopeful form of thinking in my engineering work and my daily life. I am already contemplating the writing of a new book to follow this one, which will present several case studies of application of the framework mentioned herein to real small-scale communities.

I am relatively new at systems thinking and system dynamics and there have been many times in my life when too much enthusiasm got me into some trouble. Hence, I hope that my more expert colleagues in system dynamics and dynamic modeling will understand and be lenient for any transgressions I may have made in writing this book. Their forgiveness and feedback are greatly appreciated in advance. I also want to thank them for the opportunity they gave me to become acquainted and excited about a new way of thinking late in my career.

I want to thank Momentum Press for giving me the opportunity to publish my work. I also want to thank Michael Ben-Eli from the Sustainability Laboratory, Markus Schwaninger from the University of St. Gallen in Switzerland, Robert Ricigliano from the University of Wisconsin, and Jeff Walters from the University of Colorado at Boulder for their insights in systems thinking. I also want to thank Maryanne Fantalis for her thorough editorial work and Jeff Walters, Tamara Stone, and Corey Peck for reviewing the first draft of this book.

Finally, I especially thank my wife Robin and our children Elizabeth Ann and Alex for their support, patience, and love.

Boulder, CO
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CHAPTER 1

Introduction

This book introduces the reader to systems thinking and demonstrates how the tools of system dynamics, one of the many traditions in systems science, could be integrated in the design and planning of solutions in small-scale community development projects. A systems approach is better suited than a deterministic one at handling the unpredictability and uncertainty faced by development practitioners in community development projects. In that environment, development practitioners need to use a combination of objective and intuitive tools and an adaptive and flexible approach to project management where the decision-making process is more about satisficing than optimizing: that is, coming up with good enough solutions rather than optimal (perfect, best) ones. Development practitioners need to embrace complexity, rather than ignore it, when making decisions in community development projects. This book presents the components of a system-aware approach to small-scale community development projects.

1.1 Background and Context

This book introduces the reader to the application of systems thinking in small-scale community development projects. The idea of writing this book originated from another book entitled *Engineering for Sustainable Human Development*, which ASCE Press published during the summer of 2014 (Amadei, 2014). In that book, I looked more specifically at the role of engineering in poverty reduction and in human development in general. Furthermore, that book provided a framework and suggestions on how to conduct small-scale community development projects, mostly engineering projects in rural communities in the developing world. The proposed framework was designed to combine concepts and tools that have been traditionally used by development agencies with other tools more specifically used in engineering project management.

The aforementioned book recommended using an integrated and systemic approach when addressing issues faced by communities and their households. The recommendation was based on the observation that communities are systems of systems consisting of multiple parts that are interconnected, are driven by some purpose, follow certain rules, and interact with each other and with their surrounding environment. In communities, human systems, economic systems, natural systems, capital systems, and infrastructure (engineered) systems are always interacting in a time-dependent or dynamic manner. These systems are also adaptive in the sense that they adjust to their changing environment. Their interactions create complex and adaptive community structures that cannot be analyzed in a deterministic and reductionist way by assuming that each system consists of an assembly of static and independent elements. Understanding these structures is important since they determine how communities and their households behave when faced with daily challenges. One of the recommendations of my other book was that the scientific study of complex systems, which is sometimes referred to as complexity science in the literature (Waldrop, 1992; Mitchell, 2009), provides a tangible approach to understanding and modeling communities and developing solutions to the issues they might be facing. This book addresses *how* to integrate that recommendation in the practice of community development.

My interest in writing a book on systems thinking and development grew further after reading the book written by Ben Ramalingam (2014) entitled *Aid on the Edge of Chaos*. It provides an excellent introduction to the scientific study of complex systems and a review of a wide range of applications of systems thinking in development and aid-related topics.

Ramalingam's book builds on recommendations made by several authors that "development is a complex adaptive system" and that, in development, complexity and systemic behavior are the norm and not the exception (Chambers, 1997; Rihani, 2002, 2005; Breslin, 2004; Barder, 2012). However, as remarked by Ramalingam and Jones (2008), the volume of work in the application of systems thinking and the science of complexity to international development and aid "has grown relatively slowly." There has been, however, over the past 15 years a growing interest in the literature to explore what systems thinking and the science of complexity have to offer in various aspects of development practice (Scoones et al., 2007; Bossel, 2007; USAID, 2011a, b, 2014; Taylor et al., 2012; Williams and Britt, 2014; Fowler and Dunn, 2014) mostly at the policy decision level and at the regional or country scale. Not much has been proposed in using a systems approach at the project scale.

This book builds on the two aforementioned books and looks at the challenges and opportunities associated with using systems thinking and system dynamics tools at the smaller scale of community development projects. System dynamics is one of the many traditions in systems science that studies "how systems change over time" (Ford, 2010). More specifically, this book shows how to use systems thinking when assessing community needs, modeling communities, and designing and planning solutions to community problems in order to provide long-term benefits (i.e., ensure project sustainability) to community members.

The best way to introduce the scope of this book is for you, the reader, to travel with me to a neighborhood in a city located near the Pacific coast of Costa Rica. The neighborhood consists of about 3,000 to 3,500 people with 1,000 children. It is one of the poorest neighborhoods in a town and region of Costa Rica whose affluent economy depends mostly on tourism. It was created 15 to 20 years ago when illegal immigrants from Nicaragua moved into Costa Rica. Today, they represent 90% of the neighborhood but do not have voting rights. The households do not own the land they live on and consist of large families. People live in precarious conditions in "tin (zinc) homes" with some electricity and water. There are no waste water management and sanitation facilities, clinics, or schools in the neighborhood and the roads are not paved. People have low education levels and do not benefit from the local tourist industry. Instead, many people work in the city's garbage dump. Some of the youth are involved in gang activities. Alcoholism and the use of drugs are rampant. There is no sense of community across the neighborhood despite an eight-person association with limited power.

An interesting fact about the neighborhood is that, 15 to 20 years ago, the owner of the land promised to donate it to poor families in Costa Rica but never signed and transferred land and property titles to these families. Following the death of the donor, her heirs have been debating whether to keep that promise since the value of the land has increased many times over the past 15 to 20 years. Several times, the neighborhood residents were told by the donor's heirs and the mayor of the town that agreement was almost reached and that titles would be given to existing families. As of July 2014, that had not happened yet and the neighborhood residents have found themselves facing an uncertain future, which according to them is *the* root cause for their lack of community involvement and betterment. In the meantime, the neighborhood is illegal in the eyes of the municipality (except for those born in Costa Rica) which does not want to invest in jobs, schools, infrastructure, health, and other services.

The neighborhood's dynamic described above is that of an open, complex, and adaptive system with multiple stakeholders and interacting issues (social, economic, political, ethical, cultural, etc.), some better defined and understood than others. Such a dynamic is not limited to a marginalized neighborhood in Costa Rica. Many of the problems listed above are pretty much the same in most poor communities in the developing world that I have visited over the past 15 years. The community setting may be in rural areas or be part of a poor area in a city. Issues of poor livelihood, isolation, no hope for future generation, no political representation, physical and psychological weakness are common (Chambers, 1983; Narayan et al., 1999; Prahalad, 2006). They may take different shapes and forms depending on the context of the community, but overall they are the same. It has been my experience that these issues are not isolated but are interconnected. They cannot be addressed in a linear and compartmentalized way but rather require a more holistic and systemic approach which is better suited when identifying places to intervene in a community.

Let's imagine that you and I have been selected as members of a multidisciplinary team that has been asked to address the problems of the aforementioned neighborhood and more specifically to work with the community members in developing a plan of action to improve their well-being. We have been told that a desirable outcome (overarching goal or impact) of our work should be for the community to become *more* prosperous, stable, safe, and peaceful after a certain period of time and that these characteristics should preferably be long lasting (i.e., sustainable). We have also been told that we can approach this project under "ideal" conditions where (i) adequate funding is available to conduct a study of the community and develop an action plan; (ii) some level of community participation exists and can be expected to improve over time; (iii) there are no critical project deadlines and we have time to think the problems through; and (iv) skills and resources are available from insiders and outsiders of the community. Such ideal conditions may not necessarily be realistic in the world of community development, but let's assume for the time being that they are, as the focus of this book is to demonstrate how a system approach can be integrated in the design and planning of solutions in development projects. I do not want to cloud the discussion with the many constraints that are often associated with development projects and which have been discussed in my other book (Amadei, 2014) and in the development literature.

Now that our work has been outlined, the next step is for our team to decide and agree on a methodology of intervention that is based on community participation and integrates the different systems already at play in the community: social, environmental, infrastructure, economic and finance, political, and health. In the community of interest, all these systems and their subsystems interact in a dynamic way and at different scales: individual, household, neighborhood, city, and regional. The nature and characteristics of that interaction and related interdependence define to a great extent the day-to-day well-being (or lack thereof) of the community and its members. In systems lingo, well-being (and how it manifests itself in terms of wealth, health, etc.), or lack thereof, can be seen as a property that *emerges* from the multiple functional or nonfunctional interactions in the community systems. This concept of *emergence* (i.e., a process by which patterns emerge as components of a system interact with each other and self-organize; Holland, 1999) is an important one which is emphasized throughout this book.

Having acknowledged the various systems at play, our multidisciplinary team has been asked to follow a project methodology which, as described in my other book, is likely to contain several distinct phases: community appraisal consisting of data collection and analysis, community problem identification and ranking, planning and design of various interventions followed by their execution, and project closing. Project assessment through monitoring and evaluation is likely to occur from project start to finish. These phases will be followed by a reflective practice and after project assessment to determine the long-term benefits of the solutions implemented and whether the project can be taken to scale. In following this methodology, our team will have to be mindful of the various systems involved in the community when collecting and analyzing community data, converting data into useful information, and identifying community problems. The team will also have to be mindful of how it perceives and models these systems, how it makes decisions in partnership with community members, and of the various biases it brings into the project.

Once a baseline (i.e., an assessment of where the community stands today) has been established for our neighborhood in Costa Rica and its problems have been identified and ranked, the next step for our team is to design and plan alternative solutions to the problems identified in collaboration with the neighborhood. The traditional approach in developing solutions to developing community problems can be described as *reductionist* and *deterministic*. In this approach, which is still the dominant one used by development agencies today (Ramalingam, 2014), each problem is assigned to a separate discipline and addressed by one or several experts: e.g., water issues are addressed by water engineers; sanitation issues by sanitation engineers; economic issues by economists; health issues by health specialists, etc. All these experts are likely to come up with definite, rational, but isolated well-thought solutions to definite problems in a piecemeal manner. The shortcoming of this compartmentalized and static approach is that there is no interest in understanding (i) whether community issues are interconnected and are part of dynamic feedback mechanisms and (ii) whether they share common root causes, which if addressed together could solve multiple issues in a more integrated and effective way.

As an example, consider the issues of community water, energy, food, and health which are not only interconnected at the service level (from source to the consumer) but also in relation to security and prosperity (Bazilian et al., 2011; WEF, 2011). More often than not, the connections (nexus) and feedback processes between these issues are not considered in full. Solutions to these separate issues need to be addressed not only in depth but also by considering how they interact with each other, with other socioeconomic and geopolitical issues, and at different spatial and temporal scales (Allouche et al., 2015). The same remarks could be made about individual and community health which depends on many factors related to education, economics, energy, water, food, etc. These factors depend, in turn, on health through various feedback mechanisms.

A more desirable and realistic approach to developing solutions to community problems is what this book is about: a *systems approach*. From the outset, it acknowledges that a community, such as the neighborhood in Costa Rica, and all its dependents form a system (a whole), or using a biological metaphor, an adaptive organism. Furthermore, it acknowledges that, to start with, problems in the community are complex, uncertain, interconnected, involve multiple feedback mechanisms, and are not well-defined. It also recognizes that all community stakeholders—all individuals and groups, both insiders and outsiders to the community that have a voice in making or influencing decisions—have a limited (but never complete) understanding of the community's behavior over time and all its issues at play. Finally, a systems approach takes into account the fact that all these players come loaded with their own expectations, biases, motivations, judgments, feelings, and cognitive limitations.

Despite these challenges, a systems approach recognizes that there ought to be places in the community where a well-planned intervention is more likely to yield more effective and efficient return on the investment or action taken (Meadows, 2008). They can be seen as *leverage* or *tipping points* in the community. This may take the form, for instance, of identifying what already works in the community, building community capacity, and working with existing changemakers in and outside of the community. Another example might be addressing issues that can easily be addressed first (the low hanging fruit) that will help build community confidence and resilience over time. A third example would be to change the community mindset about certain issues (e.g., water, energy, food, and health) through behavior change communication and creating awareness outside the community.

For our neighborhood in Costa Rica, a place to intervene in the system might be to work with the heirs of the donor, the city mayor, and the neighborhood's association in reaching a compromise that would result in issuing land and property titles to all households in the neighborhood. Even though this may sound like the logical leverage point according to the neighborhood residents, this root-cause solution may have its own cascading consequences which could make the situation worse than it is today. This may result, for instance, in the deportation of illegal residents who have been in the neighborhood for the past 20 years. As a result, before a solution is proposed to and in collaboration with the neighborhood, the issue of land titles needs to be addressed along with immigration and other possible outcomes that may arise, such as land planning, equity, taxation, financing and construction of new city infrastructure, etc. In complex systems, it is not uncommon that solving some specific issues may backfire and create unexpected behavior and second-order effects leading to new and unintended consequences (Watzlawick et al., 1974; Sterman, 2006; Ramalingam, 2014).

A systems approach to community development projects acknowledges that we never have a complete picture of the community at stake and its issues since "we don't know what we don't know" prior to interacting with a community. The overall community picture becomes clearer as the interaction takes place. As a result, we need to use a *complexity-mindful* (or *aware*) step-by-step approach that most engineers resent the most, which is to provide "intelligent guesses" or "approximate solutions" to ill-defined problems. This is done using a combination of *objective* tools when the situations are simple and predictable and *subjective* or *intuitive* tools in more complex and uncertain situations (Elms and Brown, 2012). In turn, this requires adopting an adaptive and flexible approach to project management through *reflection-in-action* (Schön, 1983; Barder, 2012). Because of the inherent uncertainty and complexity of development projects, the project decision-making process is more about *satisficing* than *optimizing*: that is, coming up with *good enough* solutions rather than *optimal* (perfect or best) ones (Simon, 1972). Upon implementation, these solutions need to be monitored and evaluated and, if needed, modified to reflect change. Simply put, they need to be adaptive and dynamic as projects unfold.

In summary, a systems approach can be used by development practitioners—a term used throughout this book to regroup engineering professionals and experts involved in development projects—to operate in the unpredictable and complex environment of community development projects. In that environment, development practitioners need to be more than just traditional value-neutral individuals capable of producing linear blueprints and predictable solutions delivered on time and within budget, for problems that are well-defined. They need to be system thinkers and be creative, innovative, and interactive in order to account for uncertainty, complexity, ill-defined issues, and constraints in a cultural context that they are not accustomed to. Their solutions need to be sound from a technical point of view (i.e., done right), adaptable to the cultural, economic, and social context in which they work (i.e., rightly done), and developed for the right reasons. Finally, development practitioners need to be able to work and collaborate in multidisciplinary teams. This book introduces development practitioners to a model-based management of community development projects that emphasizes systems thinking and the use of system dynamics tools which are better suited to the socioeconomic and overall context of developing communities.

1.2 Systems in Our Daily Lives

Systems can be broadly defined as groups of interacting (but seemingly independent) parts linked by exchanges of energy, matter, and/or information (Meadows, 2008). Systems consist of parts and the links or interconnections between those parts. They are driven by a common purpose to achieve certain goals, even though the parts may have conflicting purposes. The behavior of systems is also dictated by various rules that act at the component and/or system level and by how systems interact with their environment. As noted by Berry (1990), in systems "nothing is completely itself without everything else."

Systems are often assigned natural or artificial boundaries through which exchanges (inputs and outputs) are assumed to take place. As remarked by Patton (2011), systems possess all sorts of unique characteristics such as nonlinearity, feedback, emergence, dynamic behavior, adaptation, uncertainty, and coevolution (self-organization) which, at times, can be hard to comprehend and deal with. Furthermore, systems can develop patterns of behavior that may not be predictable from the behavior of each system's part; the whole is greater than the sum of its parts through *synergy* (Fuller, 1975). The interconnected and systemic nature of our world has been emphasized by many authors in various traditions but is still not our best and preferred practical mindset in our day-to-day activities and decision making.

As we manage our daily lives, we must be aware that we interact with multiple systems (social, economic, environmental, infrastructure, etc.) all the time (Laszlo, 2001). In fact, we cannot avoid systems and are part of many of them whether we are awake or asleep. Think of all the systems that you and I interact with on a daily basis: family, traffic, workplace, and all the groups with whom we interact and share (or do not share) common interests and needs. According to Bugliarello (2003), we constantly find ourselves in the so-called *biosoma*, the space at the interaction between *bio*logy, *so*ciety, and *ma*chines.

Earth's natural systems provide multiple eco-services in the background that sustain and fulfill human life, including photosynthesis, purification of air and water, cycling of nutrients, pollination, regulation of climate and oceans, and production of soils, among others (NASA, 1988; Lovelock, 1991). These natural systems interact with various populations, industries, and governments at different physical and temporal scales (Rouse, 2014). Our bodies are another example of systems of systems (cardio, digestive, nervous, immune, skeletal, etc.) that interact and contribute to our overall state of health or disease. As noted by Meadows (2008), they are "magnificent examples of integrated, interconnected, self-maintaining complexity."

In engineering, man-made (anthropocentric) systems interact with the biogeochemical processes of natural systems. A civil engineering example of such interaction would be that of a dam (a man-made system) interacting with a river (a natural system). The dam affects the environment and the environment affects the performance of the dam through various feedback (causal duality) mechanisms such as environmental changes, erosion, climate changes, and possible seismicity.

Some systems can be smaller and more manageable than others. For instance, over the course of recent human history, we have learned to interact more or less successfully with many systems when driving a car, riding a bicycle, using a computer, flying an airplane, operating machinery, or while being part of crowd or group activities. In other instances, some systems can be so large and complex that they escape our comprehension, defy our intuition, and challenge our cognitive abilities. We face such systems, for instance, when trying to understand evolution, space, nature, Earth's climate, the economy, cities (urban, peri-urban, and slums), conflict situations, natural hazards and disasters, etc.

Engineers of the 21st century have to become aware of many systems and be able to design solutions to problems ranging from the microscale (e.g. nanotechnology, bioengineering) to the macroscale and cutting across many scientific and nonscientific disciplines (C. Vest, quoted in Hutchinson, 2008; Labi, 2015). Engineers also have to design the solutions under multiple constraints (financial, human, environmental, etc.) that are hard to identify and deal with (Wulf, 1998). The aforementioned interaction between the dam and the environment is the kind of complex interaction that is hard for engineers to comprehend and predict fully. It requires integrated design under multiple constraints. Countless examples exist of engineering projects that have resulted in more harm than good for the environment and people because engineers have failed to recognize the complexity of the interaction between natural and nonnatural systems (Holling and Meffe, 1995; Allenby, 2000; Bugliarello, 2003). As a result, an emphasis has been placed over the past 20 years on integrating systems tools in engineering education and practice. Today, systems engineering represents a distinct approach to addressing complex technical and socio-technical problems and has its own body of knowledge (BKCASE Editorial Board, 2014; Labi, 2015).

In the field of international development and aid, systems (human, natural, infrastructure, economic, and capital) interact at multiple dimensions, from the local scale (individual, households, neighborhood, village, town, and city) to the regional, national, and international level. As noted by Ramalingam and Jones (2008):

> …there are many connections and interactions within the various dimensions of economic and social development, such as between education and the economy, between health and poverty, between poverty and vulnerability to disasters, between growth and environment – the list is literally endless. International aid to address these issues takes place in the context of a dense and globalized web of connections and relationships between individuals, communities, institutions, nations and groups of nations. Interactions among the various elements of these different systems are themselves complex and multifaceted. Aid relations run alongside many other kinds of international relations: military and security relations, relations of economic cooperation and trade competition.

Furthermore, many interacting systems are at play within and across existing development and aid agencies (Ramalingam and Jones, 2008):

> If that were not enough, every aid agency operates in a global aid system which is itself characterized by a huge number interacting systems, each of which is made up of multiple parts. There are a bewildering number of different relationships and interactions between bilateral aid agencies and multilateral agencies, between multilaterals and country governments, between aid agencies and communities, among neighbouring communities, between NGOs and governments, and among an increasing number of 'non-traditional' development actors such as the media, diaspora communities and the military.

As further discussed in Chapter 3, systems can be divided into four groups: simple, complicated, complex, and chaotic (Snowden and Boone, 2007; Patton, 2011). *Simple systems* involve few variables with limited and easily understandable relationships that are displayed over a short time period. Predictability and certainty are the norm. In simple systems, we "know the knowns" and a correct answer is possible. Laboratory experiments or problems at the end of each chapter in engineering textbooks fall into that category. In c*omplicated systems*, a correct answer to a difficult problem is still possible, as we "know the unknowns." Understanding such systems may require the input of experts. A car, an airplane, and a dam are examples of complicated systems.

The third group of systems is that of *complex systems* in which many variables are involved, uncertainty and ambiguity are the norm, interactions exist between the variables, and an agreement cannot be reached about the functioning of the system and how to approach it. Mitchell (2009) defines complex systems as systems exhibiting "nontrivial emergent and self-organizing behaviors." In complex systems, we "don't know the unknowns" and unexpected "black swan" or "outlier" events are commonplace (Taleb, 2007). Examples of complex systems include living systems, Earth's climate, the human body, the stock market, health care systems, enterprise network systems, communities and neighborhoods in villages, cities, and megacities, etc. Complex systems that have very high levels of unpredictability are called *chaotic*.

Communities are systems that are not only complex but also *open* as they exchange mass and energy with their surroundings. As living systems, they are also *adaptive*: that is, they self-organize as they adapt to change and adopt new structures and forms of behavior (Waldrop, 1992; Miller and Page, 2007). They can also be perceived as evolving organisms using a biological metaphor. These organisms not only depend on their environment to grow but also affect that environment. Addressing issues in communities and complex systems in general, whether as an insider or an outsider, requires making decisions in uncertain and unfamiliar environments, which is a definite challenge to our inherent bounded rationality (i.e., lack of objective reality). As noted by Simon (1957), "…the capacity…of the mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behavior in the real world – or even for a reasonable approximation to such objective rationality."

Our heuristic approach to complexity and change—that is, how we process information and act upon it—is inherently biased and limited. Hence, when facing systems such as communities and their complexity, our decisions are not likely to be fully rational, optimal (best), and complete. Instead, decisions are often made on simplified versions using conceptual models of reality and based on human perceptions, perspectives, beliefs, feelings and emotions, past experience, and habits (Dörner, 1997). These cognitive limitations affect how the different phases of community development projects are conducted. More specifically, these limitations control (i) how projects are designed, planned, executed, monitored, and evaluated; (ii) how predictable the outcome of those projects will be; and (iii) the long-term benefits, or sustainability, of the projects.

Since we cannot escape interacting with systems and are limited by our bounded rationality, we are better off working with them rather than fighting against them. In this book, the tools of system dynamics *combined with* those of community development show how complexity and unpredictability can be better (but not completely) embraced and accounted for, rather than ignored, when making decisions in community development projects. But, as noted by Westley et al. (2007), this approach requires development practitioners to make "a fundamental [and intentional] shift in perception – from complexity as obstacle to complexity as opportunity" and being constantly and fully aware of that value proposition. Ramalingam (2014) sees this much needed new approach to development and aid as breaking away from an "obsession with organized simplicity" to "embracing organized complexity" while accepting the challenges that this new approach brings forth. Likewise, Scoones et al. (2007) suggest breaking away from "equilibrium thinking" to dynamic thinking in the management of development projects and seeing these projects as not being static but rather evolving, adapting, and becoming "learning organizations" as suggested by Senge (1994).

1.3 A Systems View of the World

Looking at the world using a systems view is not new (Laszlo, 2001) and has been "embedded in [many of] our old teaching stories, common senses, and wisdom traditions" (Sweeney, 2001). The Greek philosopher Aristotle in the 4th century BC is often quoted as having stated that the "whole is more than the sum of its parts" and advocated what we call synergy today (Fuller, 1975). The interconnected nature of the world has also been part of the mindset of native wisdom traditions.

Since the Age of Enlightenment, the systems approach has been set aside in the Western world in favor of a more reductionist (Cartesian and Newtonian) one that looks at the world as a great machine consisting of parts. It is based on the premise that if one were to divide the whole into parts, analyzing and understanding the parts separately, the whole should be understood. As noted by Holling and Meffe (1995), the expectation of the reductionist approach is that solutions to any problem are "direct, appropriate, feasible, and effective over most relevant spatial and temporal scales." They are also assumed to be static and not to evolve or adapt over time (Harford, 2011). Furthermore, problems are expected to be "well-rounded, clearly defined, relatively simple, and generally linear with respect to cause and effect." In the world of international development, agencies "continue to expect predictable outcomes to actions" in a context that is characterized by uncertainty and complexity (Breslin, 2004).

We know today that an idealistic reductionist approach (and its underlying assumptions) can only capture a small fraction of the web-like nature of reality. Nevertheless, many attempts have been made to force the reductionist approach into solving complex socio-technical-economic problems without much success. These attempts usually assume that complex systems are merely simple or complicated, which can be seen as a deliberate way of avoiding complexity and reducing mental effort. Because of the limitations of the reductionist approach, various branches of systems science and the scientific study of complexity have emerged over the past 50 years to try to understand the word better (Waldrop, 1992; Laszlo, 2001; Mitleton-Kelly, 2003). The most comprehensive encyclopedia on the scientific study of complexity and systems was edited by Myers (2009) and consists of 11 volumes describing different systems formulations and their applications to various fields of science, economy, and even politics.

The interest in using a systems approach to model complex and uncertain situations has been a topic of discussion and research since WWII. As noted by Ramalingam and Jones (2008) and Miller and Page

(2007), there has been a lot of contention since the 1950s about whether a systems approach could be used in some disciplines (e.g. social, political, and economic sciences) versus more technical ones such as engineering and physics. The jury is still out on that dispute and is populated with many opponents, pragmatists, and supporters.

I present below a few examples of system-based approaches that have been proposed to address highly complex issues: global change and world development; peacebuilding and conflict; health care; water management; and critical infrastructure. I purposely selected these examples as they incorporate several aspects of human development. However, it should be noted that all these approaches are used at the global scale and do not necessarily scale down at the community or project level, which is the main interest in this book. Nevertheless, it must be kept in mind that communities operate in larger systems. There are many feedback loops operating between a community and the region and country to which it belongs. Being able to look at the big picture can help in solving local issues, and vice versa.

Global Change

Understanding and predicting global change has been in the mind of many scientists and engineers for the past 50 years. As noted by Rotmans and deVries (1997), global change can mean different things in the literature from "human-induced changes in the environment" to the "totality of changes evoked by the complex of mutual human–environment relationships." The latter definition (which is more of interest in this book, albeit at a smaller scale) encompasses a multitude of social issues (e.g., individuals and institutions), economic issues (e.g., production and consumption), and ecological issues (e.g., land, water, air, biota). All these issues are so interconnected that they can only be addressed in parts or comprehensively using systems tools. A systems approach is better suited to address global phenomena such as land degradation and desertification (Reynolds et al., 2003), climate change (Schneider, 2004; Burkett et al., 2005), the complex dynamics of cities and megacities (Bugliarello, 2003; Batty, 2007), and the interaction between social and ecological systems in general (Ostrom, 2007).

Various frameworks have been proposed since the early 1970s to model global change and predict the evolution of various world systems (e.g., population, health, the economy, finances, production, consumption, capital, etc.). An example of an early system-based global change framework was the *World3* "world model" of Meadows and coworkers which looked at different scenarios of world development (Meadows et al., 1972). It succeeded an earlier model originally developed at MIT in the early 1970s (Forrester, 1973). The most recent version of *World3* is known as *World3-03* (Meadows et al., 2004). Other world models were developed in the 1970s including those of Mesarovic and Pestel (1974) and Herrera et al. (1976). An excellent review of these models can be found in Bossel (2007).

More recent system-based global change frameworks include the *Globus Model* (Brener, 1987) and the TARGETS model which stands for *Tool to Assess Regional and Global Environmental and Health Targets for Sustainability.* Developed by Rotmans and deVries (1997), it consists of five interacting submodels covering the areas of population and health, energy, land and food, water, and biogeochemical cycles.

Another system-based framework applied to global change and the future of humanity has been proposed by the *Millennium Project*, which started in 1996. The framework acknowledges multiple global challenges involving 15 critical, equally important, and interconnected issues such as sustainable development and climate change, clean water, population and resources, and democratization. It is documented in an annual report entitled *State of the Future* (Glen et al., 2014) and a comprehensive online database called the *Global Futures Intelligence System*. The Millennium Project has also compiled an excellent review of more than 30 methods of decision making that, combined with a systems approach, could be used to address different aspects of global change (Glen, 2014).

Finally, a very comprehensive global change framework has been developed by the *Pardee Center for International Futures* (IFs) at the University of Denver in Colorado. It explores links between various systems and subsystems involved in development such as economics, agriculture, population, energy, education, health, environment, infrastructure, international politics, technology, and governance.

The framework shown in Figure 1.1 was created by Dr. Barry Hughes and is designed to explore various future trends and "what if" (or "what happens if") projections or scenario planning at the country level for 186 countries and over a time frame as far as 2100 (Hughes, 1999; Hughes and Hillebrand, 2006). The framework can also be used for regional and global predictions (IFs, 2014). Version 7.0 of the IFs software is available on the Pardee Center website. The Pardee Center also publishes a series of reports under the theme of *Patterns of Potential Human Progress* (PPHP) around reducing global poverty, advancing global education, improving global health, building global infrastructure, and strengthening governance globally (PPHP, 2014).

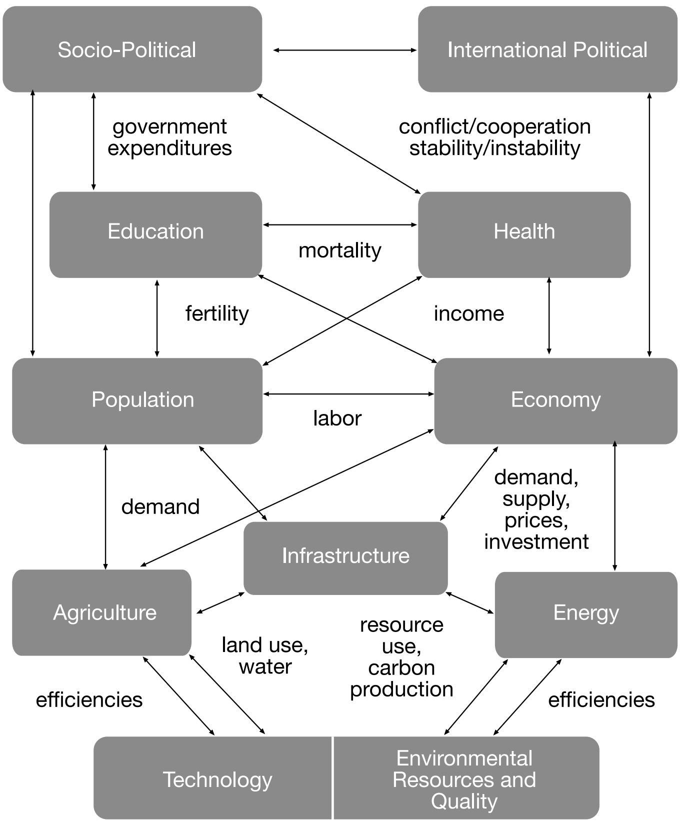

Figure 1.1. Systems-based framework used by the Pardee Center for International Futures to model global change.

Source: IFs (2014). With permission from the Frederick S. Pardee Center for International Futures originally developed by Barry B. Hughes.

Analyzing Peace and Conflict

Understanding the dynamic of conflict at the national and international levels requires considering multiple disciplines and issues, as well as a wide range of interconnected actors operating at different physical and temporal scales. As noted by Schirch (2013), "conflicts have multiple causes that interact with each other driving a cycle [or multiple cycles] of dynamic causes and effects." As remarked by Matt Levinger (2014) from the U.S. Institute of Peace, major conflicts are not always well-defined and can indeed be classified as complex. Such conflicts differ from traditional intra- or interstate conflicts. They are not limited to geographical boundaries and cultures, change over time, sometimes rapidly, and cut across various factions with different beliefs and ideologies. In such conflicts, humanitarian assistance can be difficult to manage and requires a systems approach (OECD, 1999).

Before conflict analysis can be carried out, it is important to assess the actors involved in the conflict, their connections, the effects of the conflict, the factors driving the conflict, and the conflict boundaries. Because conflicts tend to be complex, systems tools have been proposed (Coleman et al., 2007; USAID, 2011a; Ricigliano, 2011, 2012; Schirch, 2013) to (i) analyze the results of conflict assessment; (ii) predict how conflicts may evolve; (iii) identify places to intervene in the conflict; and (iv) propose meaningful interventions leading to peace and stability. An excellent review of the use of systems thinking into conflict analysis can be found in Jones (2015). It is becoming clear that a multitrack approach to diplomacy is necessary to capture the multidimensional and systemic nature of peace and conflict (Diamond and McDonald, 2013). That approach needs to also recognize the complex interconnectedness between diplomacy, defense, and development (Frej and Ramalingam, 2011).

An interesting study that shows the intricate and multifaceted nature of peacebuilding was conducted by the U.S. Institute of Peace and the U.S. Army Peacekeeping and Stability Operations Institute (USIP, 2009). The study led to laying out a series of guiding principles for stabilization and reconstruction in peacebuilding operations. These principles recognize that human security requires meeting five interconnected goals as shown in Figure 1.2: a safe and secure environment; rule of law; stable governance; a sustainable economy; and social well-being. Each goal requires that certain conditions (22 of them altogether) be fulfilled; they are listed in each circle in Figure 1.2. The center of that figure shows seven cross-cutting principles that can be applied to all of the goals. According to Schirch (2013), each goal needs to be addressed at four dimensional levels: (i) structural (institution, infrastructure, and attitude); (ii) cultural (i.e., a culture of peace); (iii) relational (interpersonal relationships, attitudes, patterns); and (iv) personal (beliefs, attitudes, behaviors, skills, knowledge). A systems approach to model, both qualitatively and quantitatively, the complexity of Figure 1.2 is still a work in progress (USIP, 2013).

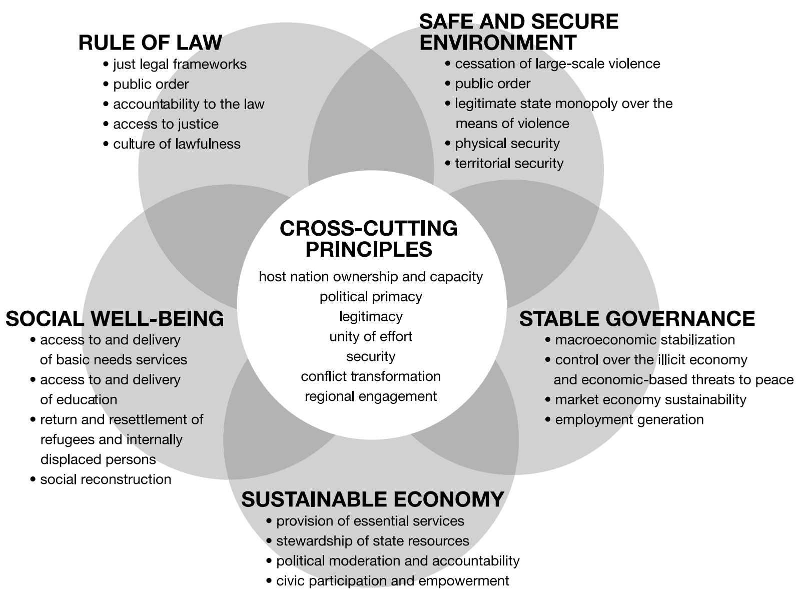

Figure 1.2. Guiding principles for stabilization and reconstruction in peacebuilding operations.

Note: End states are in capital letters, conditions are in lowercase letters.

Source: Guiding Principles for Stabilization and Reconstruction (USIP, 2009).

Health Care

Systems thinking has been used to model the interaction of health systems with other human and social activities (e.g., economic and infrastructure development) that contribute indirectly to the health and well-being of communities (Glouberman and Zimmerman, 2002; Newman et al., 2003; Lebel, 2003; McDonnell et al., 2004; Rwashana and Williams, 2008; WHO, 2009; Peters, 2014). Hargrove (1998) provides multiple examples of application of systems thinking in biological sciences and health.

Of special interest is the use of a system approach to model chronic disease prevention and the interaction of multiple diseases (Janssen and Martens, 1997; Homer and Hirsch, 2006; Jones et al., 2006) and epidemics (Ritchie-Dunham and Galvan, 1999; Zhou, 2014). In the context of policy and health, Newman (2010) describes several examples of applications of systems thinking to development projects in Guatemala, Bolivia, and Peru. The systems view was used to better understand the consequences of policy decisions at the country level on community health interventions related to malaria control and chronic malnutrition. Finally, a workshop on complex adaptive systems approaches to the strengthening of health systems in low- and middle-income countries was held in 2014 in Baltimore, MD (Future Health Systems, 2014). It explored the range of applications of system dynamics tools in the modeling of health system performance.

Water Cycle and Management

The availability of water in terms of quantity, quality, distribution, and water management is a critical issue to all communities, large or small. In general, community water systems consist of natural systems and their associated infrastructure. In water resource management projects, these two systems constantly interact with each other and involve socioeconomic issues. As reviewed by Winz et al. (2008), a systems approach has been used over the past 40 years to account for the uncertainties inherent in water resource management.

The *WorldWater* model is an example of a system-based framework that explores strategies of water management (Simonovic, 2003). It contains seven interacting components: population, agriculture, nonrenewable resources, economy, pollution, and water quality and quantity. When combined with system modeling tools, this model has been used to gain insight into the patterns of water use at the global level or at the regional level. An example of application of the model at the country scale (e.g., CanadaWater model) or within regions of a country is described by Simonovic and Rajasekaram (2004).

A more recent systems approach to model the complex interaction between socioeconomic, biophysical, and community participation in natural resources management projects was proposed by an international team of development practitioners under the Challenge Program on Water and Food (CPWF) initiative (Barreteau et al., 2010). This initiative uses a model called Companion Modeling or *ComMod* (Etienne, 2014) that incorporates the advantages of various tools such as multiagent systems, agent-based modeling, adaptive management, role-playing games for collective decision making, and collective learning process. It has been applied to a large number of development projects in Bhutan, Vietnam, and Thailand (Bousquet et al., 2002, Gurung et al., 2006).

Critical Infrastructure

Infrastructure is that part of the anthrosphere (i.e., the environment created and modified by human beings) composed of the "utilities, facilities, and systems used in common by members of a society and upon which the society depends for its normal function" (Manahan, 2000). It encompasses many physical components related to water, telecom, shelter, energy, transport, and waste (Labi, 2015). The resilience of infrastructure to hazards and disasters has become of great interest in view of several extreme events worldwide during the past 10 years. More specifically, engineers have been interested in the vulnerability of *critical infrastructure* in cities (Karamouz and Budinger, 2014). They are the lifeline parts of the infrastructure whose destruction or incapacitation would have a great impact on society's security, health, wealth, etc. A challenge in assessing infrastructure vulnerability is to map and model the various forms of intra- and interdependencies operating in the networked infrastructure systems and their connections (Chai et al., 2008). These dependencies contribute to infrastructure vulnerability and dictate possible cascading effects and unintended consequences associated with natural and nonnatural events (Pederson et al., 2006; Walsh et al., 2009).

Figure 1.3 shows an example of infrastructure intra- and interdependencies associated with the follow-up to a flood event and more specifically the flooding in New Orleans, following hurricane Katrina in 2005. The components of each infrastructure type (energy, water, transportation, information and telecom, and emergency services) are horizontally integrated; they are *intradependent*. The connections do not stop there, however, as the different types of infrastructure are also *interdependent* through vertical integration. A framework to explore that dynamic of energy infrastructure underlying such events was developed by several groups in the U.S. government under the *Interdependent Energy Infrastructure Simulation System* (Toole and McCown, 2008).

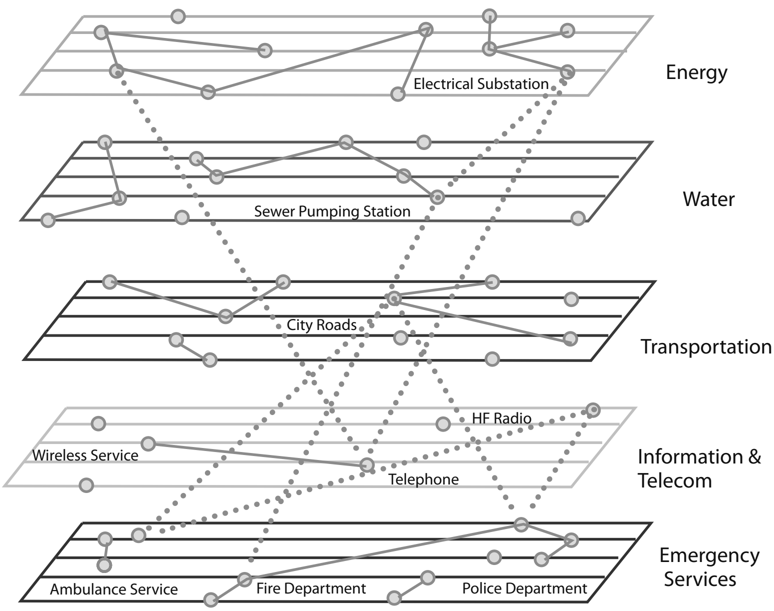

Figure 1.3. Infrastructure intra- and interdependencies associated with the follow-up to a flood event.

Source: Pederson et al. (2006).

1.4 Goals of the Book

Over the past 15 years, I have been increasingly interested in the fields of sustainable community development, human development, and poverty reduction. Following the launching of Engineers Without Borders–USA in 2001 and the Mortenson Center in Engineering for Developing Communities at the University of Colorado at Boulder in 2004, I became interested in understanding how to approach the complexity and uncertainty of the communities I was interacting with. All communities, whether in the developed or developing world, are characterized by their dynamic behavior, involve multiple players with various interests, have members that interact with each other, and interact with other groups (communities, governments, NGOs, etc.). Since such characteristics cannot be modeled using linear and predictable tools (linear causation), I started to explore how far systems thinking and its circular causation approach could be used in development projects, an approach that has not been explored much in the development literature. Furthermore, I became interested in concepts such as sustainability, peace/conflict, poverty/wealth, and resilience, and how they might be understood not as individual and tangible concepts, but rather as emergent properties or states of functional or dysfunctional systems.

The main goal of this book is to introduce the fundamentals of systems thinking and the tools of system dynamics to those involved in the design and planning of solutions of small-scale community development projects. The systems approach presented herein will hopefully inspire development practitioners to acknowledge the complex and uncertain environment of development projects and consider a new decision-making process in future projects. The systems approach complements the traditional reductionist tools that are used in development projects. The two sets of systems and reductionist tools are not exclusive of each other; they need to be used appropriately depending on the context in which they are applied and the scale of project intervention.

It should be noted that this book does not enter into the details of systems and the study of complex systems and is not designed to make its readers experts in systems thinking and complexity. It was written to make development practitioners aware or mindful of a systems approach to development projects. The term *system-aware* or *complexity-aware* is used as an attribute throughout this book to describe practitioners who (i) use an integrated but not compartmentalized approach to their projects, (ii) are knowledgeable of the advantages and limitations of systems thinking and system dynamics tools; and (iii) have received a minimum of training on how to use these tools. Readers interested in learning more about systems and complexity can find plenty of references in the literature; many of them are listed at the end of each chapter of this book.

The book emphasizes the challenges and opportunities in integrating systems thinking in the different stages of small-scale development projects with an *engineering perspective*. It also assumes that the reader is already familiar with the components and practical aspect of such projects. Furthermore, the book does not address the applications of systems thinking to medium- or large-scale projects, or to regional or country level programs, and does not enter into the fields of decision policy and governance. Finally, I have also avoided any discussion addressing the application of systems thinking in the context of emergency and rapid response situations, which could make a book on its own.

More specifically, the book shows how a systems approach to the management of community development projects could be used to:

- understand better the current dynamic of a community and its enabling and constraining environments;
- explore how certain variables or factors influence that dynamic, including feedback mechanisms, by carrying out various sensitivity studies;
- explain existing patterns of community behavior over time;
- interpret emergent properties of community systems such as poverty/wealth, peace/conflict, health, resilience, and sustainability;
- examine various perspectives of community development interventions and consider possible consequences and implications of these interventions;

- identify and explore leverage points or tipping points, those critical places to intervene in the community;
- predict how the community may respond to various constraints and disturbances and/or strategies of capacity development, thus allowing for reevaluation of decisions and actions;
- explore possible unintended consequences of decisions in community development;
- monitor and evaluate the performance of development interventions and decide on how to make adjustments as projects unfold, thus leading to more flexible and sustainable projects; and
- develop approximate but good enough solutions to community needs that are flexible and adaptive to change rather than the traditional definite, rigid, and ultimately inappropriate long-term solutions.

The development projects discussed in this book are assumed to take place in the context of developing *communities*, and not necessarily communities in developing *countries*. The terms "developing" and "developed" are controversial in the development literature and are ill-defined. Taylor et al. (2012) bypass that debate entirely by skillfully stating that "all communities are developed and are always developing in an ongoing, contextualized context."

Approaching community development projects with an engineering perspective involves a certain amount of modeling. This may consist of modeling the current state of a community or some of its components and predicting how it may react in the future if certain interventions are implemented. It should be noted that in science and engineering, modeling tools, whatever they are, always have limitations. Even though the systems approach to community development and the system dynamics models presented herein may appear to be more realistic and holistic than traditional reductionist ones, they also have their own limitations since they are created by individuals like you and me who are hampered by inherent bounded rationality and who make assumptions based on how they interpret their world. In summary, "models can be no better than the modelers" (Hannon and Ruth, 2001).

It has been my engineering experience that being aware of the limitations of models is important when developing mental or conceptual models of reality. The reality considered herein is that of communities consisting of human beings, households, institutions, and other components. It should be noted that models are not an end in themselves but represent virtual representations needed to simplify the complexity of the world around us so that we can make "more intelligent" or "less stupid" decisions. The model of a community is a simplified representation of it. Furthermore, it must be kept in mind that models cannot be validated (Ford, 2010) and are never value-free (Sterman, 2000). Furthermore, their usefulness and soundness are dictated by how well they simulate reality (Forrester, 1961; Sterman, 2006). However, models can never completely match reality, especially when trying to understand the interaction of multiple social, economic, and ecological systems. Finally, as remarked by George Box, "essentially all models are wrong, but some are useful […] the approximate nature of the model must always be borne in mind" (Box and Draper, 1987). This book is about building such useful models in the context of community development and being constantly aware of their approximate nature and of the complexity of the context they are supposed to describe.

1.5 Book Content

Chapter 2 presents a quick overview of human development. It reviews the different indices of human development such as GDP, GNI, HDI, and the more recent Gross National Happiness (GNH) index developed in Bhutan. These indices are usually determined from a list of parameters (e.g., economic growth, life expectancy, literacy rate, components of quality of life and well-being) that are deemed important without much consideration for their codependency and inherent feedback mechanisms. Furthermore, most of these indices are calculated at the country scale and do not necessarily scale down at the community or household levels.

At the community level, a new integrated approach or paradigm is necessary to capture the twists and turns and the dynamic nature of development projects and the various systems at play. This chapter introduces the reader to the value proposition that communities cannot be understood as consisting of independent parts but rather as systems of systems. The chapter concludes with a discussion on sustainability which is presented as a dynamic and symbiotic equilibrium state between two major systems (i.e., a population and its environment) involving five interdependent domains (life, materials, economics, society, and spirituality) as suggested by Ben-Eli (2011). These domains are always at play at different scales (individual, household, community, region, country, and planet).

Chapter 3 gives an overview of what systems and systems thinking are and the benefits of using a systems approach in addressing complex and uncertain problems such as those found in developing community projects. It explores how the characteristics of systems (nonlinearity, adaptation, interconnectedness, etc.) express themselves in small-scale community projects. Finally, the chapter discusses how complex issues such as poverty, sustainability, resilience, health, and peace can be seen as emerging properties of the interacting parts of systems.

Chapter 4 introduces the reader to system dynamics and a methodology necessary to develop qualitative and quantitative models of reality. Emphasis is placed on defining model content (feedback loops, links, and delays) and boundaries, and the causal loop and stock-and-flow representations of systems. The chapter also explores different system archetypes and how they manifest themselves in community projects. The qualitative and quantitative dimensions of system dynamics modeling and the dynamics of group decision modeling are also discussed. The chapter concludes with a summary of additional visualization techniques that could supplement system dynamics models.

Chapter 5 describes several stock-and-flow diagrams to model the interaction of core issues that are usually operating in small-scale communities. These issues include populations, water, food, health, housing, and behavior change communication. The diagrams were developed using the latest version of the iThink/STELLA software available through isee Systems. This chapter requires the reader to have a good understanding of system dynamics modeling which can be acquired by taking four basic online training modules called *Introduction to Dynamic Modeling I and II* and *Dynamic Modeling I and II*. These modules are available (for a fee) on the isee Systems website (Chichalky, 2014).

Chapter 6 reviews the basic stages involved in the management of small-scale community development projects. It demonstrates how to use systems thinking in the different stages of project management such as appraisal, problem identification and ranking, designing solutions, planning interventions, and ultimately closing. Reflection-in-action is shown as playing a critical role in continuously assessing projects as they unfold.

Chapter 7 provides guidelines for selecting the components and modules that need to be included in system dynamics models of communities. The chapter discusses how simple but integrated system dynamics models combined with traditional methods of community development can provide valuable tools in understanding the underlying structure behind the state of a community and duplicating some of its associated behavior patterns and ongoing issues. The proposed methodology needs to consider multiple scales and multiple layers of analysis at the system, subsystem, and modular levels.

Finally, Chapter 8 draws key conclusions on major themes addressed in the book and the value proposition of using a systems approach and system dynamics tools in small-scale projects in developing communities.

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CHAPTER 2

The Systemic Aspect of Community Development

This chapter calls for introducing a systemic or integrated approach in community development. The rationale is that community development intervention is multidisciplinary and involves multiple stakeholders (insiders and outsiders) of the community. Its success depends on synergy between stakeholders, how they act in a coordinated fashion, how they frame complex problems in a multiperspective manner, and how they agree to make decisions and compromises that account for group system dynamics. Integrating systems thinking into community development can be seen as a new paradigm or mindset in the evolution of development. It is defined as development 5.0 in this chapter. This new mindset acknowledges that the behavior of a community depends on its structure and that of its components and their interactions. Sustainable practices are integral to community development in order to ensure long-term benefits. Sustainability can be seen as a dynamic equilibrium between a population and its environment; a state of a system (i.e., the community) whose behavior is defined by its structure.

2.1 Human Development

Development can mean different things to different people. In general, it represents a transformation of society through its betterment, i.e., creating a better life for all (Peet and Hartwick, 2009). It can also be seen as an "increase in capacity and competence" (Patton, 2011). Of special interest in this book, *human development* is about "creating an environment in which people can develop their full potential and lead productive, creative lives in accord with their needs and interests" (UNDP/HDR, 1990). It is also about creating *real wealth* by "tapping into the ingenuity and creativity of the poor, and enabling them to express their own hopes for their families and their communities" (Narayan, 1993). Human development is based on the core concept that "people are the real wealth of a nation" (UNDP/HDR, 2006). It is a key indicator of economic development and a prerequisite for subsequent economic growth in the form of poverty reduction, aid delivery, debt reduction, community participation, small-scale technology, and local capacity building. One of the many challenges of human development (and development in general) is its ability to sustain changes over time (Seidman and Frederick, 1992; mentioned in Lederach, 1995).

As summarized in the 2010 UNDP/HDR report, human development has the potential for expanding people's choices when combined with freedom, equity, and empowerment. This has become the dominant logic of the field of development over the past 20 years as testified by the various reports written by multilateral agencies (e.g., UN, World Bank, regional development banks, and IMF), bilateral in-country agencies (e.g., USAID, EuropeAid, and other in-country aid organizations), nongovernment organizations (NGOs and INGOs), and the private sector. These reports originated following the 1992 Conference on Environment and Development (also known as the Earth Summit or Rio Summit) and the launching of the United Nations Millennium Development Goals (MDGs) in 2000.

There is a general consensus in the development literature that over the past 100 years, and especially since 1990, consistent gains in human development have led to increased life expectancy, better health, access to education, and more democratic and stable governance around the world (UNDP/HDR, 2011, 2013). The recent MDGs report card (UNDP, 2014) shows many reasons for being enthusiastic about recent trends. Despite such gains, however, the world is still facing poverty, inequalities, and their consequences (UNDP/HDR, 2014).

Today, we still have a planetary baseline where 10% of the world's population lacks access to improved sources of clean water; 35% lacks access to improved sanitation; 15% is suffering from chronic malnutrition; 15% of adults are illiterate; 20% is without access to electricity; 35% has no access to clean cooking facilities; and 20% lacks adequate housing (UNDP/HDR, 2013). As remarked by Zoellick

(2010), "poverty remains and must be addressed. Failed states remain a major issue. Global challenges are intensifying and must be addressed." In the 2011 UN report on the MDGs (UN, 2011), it was concluded that "although many countries have demonstrated that progress is possible, efforts need to be intensified. They must also target the hardest to reach the poorest of the poor and those disadvantaged because of their sex, age, ethnicity, or disability. Disparities in progress between urban and rural areas remain daunting."

Lifting billions of people out of poverty through economic and human development calls forth the development of innovative strategies and a new mindset in using available and limited resources more wisely than ever before. A new model of dynamic interaction between a population and the carrying capacity of the environment it depends on originated from a 1987 report by the Brundtland Commission entitled *Our Common Future* and published by the World Conference on Environment and Development (WCED, 1987). The report introduced the concepts of *sustainability* and *sustainable development* and emphasized that it is impossible to separate economic development issues from environmental and social issues as the three are interconnected. The report called for a new era of international economic growth: "growth that is forceful and at the same time socially and environmentally sustainable" (WCED, 1987).

The recommendation of the WCED led to the Conference on Environment and Development (also known as the Earth Summit or Rio Summit) organized by the United Nations in Rio de Janeiro, Brazil, in June 1992. The summit concluded that we are living in a world in which human populations are more densely populated, consume more, are more connected, and in many ways are more diverse than at any time in history. They also noted that many of our living systems and cultural systems are in jeopardy as the increasing population results in a reduction in biodiversity, an increase in ecological stress, and, in general, an impoverishment of life on Earth. According to the *Global Footprint Network* (Borucke et al., 2012), the ecological footprint of humanity has exceeded the carrying capacity of the planet by 50%; that is, on average, we are using annually the equivalent of 1.5 planets for the resources we need and the disposal/absorption of our waste.

As reinforced in the subsequent 2012 Rio+20 summit (UN, 2012a), the dynamic between populations and their environments is even more at play today within the context of an overall population exceeding 7 billion, increasing at an annual rate of 1.1%, and expecting to reach 8 billion by 2025, 9.6 billion by 2050, and 10 billion sometime between the years of 2085 to 2100 (UN, 2012b). It should also be noted that most of the population growth over the next 40 to 50 years is likely to occur in the developing world and in cities and megacities which will create unprecedented demands for energy, food, land, water, transportation, materials, waste disposal, earth moving, public health care, environmental cleanup, telecommunications, and infrastructure (NRC, 2014).

In order to keep up with the demand of the world's population, it is estimated that food production worldwide will have to increase by 50 % by 2030 and 75% by 2050 which will double the demand for water (UNDP/HDR, 2011) as populations adopt a more affluent diet of meat and dairy. Rapid urbanization in cities and megacities in the developing world, areas that do not have adequate basic infrastructure to start with and cannot keep up with the demand, represents a formidable challenge in guaranteeing a quality of life for all while maintaining individual and community security. Dense, complex, connected, and overcrowded urban environments may be more efficient in providing resources to a given population if well governed and with proper resources available. However, they may also be breeding grounds for messy and complex urban conflict situations if overstressed, poorly managed, and unable to provide basic services and resources to their constituents (Liotta and Miskel, 2012; Kilcullen, 2013).

Due to population growth and the current and forthcoming demand from hundreds of millions of new customers in emerging markets such as China and India within the next 20 to 30 years, stress on the environment and on our natural resources is expected to increase in the near future and will be more damaging to the Earth's human population and its life-support systems than ever before (Meadows et al., 2004). The resulting environmental degradation will not only be a problem for industrially wealthy nations which have opportunities to adapt, but it will also become a major issue for developing countries as they become trapped in a downward spiral of ecological and economic decline and become more vulnerable to hazards. Today, more people than ever are exposed to adverse events and conflicts at the local, regional, and national levels because of overpopulation, limited resources, natural hazards, variations in climate change, rogue economic development, and geopolitical issues that often do not respect geographical boundaries. As remarked in the UNDP/HDR (2011) report, the combination of (1) everyday events and other uncontrollable events with (2) the inherent isolation, powerlessness, physical and psychological weakness, and precarious livelihood associated with poverty creates a *double burden* for the world's most disadvantaged people. In turn, the lack of security resulting from this increased vulnerability creates ill-health, less access to natural resources as sources of income, endangered livelihoods, and a less secure world.

The challenges faced by humanity can be summarized as follows:

- How to educate a global community?
- How to feed a global community?
- How to power a global community?
- How to safely hydrate a global community?
- How to communicate and connect in a global community?
- How to create a peaceful global community?

These overarching, broad, and seemingly insoluble issues involve multiple stakeholders and are interconnected. Addressing these multidisciplinary issues requires adopting a new system-based mindset at all levels of decision making.

Since its inception at the Rio summit in 1992, sustainable development has been presented as an alternative to development as usual and a potential road map for a better planet for all. The discussion has centered around the questions whether mankind can (i) stay within the limits of its available resources, life-support systems, and carrying capacities; and (ii) avoid or minimize irreversible long-term negative environmental, economic, and social consequences in future production–consumption models that could impact developed and developing countries alike. Answering these two questions requires that two concepts of human development and sustainable development are seen as closely intertwined. It is clear that one cannot talk about creating a sustainable planet without including human development, and vice versa. Both concepts have been regrouped under *sustainable human development* as suggested in the 2011 UNDP/HDR report: "Sustainable human development is the expansion of the substantive freedoms of people today while making reasonable efforts to avoid seriously compromising those of future generations." Of additional interest in the 2011 UNDP/HDR report is the integration of sustainable practices and human rights into human development.

Even though the concept of sustainable human development may sound like a Utopian ideal at first, we need to realize that no other alternatives have been proposed to replace the current dysfunctional global mindset which benefits the 1 to 2 billion richest segments of the world and ignores the rest of humanity (4–5 billion), mainly the poor. These two groups are by definition interrelated and cannot operate separately from each other in a global economy. As noted by John F. Kennedy (1961), "if a free society cannot help the many who are poor, it cannot save the few that are rich."

2.2 Models and Measures of Human Development

Development is a global concept that involves many interacting systems (human, infrastructure, natural, capital, and economic) constrained by multiple issues (economic, social, cultural, political, ethical, security, and environmental). The challenge in the development world has been to come up with a measure of development that can (i) capture the complex interaction and interdependence of these systems; and (ii) be useful enough to classify countries or economies beyond the mere concept of economic growth.

World Bank Measures

Over the past 50 years, the World Bank has used the gross national product (GNP), the gross domestic product (GDP), and more recently the gross national index (GNI) as metrics of the economic health and well-being of nations. The GNI of a country is "the total domestic and foreign output claimed by residents of a country, consisting of GDP plus factor incomes earned by foreign residents, minus income earned in the domestic economy by nonresidents" (Todaro and Smith, 2011). The GDP, GNP, and GNI are based on the concept that economic growth is the main measure of development and are often expressed in U.S. dollars per capita.

Every year, all 188 World Bank member countries and all other economies with populations of more than 30,000 (214 in total) are divided into three groups based on GNI per capita. The most recent classification (World Bank, 2014 a, b) divides economies into low income (< $1,045); middle income ($1,045–$12,746); and high income (>$12,746). Low- and middle-income economies are often regrouped as *developing economies*, despite reservations and intense discussion as to the relationship between income and the status of development.

Over the past 20 years, the World Bank measures of development have received much criticism. It has been emphasized that GDP, GNP, and GNI do not necessarily translate in a measure of progress since they only reflect increased spending of a nation, whether that spending is good or bad. They ignore the social and environmental costs and externalities associated with growth, and therefore can be a misleading measure of progress and well-being. Furthermore, as noted by Max-Neef (1995), "for every society there seems to be a period in which economic growth (as conventionally measured) brings about an improvement in the quality of life, but only up to a point – the threshold point – beyond which, if there is more economic growth, quality of life may begin to deteriorate." In other words, beyond a certain point of economic growth measured in terms of GDP, GNP, or GNI, the quality of life needs to become of a higher priority in development.

In order to address the aforementioned concerns, an alternative index, called the *Genuine Progress Indicator* (GPI), was introduced in the 1990s as a new measure of economic well-being of a nation to address whether economic growth benefits people. Its calculation starts with the same consumption-related data of the GDP and GNP, but excludes activities that are harmful to the environment and its people. These activities include resource and natural capital depletion; social issues such as crime; family breakdown and reduced quality of family life; pollution and its effect on environmental health; erosion of farmland; and loss of wetlands, among others. The GPI also adjusts the contribution of certain activities that lead to more equitable income and resource distribution and the contribution of activities such as household work and volunteer work. Needless to say, the GPI has been a topic of intense discussion among different groups of economists. Furthermore, it has only been promoted in a limited number of developed countries, such as the United States, Canada, and some EU countries.

Human Development Index

The *human development index* (HDI) was developed by the UNDP in 1990 and recognizes that people and their capabilities are key criteria in assessing the level of development of a country. The HDI is calculated as the *geometric mean* of three subindices corresponding to three dimensions of human development: (i) a long and healthy life in terms of life expectancy; (ii) access to knowledge and education in terms of literacy rate and school enrollment; and (iii) a decent standard of living in terms of GDP per capita at purchasing power parity.

The most recent values of the HDI for 187 countries based on 2013 data were released in the 2014 UNDP/HDR report. The HDI values range between a maximum of 0.944 (Norway) and a minimum of 0.337 (Democratic Republic of Congo and Niger), with a worldwide average of 0.702. According to the UNDP, countries fall into four categories based on the value of their HDI: Very High Human Development, High Human Development, Medium Human Development, and Low Human Development. The last two categories are somewhat folded into a broader category of *developing countries* with an HDI of 0.7 or less.

The HDI can be seen as a step up from the World Bank metrics (GDP, GNP, GNI) in addressing human development issues. Since 2010, it has been supplemented by three additional indicators to address the more specific issues of inequalities, gender, health, education, and living conditions (UNDP/HDR 2010):

- The *inequality adjusted human development index* (IHDI) which accounts for inequalities in the three dimensions that enter into the calculation of the HDI;

- The *gender inequality index* (GII) which is a "composite measure reflecting inequality in achievements between women and men in three dimensions: reproductive health, empowerment, and the labor market"; and
- The *multidimensional poverty index* (MPI) which incorporates three critical dimensions of human development: (i) health (nutrition and child mortality); (ii) education (years of schooling and children enrolled); and (iii) living conditions (availability of cooking fuel, toilet, water, electricity, floor type, and assets).

Values of the IHDI, GII, and MPI have been determined annually for all 187 countries since 2010. The most recent values can be found in the 2014 UNDP/HDR report.

Gross National Happiness Index

As early as 1972, the country of Bhutan recognized the importance of simultaneously addressing individual, community, and country well-being and introduced the concept of *Gross National Happiness* or GNH (Ura et al., 2012). It measures "the quality of a country in more holistic way [than GNP] and believes that the beneficial development of human society takes place when material and spiritual development occurs side by side to complement and reinforce each other." The GNH recognizes that happiness is more than the subjective well-being of an individual and includes other dimensions related to the collective well-being of others (i.e., the community and country). It also includes "serving others, living in harmony with nature and realizing our innate wisdom and the true and brilliant nature of our minds."

A GNH index has been introduced as a multidimensional measure of quality of life and well-being. It was originally based on four basic pillars (sustainable and equitable socioeconomic development; preservation and promotion of cultures; environmental conservation; and good governance) which have recently been folded into nine interacting domains (Table 2.1). In turn, the domains are measured using 33 indicators and 124 variables.

Table 2.1. The nine interacting domains and 33 indicators involved in calculating the Global National Happiness (GNH) index.

Domains	Indicators	Weight %	Domains	Indicators	Weight %
Psychological well-being	Life satisfaction	33	**Time use**	Work	50
	Positive emotions	17		Sleep	50
	Negative emotions	17	**Good governance**	Political participation	40
	Spirituality	33		Services	40
Health	Self-reported health	10		Govt. performance	10
	Healthy days	30		Fundamental rights	10
	Disability	30	**Community vitality**	Donation (time, money)	30
	Mental health	30		Safety	30
Education	Literacy	30		Community relationship	20
	Schooling	30		Family	20
	Knowledge	20	**Ecological diversity & resilience**	Wildlife damage	40
	Value	20		Urban issues	40
Cultural diversity & resilience	Zorig chusum skills (Thirteen arts & crafts)	30		Responsibility toward environment	10
				Ecological issues	10
	Cultural participation	30	**Living Standard**	Per capital income	33
	Speak native language	20		Assets	33
	Driglam Namzha (Etiquette)	20		Housing	33

Source: From Ura et al. (2012), The Center of Bhutan Studies.

The GNH index is a weighted average that varies between 0 and 1. All nine domains are equally weighted. As shown in Table 2.1, the 33 indicators have different weights depending on their level of subjectivity and reliability: “the subjective and self-report indicators have lighter weights and the indicators which are anticipated to be more objective and/or more reliable have relatively higher weights when the domains mix subjective and objective indicators” (Ura et al., 2012). Based on the value of the GNH index, citizens of a country are classified based on their level of achieving sufficiency in the nine domains: unhappy (less than 50% sufficiency); narrowly happy (50%–66% sufficiency); extensively happy (66%–77% sufficiency); and deeply happy (more than 77% sufficiency). A more recent version of that classification is to use the 66% sufficiency achievement as the happiness threshold between *not-yet-happy* (below 66%) and *happy* (above 66%). As an example, the GNH of Bhutan in 2010 was 0.704 with 41% of its citizens being happy and 59% not-yet-happy.

The GNH concept truly captures the multidimensional and systemic nature of development at different scales (individual, household, district, and national) and acknowledges that these scales interact all the time. It departs greatly from the traditional concept of the economic pyramid (Prahalad and Hart, 2002) and does not introduce a poverty line based on sufficient income; in fact, it skips the concept of poverty altogether. It should be noted that the GNH concept was introduced within the context of the country of Bhutan and the policies that the government of Bhutan has prioritized since 1972.

The GNH was a subject of discussion at the 2012 United Nations High Level Meeting on Happiness and Well-Being and the Rio+20 conference (Helliwell et al., 2012; Royal Government of Bhutan, 2012). It can be seen as an alternate measure of development that goes well beyond the traditional economic growth paradigm. Since 2012, the GNH has served as a possible model and source of inspiration to various government interested in integrating subjective well-being and happiness into their national policies (Helliwell et al., 2015).

From Global to Local

Except for the GNH, the development metrics mentioned above describe the level of development at the country level but fall short of capturing an adequate snapshot of development at smaller scales (regional, community, and household). Nevertheless, we must acknowledge that indices such as the HDI and its subcomponents are steps in the right direction in measuring human development and encompass a large number of separate parameters that define human development at a large scale. It is not clear, however, how the relationships between the various parameters that enter into the indices and their synergy are accounted for.

Essentially, all development metrics consist of, to paraphrase Richmond (2004), a weighted "laundry list" of parameters assumed to operate independently of each other, acting in one cause-to-effect direction (linear causality), and with no information feedback mechanism. A more powerful way to measure sustainable human development would be to relate the overall behavior of a system (i.e., a country, a region, or a community) to its internal structure while accounting for the links and influences between the components of the system; a type of thinking referred to as *operational thinking* by Richmond (1994).

Finally, the global development metrics such as GDP, GNI, and HDI may be useful to economists, policy makers, and development agencies, and they can help shape global initiatives such as the MDGs and the upcoming sustainable development goals or SDGs (UN, 2014). However, these existing metrics are of limited value to development practitioners interested in implementing local solutions at the community level. Compared to the GDP, GDI, and HDI, the GNH is a much better index to determine places of intervention at the community, or even regional or national levels.

2.3 Community Development

Community development calls forth a thorough understanding of what a community is, how it interacts with other communities, and how individuals and households interact under its overall structure. Systems thinking provides a unique approach to understanding the adaptive complexity and uncertainty of communities and their components (USAID, 2014). Let's start first with what a community is and follow up with a discussion of the attributes of community development. We conclude with why systems tools are indeed more appropriate in modeling community development.

Community

The term "community" can be defined as an assembly of interacting households and individuals with a mutual sense of belonging and common interests. It can be seen as a place of social interaction, connection, and participation; a grouping of individuals who feel a mutual sense of belonging; and a system designed to attain some goals (Hillery, 1964). In general, we all belong to and interact with many communities of importance in our daily lives, whether they are geographical communities, communities of identity (i.e., sharing common interests), or issue-based communities (i.e., defined around common causes or issues). In general, communities:

- consist of various components (social, economic, institutional, environmental, etc.) that all interact in complex and uncertain ways;
- consist of interacting units called households;
- interact with other communities at the local, regional, or global scale;
- manifest all the attributes of complex dynamic systems (e.g., nonlinearity, emergence, uncertainty, and synergy where the behavior of the whole can be quite different from that of its components);
- possess capacity (strength), resources, assets (capital), and knowledge;
- show some form of spirit, engagement, cohesion, and collective action (social capital); and

- have household security needs and are vulnerable to a variety of adverse events ranging from everyday issues to large disaster events, each one carrying a certain level of risk for the community.

In other words, communities are complex, open, adaptive, and dynamic social organizations with their own unique characteristics, security needs, challenges, and potential solutions to their own problems. We can say with a high level of certainty that no two communities are alike. Communities may have similar core issues (food, energy, health, water, jobs, etc.) but also possess specific issues that come from the dynamic interaction of their components within the constraints imposed onto them (social, economic, cultural, environmental, political, security, and ethical). When seen as organisms, communities lend themselves well to using a systems approach when addressing their development needs.

Community Development

In general, community development is a dynamic process which changes over time and has unique characteristics. According to Craig (2004, 2007), it is about (i) strengthening civil society; (ii) empowering local groups; (iii) strengthening the capacity of the community and its members; and (iv) supporting active democratic life. Community development is often synonymous to *community-based development* or *community-driven development* and closely linked to the concepts of decentralization and participation (Mansouri and Rao, 2012).

Since the 1960s, development agencies have argued about the nature of community development, and development in general. The discussion has evolved from economic aid which I am calling development 1.0, to technical assistance (development 2.0), to technical cooperation (development 3.0), to, more recently, understanding the conditions necessary for people to be more self-aware, address their basic human needs, and realize their basic human rights by "strengthening endogenous capabilities" (UNDP, 2009) through capacity development (development 4.0).

As summarized in my recent book (Amadei, 2014), community development encompasses many of the following characteristics:

- *change* in a complex, uncertain, open, adaptive, and dynamic multidisciplinary environment;
- *participation* and *integration* of various disciplines and stakeholders;
- *empowerment* (i.e., having beneficiaries sit in the driver's seat and define what development is and is not for them);
- *justice*, *equity*, *equality* (social power, income, wealth, opportunity), and protecting human rights;
- *freedom* to find meaningful solutions;
- *finding common ground* between bottom-up and top-down approaches; and
- *strategies* that empower not only the community but also the individual, the private sector, the state and the public sector, and the household.

More specific tasks in community development involve connecting the different components of a community in order to:

- promote social change by building on existing community strengths and encouraging meaningful behavior change (Kretzmann and McKnight, 1993; Taylor et al., 2012);
- create partnerships to identify the solutions (technical and nontechnical) that best match the community development level and the community capacity;
- bring the community to a higher level of development through education while spearheading social entrepreneurship, infrastructure, health, and economic growth through capacity building; and at the same time assuring the respect of human rights; and
- develop solutions that link development with various sectors including technology, public health education, poverty, gender, security, policy, governance, etc.

Finally, community development can also be seen as a place for transformation (Korten, 1981; Sen, 1999; Silver, personal communication, 2011) that drives the community as a system to embrace a new vision or mindset for itself. The transformation can be seen at four interrelated levels: (i) *personal* by ensuring freedom, empowerment, liberation from oppression and poverty; (ii) *household* by meeting basic human needs at the household level; (iii) *community* by respecting cultural heritage, diversity, and inclusivity and building self-reliance; and (iv) *community of life* by adopting a multigenerational approach toward the population and the environment.

A Holistic Approach

The above discussion emphasizes first that community development is multidisciplinary and therefore requires a systemic or integrated approach rather than a piecemeal one. After all, healthy communities are open and adaptive complex systems, which consist of parts and the interaction between parts, are driven by a vision or mindset of livelihood and well-being, and operate under certain rules. This important observation implies that all tools used in the phases of community development need to be sensitive to the systemic nature of communities. This influences (i) how a community appraisal is carried out in order to develop a community baseline; (ii) how community problems are identified and prioritized from analysis of the appraisal; (iii) how solutions to the problems are developed, planned, and implemented; and (iv) how the solutions are designed to be long lasting (i.e., sustainable).

Integrating systems thinking into community development can be seen as a new step in the evolution of development work (*development 5.0*) which builds on the previous step of capacity development (development 4.0). It sees a community as a system of systems rather than an assembly of independent objects and subjects. It also acknowledges that the behavior of the community depends on its structure, its components, the relationships between these components, and the environment in which component interactions take place.

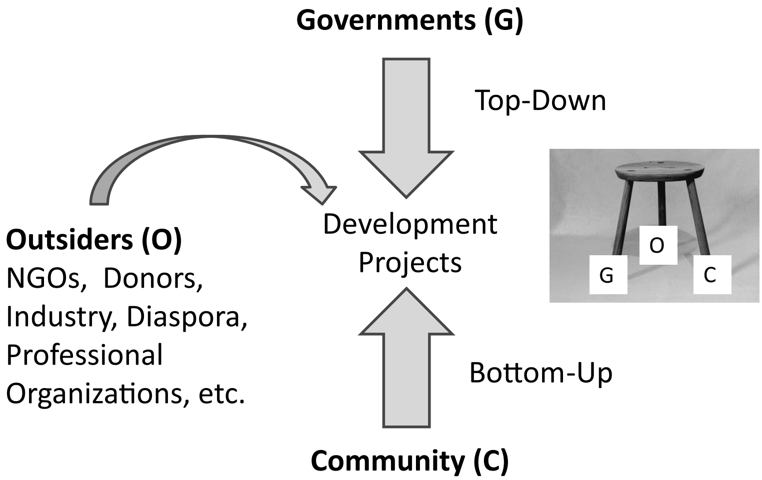

Figure 2.1. A collaborative framework for community development involving a combination of bottom-up, top-down, and outside-in contributions. Community development is seen as a three-legged stool involving the community (C), governments (G), and outsiders (O).

The aforementioned discussion also shows that any community development intervention must include the combined input of many stakeholders who are insiders or outsiders to the community. As shown in Figure 2.1, community development consists of a three-way partnership as suggested by Taylor-Ide and Taylor (2002) and Taylor et al. (2012). It combines (i) a *bottom-up* approach which originates at the grassroots community level and involves individual and groups of insiders; (ii) a *top-down* approach influenced by local and national governments and in some cases corporations and large development related institutions; and (iii) an *outside-in* approach through consultancy from outsiders who bring support, resources, skills, and expertise. The dynamic shown in Figure 2.1 is necessary for development 5.0 to unfold and be successful. One cannot emphasize enough the need for collaboration and synergy between these three groups of stakeholders. When seeing community development as a three-legged stool (Figure 2.1), its stability or success depends on the strength of all three components simultaneously; a weak leg of the stool makes it unstable and development unsuccessful. Success also depends on how well the three components interact with each other and share similar visions. The stool shown in Figure 2.1 can itself be seen as a large system consisting of three equally important interacting systems which can be decomposed into further subsystems and components.

Finally, the above discussion demonstrates that development practitioners involved in community projects need to be trained to use a development 5.0 paradigm and its associated mindset when working with the three groups of stakeholders shown in Figure 2.1. Development practitioners need to show depth and breadth in their skills and knowledge and be willing to make decisions in uncertain and adaptive complex conditions where answers are not well-defined and rules of traditional project management do not always apply. These complexity-aware and system-aware individuals need to be able to combine *critical* thinking using *directive methods and tools* (i.e., a blue print and directive approach) as well as *creative* thinking using *interactive methods and tools* (i.e., an adaptive and interactive approach) (Nolan, 1998; Vaughan, 2013). At times, some tools are more appropriate than others and vary with the context in which development projects take place.

An image that I often use to explain the multidisciplinary nature of community development is to imagine a conference room where development is being discussed. The room can be accessed through multiple doors. The doors are labeled: engineering, economics, health, education, governance, etc. In the middle of the room, there are many chairs placed around a table and each chair represents a discipline involved in development. Whoever is interested in joining and contributing to the conversation by entering the conference room through one of the doors needs to not only excel in their respective skills (show depth of understanding), but they must also have a broader vision about what development is (show breath of understanding). They also need to have appropriate skills to communicate with individuals from other disciplines who have different opinions about development. Finally, all of these individuals around the table must act together in a coordinated and synergistic fashion which requires being able to frame complex problems in a multiperspective manner and agreeing on making decisions and compromises that account for group (system) dynamics (Vennix 1996; Richardson and Andersen, 2010) as further discussed in Section 4.6.

2.4 Sustainability and Development

Background

Today, it is common to read in the development literature that progress in development requires the integration of sustainable practices into current and future models of human development in developed and developing countries alike (e.g., sustainable development goals, UN, 2014). In the developed world, the challenge of development has been, and still is, to consume less and more intelligently with less disruptive forms of consumption at different scales (local, regional, national, and planetary) while being more efficient and respectful of natural and human systems.

In the developing world, the challenge of development is to ensure that current and future basic needs of people are met and that they are able to step out of poverty and live in *more* stable, peaceful, equitable, and prosperous communities, and for a long time (USAID, 2014). The solutions also need to be good to the environment and the people without duplicating the mistakes made by the developed world over the past 150 years.

It is becoming clear that exporting the past and current Western dysfunctional production–consumption model of economic growth (based on take, make, and waste) to millions of people in the developing world, especially those in emerging markets, would jeopardize their growth by trapping them into a downward spiral of ecological and economic decline and condemning them to dysfunctional social consequences. Nothing prevents, however, the developing world from leapfrogging from survival to healthy market economies without repeating those mistakes, while "constructing new development pathways that place much less strain on the global environment" (Ewing et al., 2010). Short of that, the planet will never recover from the additional demand and consumption placed upon it by a burgeoning population. Meeting that challenge obviously assumes that the developing world has an opportunity to do so, is given a "right to develop meaningfully" and that conditions are in place for development to take root such as equity, rules of law, and democracy, among others. In the context of the developing world, development is about creating the stage for real or authentic wealth enhancement rather than fuzzy poverty reduction.

The concepts of sustainability and the associated process toward sustainability, also known as sustainable development, originated shortly before the Rio summit in 1992 and became main stream following that event. It is generally agreed upon that sustainability is characterized in harmonizing three basic elements: people, planet, and profit (the three P's) or equity, environment, and economics (the three E's). This is often referred to as the *triple-bottom line* and is often represented as three overlapping circles, one circle for each of the three E's or P's.

The triple-bottom line acknowledges the intimate interaction and balance that exist between society (the anthrosphere), the environment (biosphere, lithosphere, atmosphere, and hydrosphere), and economic/financial (capital and production) systems. The following definition of sustainability, approved by the board of the American Society of Civil Engineers (ASCE, 2013), captures well the interplay between the three E's or three P's as: "a set of economic, environmental and social conditions [or states] in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely, without degrading the quantity, quality or the availability of natural, economic and social resources."

A key document from the 1992 Rio meeting was a 600-page summary of 2,500 sustainable issues and recommended solutions, also known as Agenda 21 (UNCED, 1992). It has been seen as a plan of action and a road map for how people could meet their needs while simultaneously nurturing and restoring the environment. In the developed world, sustainability has been embraced, at least *in theory*, by all sectors of the economy (public, private, academia, and government) and has been presented as a radical new platform of opportunities for research, education, technology, and business. It has also been acknowledged that actions need to be undertaken worldwide in order to accelerate progress in a transition toward sustainability in the near future.

Despite that enthusiasm, the sustainability movement has been very slow in grounding itself into the real world over the past 20 years and has sometimes been a source of controversy in some political and economic circles. For developed countries, integrating sustainability into economic and human development is still perceived by many as an option, although its value proposition is gaining ground. For developing countries, however, integrating sustainable practices into their current and future development plans at multiple scales (local, regional, and national) is an obligation since it is more about their long-term survival. Unfortunately, this is not always perceived that way by decision makers in developing countries who are preoccupied with "catching up" economically with the rest of the world.

The Five Domains

Sustainability is a difficult concept to grasp and is "more of a guiding principle to be applied heuristically than a scientific concept waiting for a strict definition" (Rotmans and deVries, 1997). It is not clear what the attributes of sustainable systems, structures, or communities are. As human beings, we may have an idea of what we want to sustain such as the natural environment, the human race, and the built environment, but we still have questions about over the temporal and physical scales of such projects. More recently, major issues such as the economic crisis in 2008, climate change, and international conflicts have made it even more difficult to identify what we want to sustain. As a result, it has been proposed that the concept of resilience—being able to cope with change and adapt to a new normal—might be a more appropriate concept to address than sustainability (Benson and Craig, 2014). Other questions arise as to the quantification and measurement of sustainability and how sustainability practices express themselves in different contexts and at different scales in the developed and developing world (Wallace, 2005; ISI, 2012; FIDIC, 2013).

Seeing sustainability as harmonizing people, planet, and profit (the three E's or three P's) does not go far enough in capturing the dynamic and systemic interaction between people and their environment; it is too static of a concept and does not allow for any change or adaptation over time. A more holistic and practical concept of sustainability, which fits better with the systems approach to development suggested in this book, was proposed by USAID (2014) where "sustainability refers to the ability of a local system to produce desired outcomes over time. Discrete projects contribute to sustainability when they strengthen the system's ability to produce valued results and its ability to be both resilient and adaptive in the face of changing circumstances."

Another pertinent definition was proposed by Ben-Eli (2011, 2012), where sustainability is seen as an *organizing principle*, and "a dynamic equilibrium in the processes of interaction between a population and the carrying capacity of an environment such that the population develops to express its full potential without adversely and irreversibly affecting the carrying capacity of the environment upon which it depends."

This cybernetics type of definition recognizes the dynamic and time-changing nature of sustainability and the intimate link and interaction that exist between human development and the preservation (i.e., carrying capacity) of the environment that populations depend on. Figure 2.2 shows a two-way causal loop representation of that interaction which describes a system consisting of the two subsystems of population and the environment. The dynamic of the population is controlled by its growth rate. As the population grows, its level of activity increases which demands access to natural resources (renewable and nonrenewable) and generates byproducts in the form of waste. In turn, the carrying capacity of the environment affects the population's well-being and its levels of fertility and mortality. As remarked by Ben-Eli, the population and environment subsystems *hold each other in check* through a *cocreative* (or *coevolutionary*) process characterized by multiple closed-loop interactions. Hence, sustainability is not just about preserving humans and their activities. It is also about stewardship: that is, preserving (or even enhancing) the natural environment and the eco-services it provides.

According to Ben-Eli (2011, 2012), sustainability should be seen as a "particular *system state* born by a particular underlying structure" that dictates its behavior. He introduces five core principles of sustainability that are associated with five *interrelated* fundamental domains (Figure 2.3) that play an active role in the feedback mechanism shown in Figure 2.2. They include the following:

1. The *material domain* (flow of energy and materials, infrastructure) Core principle: "Contain entropy and ensure that the flow of resources through and within the economy, is as nearly nondeclining as permitted by physical laws."

2. The *economic domain* (creating and managing wealth)
   Core principle: "Adopt an appropriate accounting system, fully aligned with the planet's ecological processes and reflecting true, comprehensive biospheric pricing to guide the economy."
3. The *life domain* (biosphere)
   Core principle: "Ensure that the essential diversity of all forms of life in the biosphere is maintained."
4. The *social domain* (social interactions)
   Core principle: "Maximize degrees of freedom and potential self-realization of all humans without any individual or group, adversely affecting others."
5. The *spiritual [or value] domain* (code of ethics)
   Core principle: "Recognize the seamless, dynamic continuum [of] mystery, wisdom, love, energy, and matter..."

Each domain in Figure 2.3 consists of multiple components that are also interrelated. According to Ben-Eli, all five domains need to be considered in any sustainable development plan.

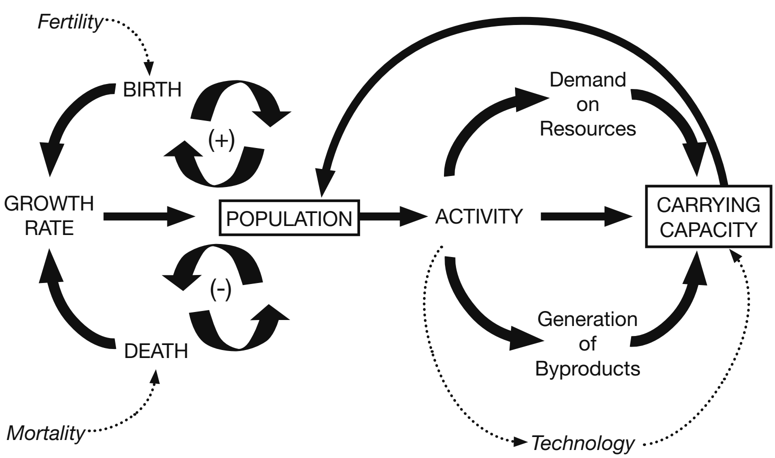

Figure 2.2. Causal loop diagram representing the interaction between a population and the carrying capacity of the environment. The population affects the carrying capacity of the environment and the latter affects the population.

Source: Reproduced with permission from Ben-Eli, The Sustainability Laboratory, 2011.

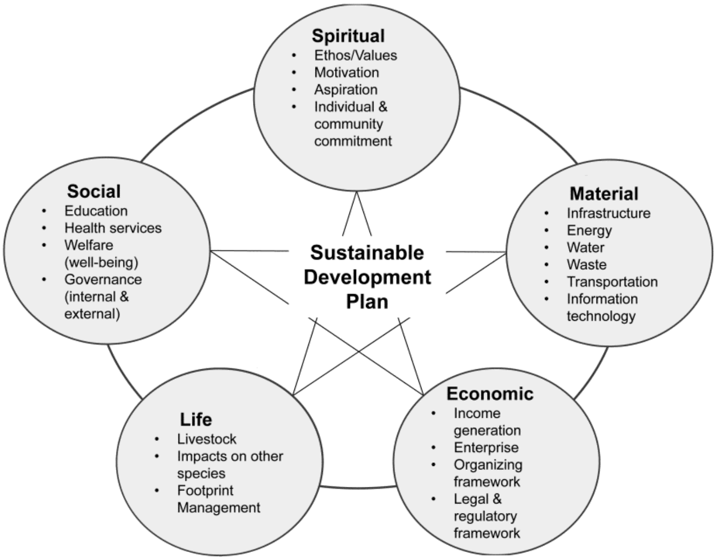

Figure 2.3. The five interrelated fundamental domains of sustainability that need to be considered in a sustainable development plan.

Source: Reproduced with permission from Ben-Eli, The Sustainability Laboratory. Presented by Ben-Eli at the 2014 Global Sustainability Fellows Program at Earth University in Costa Rica.

As noted by Ben-Eli (2011, 2012), the five core principles of sustainability can be summarized as "contain entropy; account for externalities; maintain diversity; self-actualize benignly; and acknowledge the mystery." For each domain and associated core principle, a set of policy and operational implications can be outlined (Table 2.2). Ben-Eli's definition of sustainability and the five domain sustainability framework lend themselves well to a systems approach to sustainable community development which can be applied at different physical scales (individual, household, community, regional, and national) and over time.

Figure 2.4 illustrates an example showing how the five aforementioned domains are linked at the community level for the neighborhood in Costa Rica mentioned at the start of Chapter 1. This figure describes several cause-and-effect loops at play in that neighborhood. They all converge to a main goal which is to improve the quality of life of the neighborhood. Figure 2.4 also shows the role played by social and health dynamics, the dynamics between the neighborhood and the public sector, and the link between women's education and economic opportunities in contributing to improving the quality of life.

Table 2.2 Policy and operational implications for each domain and associated core principles of sustainability

Domains	*Policy and Operational Implications*
Material	• Strive for highest resource productivity • Amplify performance with each cycle of use • Employ "income rather than capital" sources and continuously recycle non-regenerative resources • Affect an unbroken closed-loop flow of matter and energy in a planetary productive infrastructure conceived as a whole • Control leakages and avoid stagnation, misplaced concentrations or random diffusion of chemical elements during cycles of use • Establish a service "performance leasing" orientation for managing durable goods
Economic	• Employ a comprehensive concept of wealth related to the simultaneous enhancement of five key forms of capital: natural, human, social, manufactured, and financial • Align the world's economy with nature's regeneration capacity and incorporate critical "externalities" in all cost and benefit accounts • Design regulation and taxation policies to accentuate desirable and eliminate adverse outcomes, optimizing the whole • Rely on market mechanism, calibrated to reflect "true" costs, for allocation of capital assets
Life	• Assume a responsible stewardship for our planet's web of biological diversity • Harvest species only to regeneration capacity • Conserve the variety of existing gene pool • Shape land use patterns to reduce human encroachment on other forms of life and enhance biological diversity in areas of human habitat
Social	• Foster tolerance as a cornerstone of social interactions • Enhance universal rights within a framework of planetary citizenship • Provide for inclusion and effective democracy in governance • Ensure equitable access to life-nurturing resources • Establish cooperation as a basis for managing global issues and planetary commons • Outlaw war and trade in weapon technologies • Promote sustainability literacy through education at all levels • Embody sustainability enhancing concepts in an effective planetary framework of legislation

Domains	*Policy and Operational Implications*
Spiritual	• Acknowledge the transcendent mystery that underlies existence • Seek to understand and fulfill humanity's unique function in universe • Honor the Earth with its intricate ecology of which humans are an integral part • Foster compassion and an inclusive, comprehensive perspective in the underlying intention, motivation, and actual implementation of human endeavors • Link inner transformation of individuals to transformation in the social collective, laying foundations for emergence of a new planetary consciousness.

Source: Reproduced with permission from Ben-Eli, The Sustainability Laboratory, 2011.

It should be noted that Figure 2.4 was created in a participatory manner using group model-building methods (Vennix, 1996; Richardson and Andersen, 2010) through interviews of women who lived in the neighborhood. These women had no prior knowledge of systems thinking and system dynamics modeling. Development workers used causal links (arrows) and feedback loops to capture how women explained the issues faced in their neighborhood and how they perceived their interactions. Double parallel lines crossing the arrows in Figure 2.4 represent possible time delays in the causal links.

Viability Loops in Community Development

Using causal loop diagrams, such as the one shown in Figure 2.4, to model the connection between humans and their environment in community development can assist with understanding the consequences associated with disturbing parts of the systems. It can also help in emphasizing the importance of certain causal loops that are more critical than others. These loops were defined as *viability loops* by Hjorth and Bagheri (2006). They are "responsible for the viability of all ecosystems including human based ecosystems" and can be regrouped into four categories: human needs, economic capital, the environment, and life-support structures. They are critical in maintaining the balance between humans and their environment if sustainability is to be achieved. According to Hjorth and Bagheri (2006) sustainable development can be seen "as the process in which the viability loops are kept functional . . . and in a healthy state."

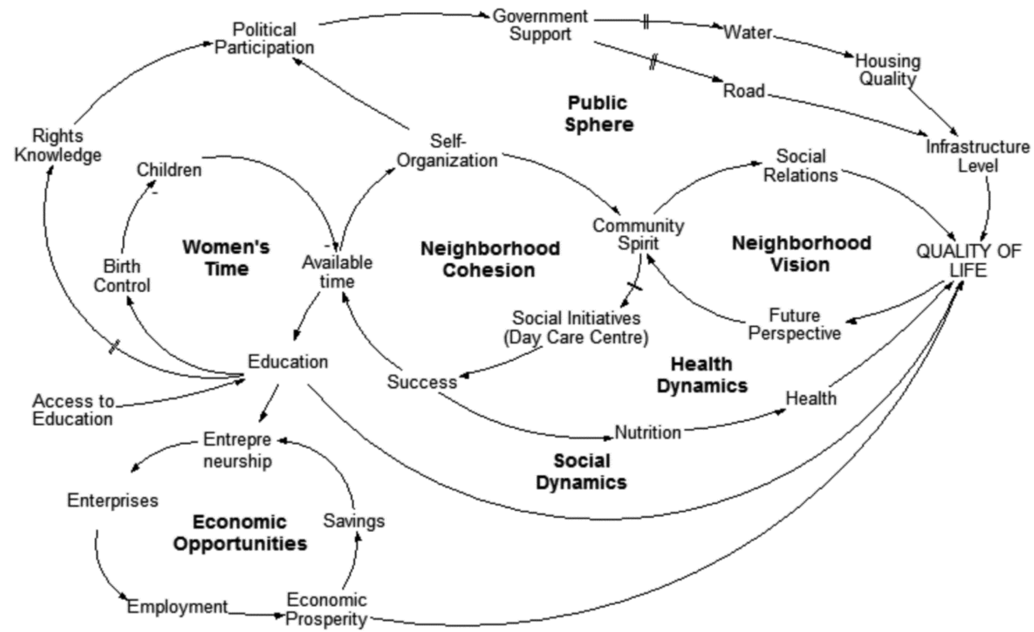

Figure 2.4. Causal loop diagram showing several cause-and-effect loops at play in a neighborhood. They all converge to a main goal which is to improve the quality of life of the neighborhood.

Source: Developed by students in the 2014 Global Sustainability Fellows program conducted by the Sustainability Laboratory at Earth University in Costa Rica.

Disturbing viability loops, intentionally or not, may lead to major unintended consequences for the entire system. An example is what would happen when exceeding the carrying capacity of the environment as illustrated in the *tragedy of the commons* (Figure 4.5). This archetype is often used in the sustainability literature to describe the diminishing return associated with individuals in a group sharing a common resource independently of each other (unmanaged commons), but each consuming the resource without consideration for the collective good (Hardin, 1968).

As a result, viability loops need to be protected in community development. They are the life-lines of natural systems and human systems and the basic components that contribute to system resilience. Representing the interaction of human systems and their environment as a system (e.g., Figure 2.2) and using causal loop diagrams, such as in Figure 2.4, can help identify ahead of time what would happen if some viability loops are disturbed and how the overall state of sustainability of the system would be affected.

2.5 Concluding Remarks

This chapter calls for introducing systems thinking into community development and development in general. Existing measures of country development, such as the GDP or HDI, are of limited use in capturing an adequate snapshot of development at the community scale. Communities are more than an assembly of components whose state could be assessed using a laundry list of independent indicators. The state of a community could not be determined even if all of its components could be individually selected without due consideration for connections between the components, the shared purpose between components, their rules of behavior, and the community's interaction with its environment. At best, the state of a community can be defined subjectively as discussed in Section 2.3.

As we will see in the forthcoming chapters, a systems approach to community development can help overcome *some* of the aforementioned limitations. It can be used to understand better the relationship between community structure and its patterns of behavior. The advantage of the approaches by Ben-Eli (2011, 2012) and Hjorth and Bagheri (2006) presented in the previous section is to be able to take under consideration the multiple causal loops at play at the community level, especially the dynamic that operates between people and their environment. These loops are fundamental to understanding the current state of a community and developing an action plan to reach a more desirable state, even a state of sustainability. The use of system dynamics tools to model the link between community structure and behavior will be discussed in Chapter 7 of this book.

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CHAPTER 3

Communities as Complex Adaptive Systems

Communities are open, complex, and adaptive dynamic systems consisting of many interacting parts operating at multiple scales. A systems approach to community development is the most appropriate means to address the complexity and uncertainty inherent to these systems. It provides a tangible alternative to reductionist Cartesian thinking that sees communities consisting of independent parts having separate issues to be addressed by separate experts. Among all the systems involved in community development, human systems are the most complex, least understood, and difficult to model as they learn, grow, self-organize, evolve, and adapt. Bounded rationality is a limiting factor forcing human beings to make decisions that are not always logical and often based on incomplete understanding. This in turn has implications in the decision-making process conducted by various stakeholders involved in community projects. This chapter gives an overview of what systems and systems thinking are and the benefits and limitations of using a systems approach to address complex and uncertain problems such as those found in developing community projects. The characteristics of complex adaptive systems such as communities are also discussed. Health, wealth, peace, resilience, and sustainability can be seen as states emerging from the good functioning of multiple subsystems operating in communities.

3.1 Types of Systems

Simple, Complicated, Complex, and Chaotic Systems

According to Meadows (2008), a system can be defined as "a set of elements or parts that is coherently organized and interconnected in a pattern of structure that produces a characteristic set of behaviors, often classified as its "function" or "purpose . . . . A system must consist of three kinds of things: elements, interconnections, and a function or purpose." To this definition, we can add that a system has components that operate under certain rules that dictate their behavior. Finally, a system is always contained in an environment that it affects as well.

As discussed in Sections 1.2 and 1.3, it is clear that we live in a physical world comprised of many interacting systems operating at multiple scales from the micro to the macro (Laszlo, 2001). This picture is captured quite well in the *Power of Ten* (1977) video which shows the interconnected nature of reality, and the storybook *Zoom* (Banyai, 1998) which emphasizes the importance of using the appropriate perspective and scale when drawing conclusions about any system (Sweeney, 2001).

Figure 3.1 summarizes the various systems involved in community development. In general, a community consists of human systems interacting with other systems (natural, economic, infrastructure, and capital). The "space of possibilities" (Mitleton-Kelly, 2003) in which these interlinked systems interact is constrained by a wide range of issues (social, economic, cultural, etc.). Human systems include, for instance,

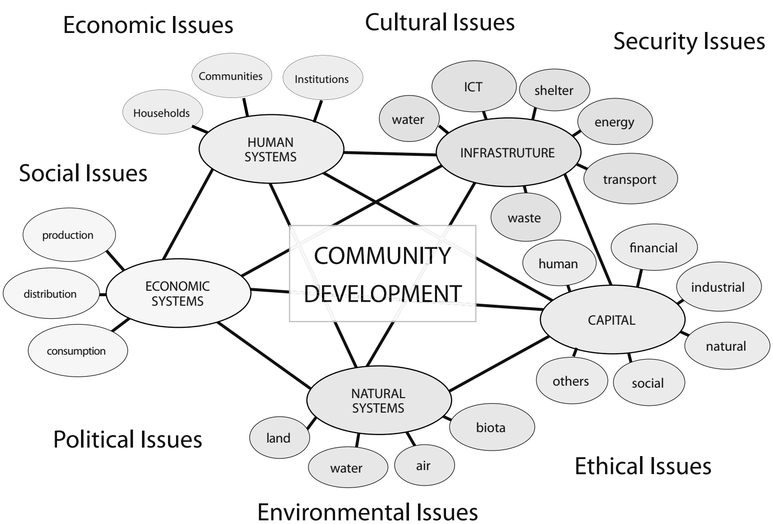

Figure 3.1. Systems involved in community development and their multiple constraints. Each group of systems consists of subsystems.

Note: A simpler version of this graph was originally proposed by Jorge Vanegas (personal communication, 2000).

households, communities, and institutions. Infrastructure systems, which could be called engineered systems, include several components such as water, telecom, shelter, energy, transportation, and waste (Labi, 2015). Likewise, the natural systems consist of the hydrosphere (water), the geosphere (land), the atmosphere (air), and the biosphere (biota). Economic and capital systems consist of many components as well. These systems can themselves be divided into interacting subsystems consisting of nested sub-subsystems, ad infinitum. Systems and subsystems interact at different physical scales which, in the case of communities, do not always coincide with their geographical boundaries: a community may interact with other groups such as neighboring communities, government agencies, and other stakeholders and partners.

The interest in complex systems represents a "new [recent] approach to science that studies how relationships between parts give rise to the collective behaviors [or states] of a system and how the system interacts and forms relationships with its environment" (Wikipedia, 2014a). Starting about 70 years ago, several researchers have tried to model several forms of behavior found in social, natural, and economic sciences that could not be explained using a traditional reductionist Cartesian approach. A systems approach was found to be more appropriate to model these forms of behavior. The study of systems is called *systems science* in the literature. An excellent map showing how systems science has evolved over the past 70 years can be found on the sociology and complexity science website (SACS, 2015). It should be noted that the scientific study of complex systems, also known as complexity science, can be seen as a subset of systems science.

In community development, systems theory can be used to understand the connections that operate between the various systems of Figure 3.1 (Ramalingam and Jones, 2008) and the emerging patterns of community behavior. It can also be used to demonstrate how the systems and their subsystems (individually or synergistically) contribute to the overall economic stability, well-being, and growth of the community through a variety of services related to commerce, education, communication, health, energy, and transportation, among others.

Systems theory helps emphasize that a community and its dependents (within and outside the community's boundaries) form some kind of an organism. This biologically inspired metaphor best illustrates that a community consists of learning, growing, and adapting components or agents (i.e., individuals, households, institutions, etc.), and that the links between these components shape the community and contribute to its dynamic functionality or dysfunctionality. Community development is not only about looking at how its components provide separate resources to the community, but it is also about looking at how its components interact and depend on each other within that organism.

In general, systems can show different levels of complexity, meaning that they can assume different states or forms of behavior; some of them defy intuition. When faced with the decision to intervene in any system, whether in one's everyday life, at the community level, or in a professional environment, it is important to identify what type(s) of system and what type(s) of system behavior is at play. In community development, some communities or subparts of a community may be more complex or show more complex behavior than others. Thus, each one needs to be addressed using strategies that best reflect the context in which their development takes place.

In a discussion on the various frameworks that executives can choose to make decisions, Snowden and Boone (2007) introduced the so-called *Cynefin* framework in which systems are divided into four groups: simple, complicated, complex, and chaotic (Figure 3.2). As discussed by Patton (2011), systems differ in (i) the "degree of certainty" with which problems can be solved and (ii) "the degree of agreement" on how to solve such problems.

Simple systems have few variables with limited relationships where certainty and predictability are common. In such systems, decision makers "know the knowns" and can come up with a right answer to a problem. An agreement can be reached on what to do about addressing the problem. This can lead to establishing best practices. Problems at the end of chapters in engineering textbooks are formulated in terms of simple systems that have a correct answer.

In *complicated* systems, the components are well-defined but their linkages are more difficult to comprehend and require the input of experts. In such systems, decision makers "know the unknowns" and a solution (but not necessarily the best) is still possible. In fact, there may be multiple good solutions to a problem which can be analyzed in a cause-and-effect manner. Patton (2011) distinguishes between technically complicated and socially complicated systems. As shown in Figure 3.2, technically complicated systems are characterized by a low certainty in solving problems but a high agreement that the problem needs to be solved. Socially complicated systems are characterized by a high certainty in solving the problem but a low level of agreement on how to solve the problem.

An illustrative example related to vaccination in a developing community proposed by Britt (2013) helps understand the difference between the two types of complicated systems: (i) a technically complicated situation would be, for instance, the delivery of vaccines to a population in a community with limited health services, but the population agrees that the vaccines are necessary; (ii) a socially complicated situation would be the delivery of vaccines in a community with good health services but with a resisting population. In general, it is easier to deal with technical complications where technical and tangible issues must be resolved than social ones where intangible issues are often dominant.

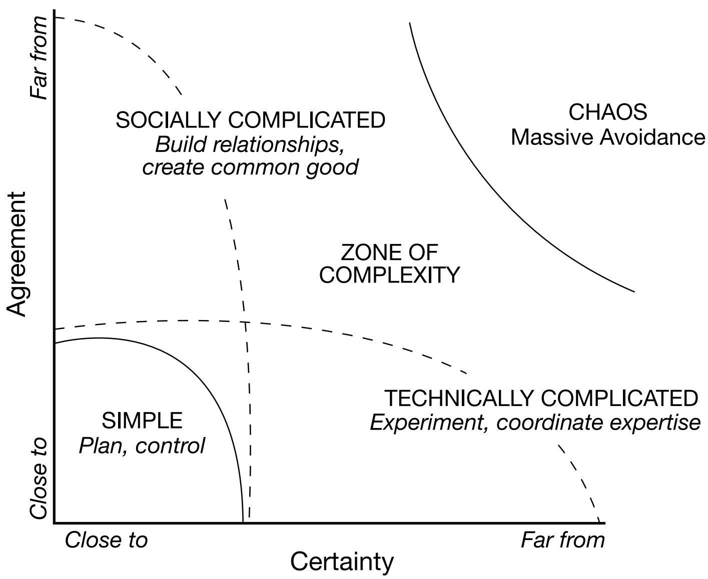

Figure 3.2. Four types of systems can be identified based on (i) the degree of certainty with which problems can be solved; and (ii) the degree of agreement on how to solve problems. Specific modes of intervention are recommended for each system type.

Source: Patton (2011). Reproduced with permission from Guilford Publications.

Complex systems differ from complicated system in the sense that we "don't know the unknowns," uncertainty and ambiguity are the norm, complex interactions take place between components of the system, causality is circular and nonlinear, all sorts of unpredictability can arise, and it is difficult to reach an agreement on how to address problems in the systems. Complexity can best be described by the meaning of its Latin root, which is "braided together" as noted by Gell-Mann (1996). It should be noted that there are multiple sciences of complexity with different approaches and lines of research as reviewed by Mitleton-Kelly (2003), Ramalingam and Jones (2008), and Mitchell (2009), among others. This book looks only at the science of *complex adaptive systems*.

As noted by Miller and Page (2007), unlike a complicated system, the behavior of a *complex system* depends greatly on the dependencies of its components; removing one element "destroys system behavior to an extent that goes well beyond what is embodied by the particular element that is removed." In general, best practices in dealing with complex systems cannot be established, but *effective*, *relevant*, and *meaningful* ones are still possible (Patton, 2011). In the vaccination example mentioned above, a complex health situation would arise if the population is opposed to vaccination and there are no health services available.

When unpredictability is amplified and extreme, complex systems become *chaotic* systems, such systems are characterized with extreme turbulence, small things can have huge consequences, and bifurcation leading to rapid change is possible. Chaotic systems can show some temporary emerging synchronicity (cohesion, convergence, or order) which may lead to additional unintended consequences and unexpected behavior (Waldrop, 1992; Kaufman, 1993). If at all possible, chaotic systems require immediate action to reestablish a reasonable sense of order. In the vaccination example, a chaotic situation would be one where (i) a contagious disease is quickly spreading among a population that is ill-informed about the importance of vaccination; (ii) no health services are available; and (iii) the population is located in an unstable area. A refugee camp situation located in a conflict setting would probably best illustrate such a chaotic situation.

These different contexts require different approaches and "situation recognition" by decision makers (Gell-Mann, 1996; Patton, 2011; Britt, 2013; Glouberman and Zimmerman, 2002). As noted by Snowden and Boone (2007), selecting an appropriate approach when assessing a system and making decisions on how to intervene in that system depends greatly on whether the system is ordered (simple or complicated) or unordered (complex or chaotic). According to Snowden and Boone, the dominant modes of intervention include *categorizing* for simple systems, *analyzing* for complicated systems, *probing* for complex systems, and *acting* quickly for chaotic systems.

Intervening in a system in a contextually appropriate manner also needs to take under consideration the temporal and physical scales (i.e., the boundaries) in which the system or its parts are operating. The decision to intervene in one part of a system and at a given scale may be different from that in another part and at a different scale. The periods of intervention may also differ. In addition to the content or the structure of a system, context and scale are two important factors that play a critical role in deciding on solutions in community development projects.

It must be noted that communities are primarily complex adaptive systems but may contain parts or subsystems that are simpler or merely complicated and for which interventions are easier to design and implement (i.e., low-hanging fruit solutions) in the short- or long-term. It is important for development practitioners to be able to make such distinctions and recognize that successful small steps can help build confidence among all project stakeholders.

Open or Closed Systems

Another way of classifying systems is to look at their mass and energy interaction with what is outside the systems. They can be:

- *isolated* with boundaries closed to import or export of both mass and energy;
- *closed* with boundaries closed to import or export of mass, but not energy; or
- *open* with exchange of both mass and energy with their surroundings.

In general, communities are open social systems from a mass and energy point of view. They may interact with their environment through exchange of goods, services, and ideas involving different forms of capital. On the other hand, from a physical and psychological point of view, developing communities (some more than others) are more likely to be closed and dependent on internal and cultural connections in order to survive.

3.2 Systems Thinking

Habits of a System Thinker

The structure of systems such as communities makes it impossible to use traditional linear reductionist (Cartesian) thinking tools and a *command* and *control* mindset (Holling and Meffe, 1996) to understand their structure and forms of behavior. Systems thinking represents a tangible alternative to reductionist thinking in order to handle complexity and uncertainty. According to Richmond (1994), "systems thinking is the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure."

Another definition, proposed by Sterman (2006), sees systems thinking as a new mindset with both depth and breadth as to how we should look at the world. Systems thinking is "an iterative learning process in which we replace a reductionist, narrow, short-term, static view of the world with a holistic, broad, long-term, dynamic view, reinventing our policies and institutions accordingly."

For Richmond (1994), systems thinking is a paradigm that provides a unique vantage point and a set of skills when looking at the world. It is also a learning method which provides a language to communicate the complexity of that world to others. Systems thinking has also been presented by Senge (1994) as the fifth discipline necessary for organizations to grow and learn. The other four include personal mastery, developing mental models, building shared vision, and team learning.

Looking at the physical world as a network or web of systems rather than a series of isolated objects and events contributes to a more holistic way of thinking in addressing a wide range of global issues (see examples in Section 1.3). Unfortunately, systems thinking is still not a mainstream approach taught and practiced in basic and higher education today except in some more progressive institutions that see systems thinking as a way of educating the future generations of global citizens. An example of transformative PK-12 education using systems thinking has been promoted by the *Waters Foundation* (2014) based in Pittsburgh, PA. Their paradigm is best reflected in their mission statement: "Our mission is to increase the capacity of educators to deliver student academic and lifetime benefits through the effective application of systems thinking concepts, habits, and tools in classroom instruction and school improvement."

Table 3.1 gives a list of what the Waters Foundation calls "habits" of a system thinker. These 14 habits can also be understood as thinking strategies (visual, listening and speaking, and kinesthetic) that a decision maker might want to follow to address complex problems. The approach used by the Waters Foundation is worth exploring further as it represents a new model of education that is more in tune with the reality of the world. It should be part of the body of knowledge of every human being and decision maker on our planet.

Table 3.1. Fourteen habits of a system thinker according to the Waters Foundation.

- Seek to understand the big picture
- Observe how elements within systems change over time, generating patterns and trends
- Recognize that a system's structure generates its behavior
- Identify the circular nature of complex cause-and-effect relationships
- Make meaningful connections within and between systems
- Change perspectives to increase understanding
- Surface and test assumptions
- Consider an issue fully and resist the urge to come to a quick conclusion
- Consider how mental models affect current reality and the future
- Use understanding of system structure to identify possible leverage actions
- Consider short-term, long-term, and unintended consequences of actions
- Pay attention to accumulations and their rates of change
- Check results and change actions if needed: "successive approximation"
- Recognize the impact of time delays when exploring cause-and-effect relationships

Source: http://watersfoundation.org/ (March 13, 2015).

Value Proposition

What is the value proposition of systems thinking? According to various authors in the literature (e.g., Richmond, 1994, 2004; Kim, 2000; Sweeney, 2001; Hjorth and Bagheri, 2006; Sterman, 2006), systems thinking helps us:

- see the world around us in wholes instead of snapshots;
- look at the world using different perspectives that may force us to step out of our self-inflicted boxes and our deeply engrained mental models;
- sense how well parts of systems work together, form structures and patterns;
- acknowledge relationships between systems components from multiple levels of perspective and circular causation rather than from cause-and-effect linear chains of reaction;
- look at events not as separate from each other but instead as parts of patterns of behavior, which themselves are created by some internal structure resulting from patterns and modes of thought;
- understand the dynamic, adaptable, unpredictable, and changing nature of life including the effect of time and delays;
- understand how one small event can influence another (positively or negatively) and the associated consequences of such interactions;
- identify leverage points in a system where actions taken yield the most return;
- understand that what we see happening around us depends on where we are in the system and our attitude and perception toward that system;
- challenge our own assumptions through mental models;
- become aware of and accept our bounded rationality, that is, our need to make decisions without knowing all the facts due to complexity; and
- realize that complexity is not an obstacle but an opportunity to step out of the boxes that we have created when describing the world.

Systems thinking can be seen as encompassing multiple special skills. According to Richmond (1997), they include the following:

- *dynamic thinking* (instead of static equilibrium thinking) that accounts for how issues and problems change and develop patterns over time;
- *system-as-cause thinking* (instead of system-as-effect thinking) that consists of finding causes to a problem or issue as residing within the system, instead of driven by external forces;
- *forest thinking* (instead of tree-by-tree thinking) that looks at trends within a system instead of focusing on specific systems parts which could result in paralysis in analysis;
- *operational thinking* (instead of factor thinking) which explores how behavior is generated through the structure of the system and its components;
- *closed-loop thinking* (instead of straight-line thinking) that considers causal loops within a system and sees a circular instead of linear one-way causality between cause and effect; and
- *quantitative and scientific thinking* where models of problems consist of quantifiable (but not always measurable) components and can be tested to see whether they match what is being observed in the real world, and if needed, require correction.

In a more recent publication, Richmond (2004) added to the previous list the skills of *nonlinear thinking* (no proportional relationship between cause and effect) and *empathic thinking* (sharing, understanding).

The aforementioned skills need to be integrated into the different steps involved in decision making when faced with a problem. As noted by Richmond (1997), these steps include (i) identify and specify the problem to be addressed; (ii) make assumptions and hypotheses about the problem; (iii) use models (mental, pen-and-paper, numerical) to test the assumptions and hypotheses; and (iv) once the models are deemed acceptable (it may take several iterations to arrive there), communicate the new understanding of the model and propose change. These four steps will be explored further in Section 4.5 dealing within the topic of system dynamics modeling.

Core Abilities

In his book, *The Thinking Effect*, Vaughan (2013) identifies three core abilities that decision makers should have. They are called critical thinking, creative thinking, and systems thinking and their characteristics are listed in Table 3.2. As remarked by Vaughan, critical and creative thinking support each other: "the output of critical thinking is the answers to the questions "Why?" and "How?" [in a system]. This output then feeds into creative thinking to produce a range of options, which generates new questions and further refines the options available until a preferred course of action [for a system] is reached." In the overall thinking spectrum shown in Table 3.2, Vaughan sees systems thinking as the fulcrum of a scale balancing critical and creative thinking, a sort of decision making middle ground where decision makers return to get the big picture after using the critical and creative thinking modes depending on the situation at hand. As will be discussed in Chapter 6, critical thinking and creative thinking are constantly at play in the decision-making process involved in the planning of community development projects. Critical thinking is needed to ensure that the projects are done the right way from a technical point of view. At the same time, creative thinking is also needed to address the uncertainty of the projects and to ensure that they are right for the people and their environment.

Table 3.2. Core abilities of decision makers.

Critical Thinking	Systems Thinking	Creative Thinking
Analytic	Systemic	Generative
Convergent	Concurrent	Divergent
Probability	Feasibility	Possibility
Judgment	Perspective	Open
Focused	Integrated	Scattered
Objective	Underlying dynamics	Subjective
The answer	Leverage point	An answer

Critical Thinking	Systems Thinking	Creative Thinking
Left brain Linear Yes, but	Whole brain Structure How and why	Right brain Associative Yes, and

Source: Vaughan (2013). Reproduced with permission from Nicholas Brealey Publishing.

First- and Second-Order Change

In the systems theory literature, an important distinction is made between thinking that leads to solutions creating *first-order* change and thinking leading to solutions creating *second-order* change (Watzlawick et al., 1974). A first-order solution addresses specific issues and creates specific change within a system without changing the overall system. On the other hand, second-order solutions have a larger impact, transforming the system completely through real change by using a new strategy or mindset, or by reframing what the system is capable of doing or not doing. Solutions associated with second-order change tend to be "unpredictable, abrupt, illogical, etc." and "are introduced into the system from the outside" (Watzlawick et al., 1974). They are the solutions associated with what Senge (1994) calls "*metanoia*, i.e., a shift in mind" in decision making. Second-order solutions are the most effective when intervening in a system and are likely to create the maximum amount of leverage in decision making. As noted by Meadows (1997), another way at looking at second-order change is that it is a change that makes a big difference to a system; it is "a change of change."

In practice, both first- and second-order thinking are needed in addressing complex issues. As an example, consider a community having problems in securing enough water for drinking, hygiene, irrigation, etc. A first-order solution would address the immediate needs of the community: for instance, to drill more wells and include rain water catchment systems. A second-order solution would seek to transform the community's mindset toward its water resources: to integrate at the community level, and in a participatory manner, a sustainable plan of water management including water collection, monitoring of water wells, building infrastructure (e.g., check dams) to replenish the water table, educating farmers to monitor their wells, creating a water management committee, deciding what agricultural practices to follow, and ensuring that the solutions benefit the entire community over a long period of time. A second-order solution would also require integrating the five domains of sustainability discussed in Chapter 2 into the community development plan.

I was once shown such an example of second-order solution in a village in India which was implemented by engineers at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad (Wani et al., 2003). The integrated solution consisting of the various interventions mentioned above was successful at providing enough year-around water in the village for humans, cattle, and agriculture. It also resulted in raising the water table by several meters. In turn, this led to tangible outcomes such as economic growth, no instances of suicide of farmers in the village, and encouraging the youth to stay in the community—the opposite of what was happening in neighboring villages. This example shows that integrating second-order thinking in the collaborative framework, illustrated in Figure 2.1, can create tangible success stories and effects that can be scaled up. Several additional examples of well-planned systemic interventions leading to second-order change in communities can be found in the book by Taylor et al. (2012).

What Systems Thinking Is Not About

It is important to give a few words of caution regarding what systems thinking is *not* about, as the concept is often misunderstood or used incorrectly. First, systems thinking is not about analysis which involves breaking down a problem into bite-size and manageable pieces with the overall intent to comprehend each part individually. A community is not an assembly of separate individuals and institutions. Such a compartmentalized approach originated from Descartes in the 17th century and has been the dominant way of linear and deterministic thinking in science and technology over the past 400 years.

Along that line, systems thinking is not about focusing on detailed complexity, which is usually handled by simulating thousands of variables and complex arrays of details. This often leads to analysis paralysis, creates intractable overloads of data and information, and distracts from seeing emerging patterns and interrelationships. Such an approach is commonly used in forecasting, planning (engineering included), and business analysis. It is the approach most commonly followed by major development agencies as discussed in Section 2.2.

Finally, systems thinking is not about making things less complicated, perfect, and simple. It is about embracing the unique attributes of systems listed above, not as obstacles but as opportunities for change. As discussed in the book *Getting to Maybe* by Westley et al. (2007), managing complex issues as if they are complicated or simple may miss the mark and create more problems. Instead, systems thinking is about "acting deliberately and intentionally in a complex uncertain world by virtue of being in and of that world" and welcoming the possibility of change and risk taking with an attitude of inquiry rather than certainty. Development practitioners are most likely to face such conditions in the world of community projects.

Reservations toward Systems Thinking

It has been my observation (and that of many of my colleagues) that systems thinking is not always welcomed in institutions. A university colleague of mine reminded me once that the best way to introduce systems thinking to an audience is never to tell its members that they are being presented a new way of thinking using systems. I have used that advice in presentations to a couple of development agencies. Another colleague told me that it was impossible for him to think holistically. For some reasons, systems thinking is seen as a threatening mindset to well-established reductionist thinking as if both thinking approaches were incompatible. This dualistic reasoning makes no sense. There are indeed times when decisions need to be made in a compartmentalized manner following a reductionist approach, and other instances when decisions require stepping out of silos and looking at the big picture. Having such flexibility and level of awareness is one of the many habits of system thinkers as shown in Table 3.1.

Another reason why systems thinking is not always embraced is related to how systems experts often present the results of their analysis to the public at large. As discussed by Knezovich (2014) and Galloway (2011), communication of systems concepts can at times be so overwhelming that it defeats its original purpose of looking at the big picture of things. As mentioned by Galloway (2011), there comes a time in systems visualization when "the more information that is represented the less information is actually conveyed." In turn, this creates some form of what Galloway calls "political violence" toward the viewer. Other challenges in communicating complexity and systems thinking were suggested by Knezovich (2014) based on some workshop discussion on systems thinking and health in Baltimore, MD (Future Health Systems, 2014). The challenges include (i) using a language that can be hard to comprehend especially within a context other than that used by the experts and (ii) showing models that can be hard to challenge and relate poorly to reality.

3.3 Characteristics of Complex and Adaptive Systems

Characteristics of Human Systems

Among all the systems shown in Figure 3.1, human systems require special attention. They consist of social agents or actors that are linked and follow different sets of rules at different scales. They are by far the most complex of all complex systems, the least understood, and the most difficult ones to model. While interacting with other systems, human systems create unique characteristics such as "bounded rationality, limited certainty, limited predictability, and indeterminate causality" (Hjorth and Bagheri, 2006). In the network shown in Figure 3.1, human systems are the most likely to create unintended consequences to themselves and other natural and nonnatural systems they interact with (Allenby, 2000; Bugliarello, 2003). As remarked by Patton (2011), "interacting human beings are the primary source of complexity." This applies to individuals and groups as well (Vennix, 1999).

Human systems are also *adaptive* agents and constantly evolve and grow as they develop and reach new states of normality (Miller and Page, 2007). They are capable of self-organization, self-correction, and adaptation by changing their structure, behavior, and rules of interaction through evolutionary and coevolutionary change (Mitleton-Kelly, 2003). These forms of behavior are often dictated by the environment in which human systems reside (Simon, 1972). Human beings learn from their environment through many feedback mechanisms (Waldrop, 1992).

When interacting with other systems, human beings bring with them a limited potential for perceiving and processing information to make decisions. As noted by Simon (1972), Jones (1999), Callebaut (2007) and social scientists interested in behavior decision theory, it is not that human beings are irrational while making decisions. They are "intendedly rational" but have a limited "cognitive/emotional architecture" (i.e., bounded rationality) that limits their response to demands from the environment. They have difficulty in handling the complexity and uncertainty associated with so-called "messy" (sometimes called "wicked or ill-structured") problems. These problems are not well-defined and many opinions exist on how to approach them (Vennix, 1999; Metlay and Sarewitz, 2012).

The social science literature is rich in discussion about how humans filter reality. For instance, humans are seen as creating their own reality (and mental models) based on selected information and values. In turn, they behave according to the reality they have created thus reinforcing and confirming its existence, a process called self-fulfilling prophecies (Vennix, 1996). According to Watzlawick et al. (1974), human beings can mishandle difficulties they face in three different ways: (i) by ignoring or denying problems even though they are clearly present ("action is necessary, but it is not taken"); (ii) by creating problems that do not exist ("action is taken when it should not be"); and (iii) by using first-order change solutions when second-order change ones are needed or vice versa ("action is taken at the wrong level").

In his book, *The Logic of Failure*, Dörner (1997) sees the unintended consequences of projects as originating from four reasons associated with human cognition: (i) slowness of human thinking (i.e., we feel obliged to economize and simplify); (ii) slow speed in absorbing new material (i.e., we don't think about problems we don't have); (iii) self-protection (i.e., we need to have things easier and under control to preserve our expectation of success); and (iv) limited understanding of systems (i.e., making mistaken hypotheses and operating out of ignorance).

Jones (1999) remarked that, since organizations consist of human beings, their behavior is likely to "mimic the bounded rationality of the actors that inhabit them." This statement may, however, be debatable as the *cognition* of a group (i.e., its "mental action or process of acquiring knowledge and understanding through thought, experience, and the senses," dictionary.com) may be better (and sometimes worse) than the cognition of separate individuals through an averaging process as the group grows in size. Different outcomes can be predicted whether the individual actors act independently of each other (averaging process may be valid) or interact with each other through feedback mechanisms (averaging process is meaningless). As noted by Miller and Page (2007), this distinction in the level of actor interaction separates complex systems between those with *disorganized complexity* and those with *organized complexity*, respectively; both types were originally suggested by Weaver (1948). Nevertheless, even though Jones's statement was made about political organizations, it applies as well to any group or organization. It certainly applies to the various stakeholders (insiders and outsiders) involved in making decisions in community development projects.

In community development projects, the aforementioned characteristics of complex adaptive social systems add to the ambiguity and uncertainty already existing in the environment in which development takes place. This, in turn, has serious implications for the decision-making process carried out by the various stakeholders involved in community projects.

- Decisions are not likely to be fully rational. They depend somewhat on the context and on a multitude of emotional, subconscious, nonrational factors that are ill-defined.
- Decisions are made on simplified versions of real problems and based on perceptions, perspectives, beliefs, experience, and habits. The problems are rarely analyzed in full, and all problems and associated solutions cannot be foreseen in their entirety.
- Decisions are likely to be incremental and require an adaptive and interactive, design-as-you-go approach that

contains enough feedback loops used in iterative and trial-and-error implementation.

- Optimal (i.e., best) decisions are impossible to make due to incomplete knowledge of the problems at stake, and therefore margins of errors must be accounted for. Decision making in complex and uncertain situations is more about finding "good enough" alternative solutions (satisficing) rather than the best solutions (optimizing) as remarked by Simon (1972). It can also be interpreted as getting to "maybe" or to "possibility" instead of "yes" or "no" while intentionally embracing complexity and uncertainty (Westley et al., 2007; Patton, 2011).

In turn, these implications will affect the degree of success of all phases of community projects discussed in Chapter 6 (i.e., appraisal, design, planning, execution, monitoring and evaluation, exit, and sustainability). In some situations where uncertainty in projects is so high and not properly handled or ignored by some or all community stakeholders, there is a high potential for project failure.

The interplay between human systems and other systems in development projects make "the process of community development inherently unpredictable and [difficult to program]. It depends critically on constant learning and adaptation to be effective" (Morgan, 1998). As suggested by Thompson and MacMillan (2010) within the context of social enterprise in the developing world, the challenge becomes to transform the realm of "anything possible can happen and we don't know the odds" (uncertainty) to the realm of "plausible, probable, and plannable and we have an idea of [the odds and] the risks involved." This requires all community project stakeholders to become system- and complexity-aware and take adaptive actions that incorporate reflection, adaptation, monitoring and evaluation, and feedback mechanisms. As a result, the challenge of managers and others involved in the project becomes one of reducing uncertainty to an acceptable level so that risks can be estimated without prematurely imposing inadequate solutions.

Properties of Complex Adaptive Systems

Complex and adaptive systems such as communities have unique characteristics, behaviors, and attributes that differentiate them from those of simple and complicated systems. They are listed below in alphabetical order along with simple community project-related examples. Understanding what these characteristics are and how they manifest themselves at the community level can help development practitioners fashion better decisions in development projects.

- *Attractor*: “A state or behavior toward which a dynamic system tends to evolve, represented as a point or orbit in the system's phase space” (dictionary.com). As an example, a community may be trapped into a perpetual state of struggle or dependency.
- *Autopoiesis*: “The property of a living system . . . that allows it to maintain and renew itself by regulating its composition and conserving its boundaries” (Merriam-Webster, m-w.com). As living systems, communities and their components create their own organization and complexity.
- *Chaotic*: “Completely confused and disordered” (dictionary.com). The system is extremely sensitive to initial conditions and small changes and shows structural instability. Chaotic behavior may be found in crisis and emergency situations following an adverse event affecting a community that is already vulnerable and nonresilient to start with.
- *Circular causation or feedback*: Component A of a system can cause component B to change. But, it is possible that component B may change component A in return, directly or through a longer chain of causation. In other words, “a variable is both the cause and effect of another” (Hjorth and Bagheri, 2006). Feedback processes consist of feedback loops. Many feedback mechanisms exist at the community level. The example shown in Figure 2.2 describes the circular causation between population growth and the carrying capacity of its environment.

- *Coevolution*: Evolution or change in one part of a system puts pressure onto another part and changes its evolution. This dynamic takes place, for instance, into what Bugliarello (2003) calls the biosoma, which is the space at the interaction between biology, society, and machines.
- *Counterintuitive*: The cause behind some effect is not necessarily the most logical one or the one that is the closest in time and space. Local water access issues at the community level may have nothing to do with water itself, but rather with the poor management of water resources and the control of these resources by a selected few.
- *Dynamic behavior*: "The behavior over time of a system or any of its components" (Meadows, 2008) as the system's components change and interact with each other. Social systems are, by definition, dynamic entities. They change, adapt, and evolve with time.
- *Hierarchy*: Systems may consist of different levels and sublevels. A community may have a decision-making structure that is based on ethnicity and gender.
- *Interconnectedness*: All parts of a system including its sublevels are connected to some other parts, but not necessarily the entire system. Changes in one part of a system may affect the entire system or parts of it depending on the level of connectivity, i.e., whether the parts are tightly, loosely, or not connected to each other. Interconnectedness defines what a community is all about.
- *Leverage points*: "Places within a complex system . . . where a small shift in one thing can produce big changes in everything" (Meadows, 1997). An example of a leverage point would be to find and empower individuals in a community that do better than others under the same conditions and scale up their solutions to the entire community (Pascale et al., 2010). As noted by Kretzmann and McKnight (1993) and Taylor et al. (2012), leverage points rely on building on existing community success and strength.

- *Nonlinear relationship*: "A relationship between two elements in a system where the cause does not produce a proportional [linear] effect" (Meadows, 2008). As an example, a population depends on its growth rate which itself depends on the population, thus creating an exponential growth or decay.
- *Patterns*: They are created when the dynamic of a system creates repetitive behavior and same outcome. Archetypes are examples of patterns. Daily behavior patterns are found at the household level. Annual behavior patterns exist at the community level around seasons and traditional practices.
- *Resilience*: An ability "to prepare and plan for, absorb, recover from, or more successfully adapt to [actual or potential] adverse events" (NRC, 2012). Communities need to adjust to adverse events and hazards, big and small.
- *Self-organization and adaptation*: "The ability of a system to structure itself, to create new structure, to learn or diversify'" (Meadows, 2008). As a system transforms itself, it adapts to change and reaches a new normal. Communities need to adapt to changes in climate and to new forms of technologies.
- *Sensitivity to initial conditions and path-dependency*: The behavior of a system depends on how it evolves from its initial state and associated conditions. Future community development depends on the community's current state of development, the availability of resources and skills, and how it is organized.
- *Synergy*: The "behavior of integral, aggregate, whole systems unpredicted by behaviors of any of their components or subassemblies of their components taken separately from the whole" (Fuller, 1975). "The interaction of elements that when combined produce a total effect that is greater than the sum of the individual elements, contributions, etc.; synergism" (dictionary.com). The behavior of a community cannot be understood by the behavior of its households and members.

- *Uncertainty versus risk*: As noted by Knight (1921), uncertainty happens if we don't know the odds and likelihood that something will happen. If the odds are known, it is better to talk about risk. Human behavior when faced with challenges is uncertain. Risk can be high if assumptions made in development projects do not materialize. Examples include community participation and empowerment or access to capital needed for the projects to unfold.

It should be noted that all these characteristics of complex and adaptive systems do not always manifest themselves at the same time. Some of them are likely to be more dominant in certain contexts than others. In other situations, however, they can be closely related and have potential to interact in disruptive ways.

Example: The Water of Ayolé

In order to illustrate how the various system characteristics mentioned above enter into the context of community development projects, let's consider a well-documented case study called *The Water of Ayolé* (1988). The case study focuses on the water needs (drinking and irrigation) of small village communities in Togo, Africa. It has been used in the literature to demonstrate appropriate practices (or the lack thereof) when introducing technology (e.g., a water well and pump) into a community. Furthermore, it demonstrates what could go wrong (*risk*) when technology is introduced for the sake of introducing technology, especially without taking into consideration the socio-economic context for its development (*uncertainty*).

The video addresses the added-value of community participation, engagement, follow-through, management, and empowerment over time (*dynamic behavior*). It also demonstrates how different stakeholders (community, government outside aid agencies) can work together (*synergy, interconnectedness*) in ensuring long-lasting solutions. This is captured in the video in the form of a narrative consisting of several successive stages, which are paraphrased below.

- Typical unimproved drinking water and sanitation practices in poor communities are described. A recurring *pattern* of behavior is for people to use surface water as their main source of drinking water, sometimes far from where they live. Women are in charge of collecting water and spend considerable amount of time doing so (*self-organization*). The water, in turn, creates health problems (guinea worms, diarrhea) that incapacitate many members of the community. Poverty leads to ill-health and ill-health leads to more poverty (*circular causation*).
- Government agencies take the initiative to drill water wells and install pumps in the communities. People are at first satisfied with the new systems and health improves for a while. They climb the water, sanitation, and hygiene (WASH) ladder. However, as the installed water systems break down over time, women resort to the traditional prepump installation methods of collecting water (*counterintuitive*). The health of the community deteriorates and the community falls down from the WASH ladder (community *readapts* to the old *pattern* of living).
- A lack of trust develops between the community and government agencies. Both groups blame each other for the failure and do not realize that there was never any agreement made about "who was responsible for what" before the wells were drilled and pumps installed (*circular causation*).
- With the assistance (financial and technical) of outsiders, representatives of government agencies (extension workers) are trained in developing an action plan for operation and maintenance of the water facilities (*leverage point*). In turn, the extension workers train local villagers. In that process, they also learn about the needs and priorities of community members (*feedback* and *cocreation*). Trust is rebuilt within the community and with outside stakeholders (*nonlinear* consequences).
- Collaboration of stakeholders (extension workers and villagers) in the project contributes to a great extent to its

success (*synergy* and *interconnectedness*). Over time, people develop a perspective and understanding (*attractor*) of what constitutes success and why things work or don't work. They climb the WASH ladder again.

- The role of a newly established water and sanitation committee and active members of the community engaged in the project contribute to more long-term success (*resilience*). When properly organized, people have more options to control their own destiny (*self-organization*).
- Clean water supply leads to better health, confidence, agricultural development, profit, and investment (new *patterns*). A new dynamic between men and women in the community is also created (*coevolution* and *adaptation*) with more participation and gender equality (*interconnectedness*, *self-organization*, and *synergy*).
- A potential of scaling up the reported success story to other communities is being considered by the government (*nonlinearity* and *synergy*).

The Water of Ayolé story is indeed hopeful and shows that when properly planned and managed, a water project in the developing world can be as successful as in the developed world. The success of the water project resides in the fact that it followed a systems approach involving three interactive and collaborative groups (i.e., the community, the government, and the outsiders) as shown in Figure 2.1. Unfortunately, this type of success is still more an exception than a rule, for instance, in the long-term performance of water and sanitation infrastructure implemented by development agencies worldwide (RWSN, 2009; WaterAid, 2011; WASH Sustainability Charter, 2013).

Emergence

A characteristic of complex and adaptive systems not mentioned in the list above, and which requires special attention, is that of *emergence*. It can be defined as "a phenomenon whereby well-formulated aggregate behavior arises from localized, individual behavior" (Miller and Page, 2007). Emergence can also be seen as "a process whereby larger entities, patterns, and regularities arise through interactions among smaller or simpler entities that themselves do not exhibit such properties" (Wikipedia, 2014b). In systems, unanticipated emerging patterns are created as components of a system interact with each other and self-organize. The concepts of emergence, self-organization, connectivity, interdependence, adaptation, and synergy are closely related (Mitleton-Kelly, 2003).

Emergence implies that the behavior of the whole cannot necessarily be determined by adding the behavior of its individual parts; something happens when the parts interact (Holland, 1999). Recall that in the case study mentioned above, poor livelihood and poverty *emerged* from a combination of ill-health, lack of economic development, poor organization of the community, lack of education, and poor dynamic between men and women. The unsustainability of the water pumping system *emerged* from a lack of trust among community members (women gave money to men who disappeared) and misunderstanding between the community and the government extension workers. Finally, the final well-being (health) of the community, its economic development (wealth), and its resilience to face future adverse events *emerged* from a renewed dynamic within the community and between the community, the government, and outsiders.

In the previous paragraph, emergence was mentioned five times with respect to poverty, sustainability, health, wealth, and resilience at the community level. In general, emergence creates unique forms of system behavior and self-organization (Holland, 1999). As human beings we experience the effect of emergence on a daily basis when phenomena, which seem independent to us, interact. A crowd behaves differently from that of individuals; a traffic jam cannot be predicted from the behavior of individual drivers; a forest shows properties that cannot predicted from those of individual natural species. Birds, insects, herds of animals, and fish tend to organize themselves through collective motion as shown in the agent-based model called *Boids* by Reynolds (2014). *Cellular automata* can yield interesting structures when the components interact (Wolfram, 2002). The health (or illness) of a human body can be seen as an emerging property resulting from the good (or bad) functioning of parts of its shared systems (cardio, nervous, skeletal, respiratory, immune, etc.). Music can be seen as the emergent property of an orchestra. Another example is that of the speed of a man-made structure such as a bicycle, airplane, or automobile. There is no place where speed is created; no "speed box" installed in these machines. Instead, speed comes from the interaction of separate machine parts, each one contributing to making the bicycle, plane, or car run properly. Speed is an emerging property of the interacting machine parts. If one or several of them are not functioning well and their connections are less than desirable, speed will be reduced and the machine will stop despite having other functioning parts.

Emergence in Community Development

Like the speed example previously mentioned, there is no specific place in a community where poverty, illness, conflict, and unsustainability can be isolated and resolved. They are all emergent properties and forms of behavior that result from some dysfunction in the community structure and in how the community interacts with its environment. According to Bugliarello (2003), the dysfunction stems from an unbalance between biological and social systems and machines. That dysfunction may affect some individual community members more than others. It may also affect one community more than the others at the regional or national level.

The overarching goal or outcome of community development projects (or groups of projects defined as programs) can therefore be seen as reducing and even eliminating the dysfunction so that a community has the opportunity to become over time, and on its own, healthier and safer and more prosperous, stable, peaceful, resilient, and sustainable. These changes are properties that emerge by investing in the strengths of the community through capacity development and reducing its vulnerabilities. It should be noted that all these desirable emergent properties are not measurable and predictable commodities but represent conditions that, when combined, may lead to a *desirable state (or order)* of a community. Many desirable states are possible and each state expresses itself in the form of *patterns of human behavior* at the individual, household, and community levels.

Since the structure of a system defines its behavior and depends on its environment, a desirable state, such as the state of sustainability discussed in Section 2.4, emerges from the interaction of structural components and attributes that are at play in the community as well as from multiple feedback processes capable of holding human, economic, and environmental systems in check (Figures 2.2 and 2.3). Some of these components and attributes are tangible and can be measured, whereas others are intangible and can only be estimated subjectively.

As discussed in Amadei (2014), community development is first and foremost about the community itself and its underlying structure. At a minimum, communities must possess key attributes necessary for the state of sustainability and its associated order to emerge and flourish:

- allow all of their members to enjoy a quality of life and well-being where basic human needs, freedoms, rights, and meaningful work are fulfilled in a safe and secure environment;
- provide equitable access to resources and knowledge, thus being capable of sustaining themselves economically, socially, and environmentally;
- provide individuals and households the opportunity to express their full potential without adversely and irreversibly affecting the carrying capacity of the environment upon which they depend;
- function in an environment where rule of law and good governance are the norm; and
- ensure sustainable livelihood opportunities for future generations.

These attributes and their associated operating rules cut across the five domains of sustainability defined by Ben-Eli (2011), i.e., material, economic, life, social, and spiritual (Figure 2.3). When successfully combined, these key attributes translate into an overall increased level of livelihood, security, and well-being at the community level but also in the basic economic and social units that form the community, that is, the households and the individuals who belong to these households. Healthy behavior patterns are created.

In turn, by being more secure and having more interconnectedness among its components, communities are less vulnerable and more resilient to possible hazards and adverse events: internal or external; small or large; routine or exceptional; natural or nonnatural; isolated or interrelated. Thus, resilience can be seen as another emergent property of well-functioning communities that are capable of (i) withstanding the impact of such events (coping resilience) and (ii) adapting to the consequences of those events and recovering from their effects (adaptive resilience). The emergent nature of community resilience is best described in the report entitled *Disaster Resilience: A National Imperative* (NRC, 2012) where resilience is, like health of the human body, dependent on the good functioning of interrelated systems.

> A human body relies on the integrated functioning of its shared systems—like the skeletal, nervous, and immune systems—to maintain health and resist disease and injury. Similarly, communities depend on a number of interrelated systems for economic stability and growth, commerce, education, communication, population wellness, energy, and transportation. The relative "health" of community systems will determine how well a community can withstand disruptive events. If a community has weakened infrastructure, like a human body with a compromised immune system, it will not withstand trauma as well as one in good health.
>
> In both human health and community resilience, investments in maintaining health and building strength, reduce the requirement for very expensive treatment and recovery. Health providers now know that prevention is a much less expensive pathway than treatment after the onset of an illness. In the same way, investment in community resilience may help a community reduce or avoid monumental recovery and restoration costs.

Finally, community resilience combined with an increased level of household livelihood security and well-being, good governance, and economic development results in more peaceful and stable communities, which translate into more stabilized nations as illustrated in Figure 1.2.

As noted by Diamond and McDonald (2013), peacemaking is the outcome of the interaction of multiple tracks related to diplomacy, conflict resolution, commerce, personal involvement, learning, advocacy, faith in action, providing resources, and information; to that list, one could add science, technology, and engineering. The outcome of the interactive multitrack diplomacy suggested by Diamond and McDonald is a world at peace, probably the best emergent property humanity can wish for.

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CHAPTER 4

System Dynamics Modeling

This chapter introduces the reader to the field of system dynamics and the methodology necessary to develop qualitative and quantitative models of reality. System dynamics models consist of networks of cause-and-effect reinforcing and/or balancing loops. The networks can be represented in the form of causal loop diagrams or stock-and-flow diagrams, which can be combined with other forms of visualization techniques. Systems often show recurring patterns that are archetypical. Archetypes emphasize the link between system structure and behavior. This chapter presents the steps involved in system modeling and group decision modeling which can be used in the different stages of community development projects.

4.1 Systems Approach

The study of systems from simple to complex, or systems science, has been used since WWII to address complex issues in a wide range of disciplines such as engineering, business and economics, health, planning, management, etc. Systems science is broad and encompasses several traditions such as general systems theory, organizational learning, operations research or system analysis, and system dynamics. A detailed analysis and comparison of these traditions can be found in Umpleby and Dent (1999), Myers (2009), and Schwaninger (2009), among others. All these traditions differ in the way complexity is handled, the beliefs and assumptions about the nature of interaction of components within a system, and the role played by cognition, adaptation, evolution, self-organization, and hierarchy in systems. Other than that, all the aforementioned traditions acknowledge that systems are organized *wholes* with some inherent levels of complexity and uncertainty and in which multiple feedback mechanisms are at play. They also emphasize the importance of addressing the content and context of systems, the relationship between system structure and behavior, and the critical role played by boundaries and initial conditions in system modeling.

It should be noted, however, that besides the serious aspect of systems science mentioned above, it has become fashionable and progressive seeming in many debates in science, engineering, politics, and economics to mention that one or a group has adopted a systems approach to address complex problems (Dent, 2001). Unfortunately, more often than not, this new trend in public discourse stays at the intellectual level and does not always translate into better solutions and policy decisions. Shallow systems thinking combined with an absence of follow-up in decision making remains an intellectual exercise with no tangible results.

4.2 System Dynamics

The branch of systems science that is of main interest in this book is that of *system dynamics.* It originated later than the other traditions with the work of Dr. Jay Forrester at MIT in the 1950s and 1960s. The book *Industrial Dynamics* (Forrester, 1961) emphasized (i) the role of "information-feedback control loops" in controlling the time-dependent (dynamic) behavior of industrial systems and (ii) the use of models in the design and control of such systems which are often nonlinear. This was a marked departure from operations research tools that were in vogue in the late 1950s. Two additional books on *Urban Dynamics* (Forrester, 1969) that explored the stagnation and growth of cities, and *World Dynamics* (Forrester, 1971) helped anchor what came to be known as the system dynamics approach to complex problems. The approach was subsequently used by a variety of researchers including Donella H. Meadows and coworkers (including Dennis Meadows) in several studies showing the impact of population growth, industrial growth, pollution, and degradation of the environment on world systems (Meadows et al., 1972, 1982, 1992, 2004; Meadows, 2008).

Since its inception, system dynamics has gained a lot of popularity in various fields of science, engineering, economics, etc. Landmark books that have promoted the applications of system dynamics include *The*

Fifth Discipline by Senge (1994) and *Business Dynamics* by Sterman (2000) in which the concept of *dynamic modeling* was introduced. Other interesting texts on various applications of systems thinking and system dynamics include those by Ford (2010) on modeling environmental processes; Hargrove (1998) on health sciences; Vennix (1996) and Richardson and Andersen (2010) on group model building and decision making; Robinson (2001) on climate sciences; Hannon and Ruth (2001a) on modeling biological systems; and Pidd (2004, Part III) on management science. Other interesting books with multidisciplinary applications include those of Wolstenholme (1990), Hannon and Ruth (2001b), Bossel (2007a,b,c), Richmond et al. (2010), and Pruyt (2013). Finally, the reader might be interested in reading the self-study guide titled *System Dynamics Road Maps* available through the Creative Learning Exchange (2015) website.

Definition and Characteristics

Several definitions of system dynamics have been suggested in the literature. According to the System Dynamics Society (2014), it is:

> a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems – literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality.

Another definition worth mentioning is that of Wikipedia (2014a) where system dynamics is defined as:

> an approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops and stocks and flows. These elements help describe how even seemingly simple systems display baffling nonlinearity.

System dynamics has several unique characteristics:

- It is a method that can be used to study how systems continuously change over time due to possible changes in their components, relationship between components, and changes in the overall direction of systems. The method allows for both qualitative and quantitative modeling.
- It requires a clear formulation of the problem(s) at stake, a mapping of the problem(s) being addressed, and an iterative approach to model the problem(s).
- Models of system dynamics are defined by closed boundaries (causally closed models) where endogenous components—those originating from within—predominantly dictate the behavior of the systems. Exogenous components—those originating from without—have limited influence. Models are designed to be self-contained in terms of cause and effect inside their boundaries. They contain the components that "are important to explain [their] dynamic behavior" (Vennix, 1996).
- Nonlinearities in the system are included in the form of first order differential equations.
- Information-feedback mechanisms in the system can be included in the form of interconnected closed loops and circular causality allowing for reinforcing and balancing trends in a system. This can help in explaining the counterintuitive forms of behavior of some systems.
- The method emphasizes that the structure of systems (i.e., their components, mutual interactions, and interaction with the environment) affects their continuous behavior. Combining feedback loops of positive (reinforcing) or negative (balancing) polarities, various dynamic patterns can be simulated and used to model different behavioral patterns of system changes such as growth, decay, overshoot, oscillations, equilibrium, randomness, and chaos. As the structure of a system changes, so is its behavior.

- More emphasis is placed on the structure of a system (its aggregated nature) than on trying to figure out the details of all of its components.

Umpleby and Dent (1999) succinctly describes how system dynamics differs from the other systems science traditions mentioned in Section 4.1:

> System dynamicists focus on modeling some observed system. They deal with the issue of knowledge acquisition, but only in terms of how one understands what is happening in the referent system. For them, the process of understanding is encompassed by the methodology of modeling. They do not assume that the philosophy of knowledge needs to be considered. They are concerned with verifying their models with historical data and helping decision makers improve their understanding of a referent system. They are not concerned with cognition as a problem in itself.

System Dynamics and Cybernetics

Related to but different from system dynamics is the tradition of *cybernetics* which originated much earlier in the 1940s with the work of Wiener (1948). Even though cybernetics is not developed further in the rest of this book, it is important to discuss the limitations of system dynamics from a cybernetics perspective. Both approaches acknowledge the link between system structure and behavior and the circular (feedback) causality found in systems (Richardson, 1999). However, they originate from two different tracks of scholarly inquiry. System dynamics uses a *quantitative* and *objective* approach to complex problems that is rooted in engineering control theory. Cybernetics uses a more *qualitative* and *subjective* approach to complex problems that is more closely linked to communication and information theory. These two traditions use different approaches and tools when looking at system complexity. Several comparative examples of application of system dynamics and cybernetics can be found in Schwaninger (2009).

As noted by Richardson (1999) and Schwaninger (2009), cybernetics is concerned with "the adaptation and control of complex systems for the purpose of maintaining stability under exogenous disturbances." The focus is on control of system behavior, self-regulation, and homeostasis ("the tendency of a system . . . to maintain internal stability," dictionary.com) rather than on dynamic change. As noted by Maruyama (1963), the focus is on the deviation-counteracting aspect of causal effects. Accordingly, it emphasizes the use of negative (balancing) feedback loops for sending discrete messages between system components as the system evolves and reorganizes itself toward stability. In cybernetics, phenomena are described "in terms of events, decisions, and messages" and the context in which phenomena unfold is very important.

On the other hand, system dynamics "takes an endogenous view, being mainly interested in understanding circular causality as a source of system's behavior." Phenomena are described as "dynamic patterns of behavior" that come from the interaction of feedback loops, some of them positive (reinforcing) and others negative (balancing), but all contained within the boundaries of the system. The deviation-multiplying effect of causal effects is taken under consideration (Maruyama, 1963). The content of the phenomena is emphasized over the context.

According to Richardson (1999), system dynamics has several limitations if viewed from a cybernetics point of view and if specifically used to model social or sociotechnical systems:

- It uses a deterministic point of view that ignores the inherent variability, consciousness, and values found in social systems;
- The systems analyzed are fixed which does not match well the dynamic aspects of social systems;
- The underlying mathematical tools cannot always be applied to model phenomena in social systems that can be understood more qualitatively than quantitatively;
- The systems are assumed to be closed and do not account for the exchanges that social systems have with the outside world (i.e., flow of energy or information);

- It can model problems that have definite patterns of behavior but cannot address social problems that do not show such patterns or focus on singular decisions or events;
- Using patterns of behavior requires using a more distant and continuous approach to phenomena which cannot be used to model the impact of special events, information, or decision on social systems;
- Messages and meaning in feedback loops and links between system components cannot be modeled. Self-reference issues such as "reflection, self-organization, self-transformation, and autopoiesis (self-generation)" are not addressed.

It is noteworthy that cybernetics and system dynamics are not exclusive of each other (dualistic approach) and can be combined (dialectical approach) to model complex systems where qualitative/quantitative, context/content, objective/subjective issues are at play. To that effect, Schwaninger (1997) proposes the *Integrative Systems Methodology* (ISM) framework that combines the best of both traditions. An excellent real-life sociotechnical case study of how the framework was applied by several communities in a valley in Austria to reach a decision of building a new railway line was published by Schwaninger (2013). The tools of system dynamics and organizational cybernetics were integrated to reach a consensus between the different stakeholders involved in the decision process. Different tools were used for different aspects of the decision process.

4.3 System Dynamics Components

Cause-and-Effect Loops

Unlike linear systems that consist of unidirectional cause-and-effect relationships, complex systems involve multiple feedback mechanisms (circular causation) that control their behavior. These cause-and-effect feedback loops are described by Senge (1994) as reinforcing loops and balancing loops:

- *Reinforcing (R) loops* create a compounding effect and are self-reinforcing feedback processes. They amplify or add to change, create a snowball effect, and have potential to increase growth or decline.
- *Balancing (B) loops* are those that bring two things into agreement. They are self-correcting feedback processes and seek stability and equilibrium toward reaching a goal or objective.

In systems, reinforcing and balancing loops interact with each other as there is a limit to growth. Balancing loops always accompany reinforcing loops to reach some dynamic equilibrium, provide self-correction, and keep reinforcing loops from going on forever. Delays may also be added to balancing and reinforcing loops in order to account for the role of time in linking causes and effects and any adjustment processes.

The interaction between reinforcing and balancing loops can be represented using so-called mental models in the form of *causal loop diagrams* or *stock-and-flow diagrams*. Such diagrams represent useful tools in (i) depicting how parts of a system interact and create patterns of behavior, (ii) communicating the dynamic of systems with others; and (iii) designing and planning interventions to address issues faced by the system.

Causal Loop Diagrams

As noted by Pidd (2004), causal loop diagrams were first suggested by Maruyama (1963) and represent a way to show how elements of feedback mechanisms mutually interact in a causal manner. Figure 4.1 shows an example of a *causal loop diagram* consisting of two interacting causal loops that define the size of a population. In that diagram, arrows represent *causal influences* or *links*. A + or – polarity can be assigned to each arrow. Arrows labeled with a + sign link things that move in the same direction. Arrows labeled with a – sign link issues that move in the opposite direction. In some causal loop diagrams, the + and – signs attached to the arrows can be replaced by the letters “s” (for same) and “o” (for opposite).

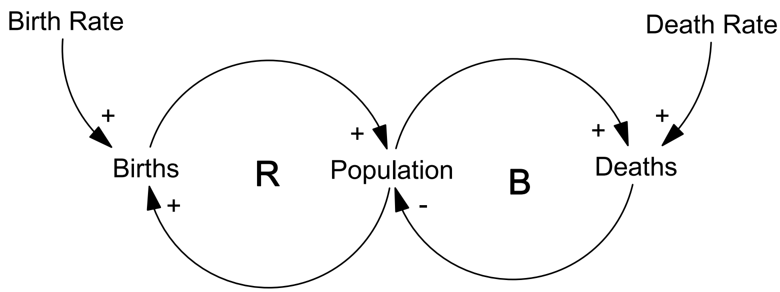

Figure 4.1. Population causal loop diagram.

Note: Arrows with a + sign link things that move in the same direction. Arrows with a ~ sign link issues that move in the opposite direction. Births add to the population (R) and create a compounding behavior, all else being equal. Likewise, deaths decrease the population (B) and create a draining behavior, all else being equal. The increase or decrease of the population depends on the birth and death rates, their relative values, and the current size of the population. The dominant loop dictates the behavior of the system, that is, population growth or decay.

In Figure 4.1, births add to the population (a reinforcing or R loop) and create a compounding (exponential growth) behavior, all else being equal. Likewise, deaths decrease the population (a balancing or B loop) and create a draining (exponential decline) behavior, all else being equal. The increase or decrease of the population depends on the birth and death rates, their relative values, and the current size of the population. In this causal loop diagram, the dominant loop dictates the behavior of the system, that is, population growth or decay.

Causal loop diagrams, such as those shown in Figures 4.1 and 2.4 are used to visualize what contributes to growth, decline, or stability, and are mostly used at the project *strategy* level. They show trends and connections and causal feedback mechanisms in a system. They are *not* used to conduct numerical simulations of systems. They help in laying out the different components of a system and show how they interact dynamically in a *qualitative* manner. They are useful "for communication, not for simulation" (Ford, 2010).

Stock-and-Flow Diagrams

Another way of describing the dynamic of systems is to use *stock-and-flow diagrams* which consist of combinations of several building blocks as shown in Figure 4.2.

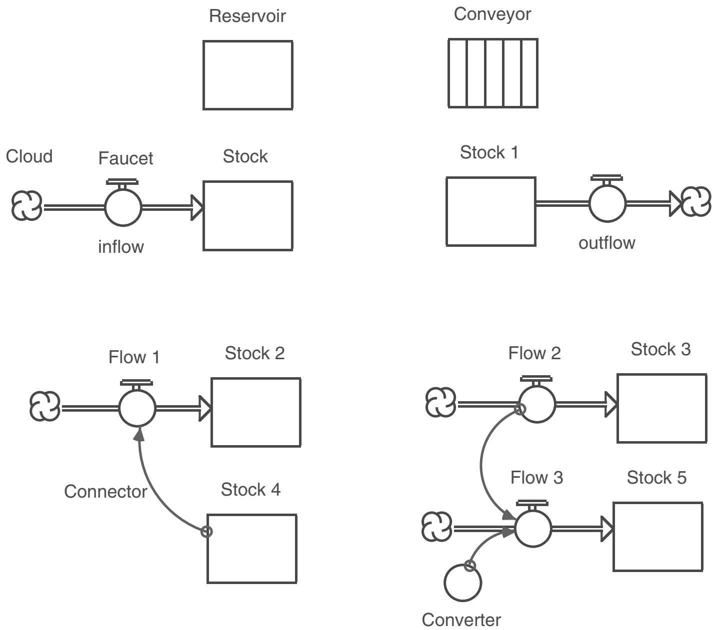

Figure 4.2. Basic building blocks of mental models: Stocks (reservoir or conveyor), flow (inflow and outflow) with clouds, converters, and connectors.

- *Stocks* correspond to accumulations of something that can be measured at one point in time (for example, water in a bathtub or behind a dam, a human population, trees in the forest, etc.). A stock can be expressed as a reservoir (or level; Forrester, 1969) in and out of which information flows. It can also be represented as a *conveyor belt* to account for the time it takes for information to pass through the stock. If a stock represents, for instance, the trees in a forest, the conveyor belt will allow for the time it takes for trees to grow from seedlings to maturity and before they can be harvested. Stocks can be seen as *state variables*: they define the current state of a system.
- *Flow* (inflow, outflow, or bi-flow) is represented in the form of pipelines (with a faucet controlling the flow). It refers to activities that cause *change over time* of information or materials (number of births per year, inflation rate, flow of a river, cash

flow, carbon emission and sequestration, rate of cutting or planting trees, etc.). Flow (flux or rate; Forrester, 1969), in turn, results in changes (dynamic behavior) in the stock accumulations and in the entire system. Flows can be seen as *control variables*; they create change in the state of a system.

- C*louds* indicate infinite sources or sinks, somewhere outside of the system boundaries.
- *Converters* are used to convert or transform information from one stock-and-flow path to information driven by another stock-and-flow path, or to feed information into an existing flow. A converter can also represent a stock if there is no flow in and out of the stock. They can be seen as *converting variables*. Converters can change over time and be described in a functional form.
- *Connectors* indicate transmission or links of actions and information (i.e., causal connections) between variables such as stock-to-flow, flow-to-flow, or between converters. One or several variables can provide input to and have influence on another variable through connectors.

Figure 4.3 shows the stock-and-flow diagram corresponding to the example of Figure 4.1. Such mental models help visualize how things flow, accumulate, and dissipate in the reinforcing and/or balancing loops.

The different components of stock-and-flow diagrams mentioned above can also be interpreted as representing the basic elements of an *operational language* of system dynamics. As suggested by Richmond (2004a, b), the language consists of basic nouns represented by stocks, linked by verbs represented by flow, which when combined together form sentences. In these sentences, adverbs are represented by converters. The sentences can be linked by connectors to form paragraphs represented by feedback loops.

In general, stock-and-flow diagrams allow for numerical (*quantitative*) simulations and parametric or sensitivity studies and can therefore be used at the project *operation* level. Stock-and-flow diagrams are used for "both communication and simulation" (Ford, 2010).

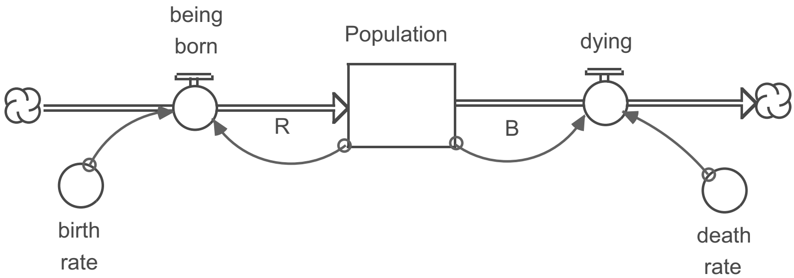

Figure 4.3. Population stock-and-flow diagram.

Note: Population is represented by a stock. The change in population is controlled by the "being born" and "dying" control variables and their respective rates of change.

4.4 System Archetypes

As remarked by Senge (1994), some patterns in systems seem to occur over and over again. They are called *systems archetypes* or *generic structures*. Several of these archetypes have been identified and are well documented. They represent common patterns of human behavior. It is likely that in the field of human development, such patterns and the community response to them are similar in different regions of the world, or at least have similar core characteristics that are supplemented with local characteristics. Archetypes allow for recognizing such patterns.

According to Meadows (2008), archetypes are traps or grooves forcing a system to produce the same answer under the same conditions; they create *habits*, which in turn define the character of the system and ultimately its destiny. As noted by Meadows, recognizing archetypes at play is also an opportunity for forcing change "ahead of the game" and creating a way out of the trap or the groove. Archetypes clearly demonstrate that the structure of systems controls their behavior.

Systems archetypes are formed by combining the fundamental building blocks discussed in the previous section. According to Sterman (2000), the vast majority of archetypes include, in their respective causal loop diagrams, basic modes such as: (i) linear growth or decay; (ii) exponential growth or decay that can be modeled by a single reinforcing (for growth) or balancing (for decay) loop; (iii) goal seeking that can be modeled using a single balancing loop; (iv) oscillation which can occur when delay is combined with a balancing loop; and (v) delays. Other higher forms of behavior can be obtained by combining the aforementioned basic modes such as: S-shaped growth (sequence of reinforcing and balancing loops), S-shaped growth with overshoot and oscillation or overshoot and collapse (sequence of multiple reinforcing and balancing with or without delay). Many of these basic modes are listed in Tables A.1 and A.2 in the Appendix. Other modes of system behavior include equilibrium, random behavior, and chaos.

Several archetypes were initially proposed by Forrester (1969) and Meadows (1982). The most well-known are the nine archetypes proposed by Senge (1994). They include balancing process with delay; limits to growth; shifting the burden; eroding goals; escalation; success to the successful; tragedy of the commons; fixes that fail; and growth and underinvestment. Figure 4.4 shows an "archetype family tree" originally proposed by Goodman and Kleiner (1994) that describes how the various archetypes are related to each other. Each archetype is further described in Table 4.1 along with examples of its application related to community development projects. Other examples of application of archetypes in social and economic sciences can be found in *The Fifth Discipline Field Book* by Senge et al. (1994), the system archetypes toolboxes by Kim (2000), and a discussion by Braun (2002).

Table 4.1 Nine different types of system archetypes with community development examples.

Archetypes	Description and Dynamic (from Braun, 2002)	Community Development Examples
Limits to growth	"A reinforcing process of accelerating growth (or expansion) will encounter a balancing process as the limit of that system is approached . . . Continuing efforts will produce diminishing returns as one approaches the limits"	• Rapid urban, periurban, slum development without planning and resources • Agricultural economy is limited by unavailability of roads or infrastructure (pumps, energy) • Increase in poor

Archetypes	Description and Dynamic (from Braun, 2002)	Community Development Examples
		population with availability of water, energy, food • Community services limited by lack of trained personnel
Shifting the burden	"A problem symptom can be resolved either by using a symptomatic solution or applying a fundamental solution . . .. Once a symptomatic solution is used, it alleviates the problem symptom and reduces pressure to implement a fundamental solution, a side effect that undermines fundamental solutions"	• Relying on a charity model of development instead of capacity development • Dependency on NGOs, governments, and outsiders • Quick fixes made to infrastructure without considering long-term performance • Solving one immediate problem without considering unintended consequences (see example of providing land titles in Costa Rica in Chapter 1)
Eroding (or drifting) goals	"A gap between a goal and an actual condition can be resolved in two ways: by taking corrective action to achieve the goal, or by lowering the goal… When there is a gap between a goal and a condition, the goal is lowered to close the gap. Over time, lowering the goal will deteriorate performance"	• Community identifies high goals for itself. Over time, the goals cannot be met because (i) goals were too complex with and did not match the capacity of the community; (ii) the interest of the community erodes away with time • External assistance and services to the community decrease over time due to a decreasing

Archetypes	Description and Dynamic (from Braun, 2002)	Community Development Examples
		commitment from NGOs, government, community leaders
Escalation	"One party's actions are perceived by another party to be a threat, and the second party responds in a similar manner, further increasing the threat... The two balancing loops create a reinforcing figure-8 effect, resulting in threatening actions by both parties that grow exponentially over time"	• Two ethnic groups live side by side and compete for attention for NGOs and the government and compete for resources (human, environmental, financial) • Two NGOs compete for a same project and/or limiting funding
Success to successful	"If one person or group (A) is given more resources than another equally capable group (B), A has a higher likelihood of succeeding… A's initial success justifies devoting more resources to A, further widening the performance gap between the two groups over time"	• Outsiders favor one ethnic group over another • Corruption is rampant and benefits once class, cast, etc. • Men are expected to be successful and not women • Men go to mines for jobs, make money, spend it all, and ignore families leading a breakdown in the community family structure
Tragedy of the commons	"If the total usage of a common resource becomes too great for the system to support, the commons will become overloaded or depleted and everyone will experience diminished benefits"	• Overuse of shared natural resources, grazing, fishing, and deforestation • There is no agreement as to how to share the resources
Fixes that fail	"A quick-fix solution can have	• A water pumping and

Archetypes	Description and Dynamic (from Braun, 2002)	Community Development Examples
	unintended consequences that exacerbate the problem…The problem symptom will diminish for a short while and then return to its previous level, or become even worse over time”	distribution system is installed without consideration for long-term performance. Systems break down very quickly • Political promises fail to materialize • Lack of accountability in development planning and execution
Growth and underinvestment	“If a system is stretched beyond its limit, it will compensate by lowering performance standards, which reduces the perceived need for investment. It also leads to lower performance, which further justifies underinvestment over time”	• Community development is going well but community members and/or outsiders underestimate what’s necessary to carry out the development forward • Community does not invest in its own resources and capabilities
Accidental Adversaries	“When teams or parties in a working relationship misinterpret the actions of each other because of misunderstandings, unrealistic expectations or performance problems, suspicion and mistrust erode the relationship. If mental models fueling the deteriorating relationship are not challenged, all parties may lose the benefits of their synergy”	• Conflict emerges during development projects between community members and NGO and/or government because of misunderstanding, lack of initial shared vision, and lack of capacity in adapting to change • Conflict resolution was not included in project planning

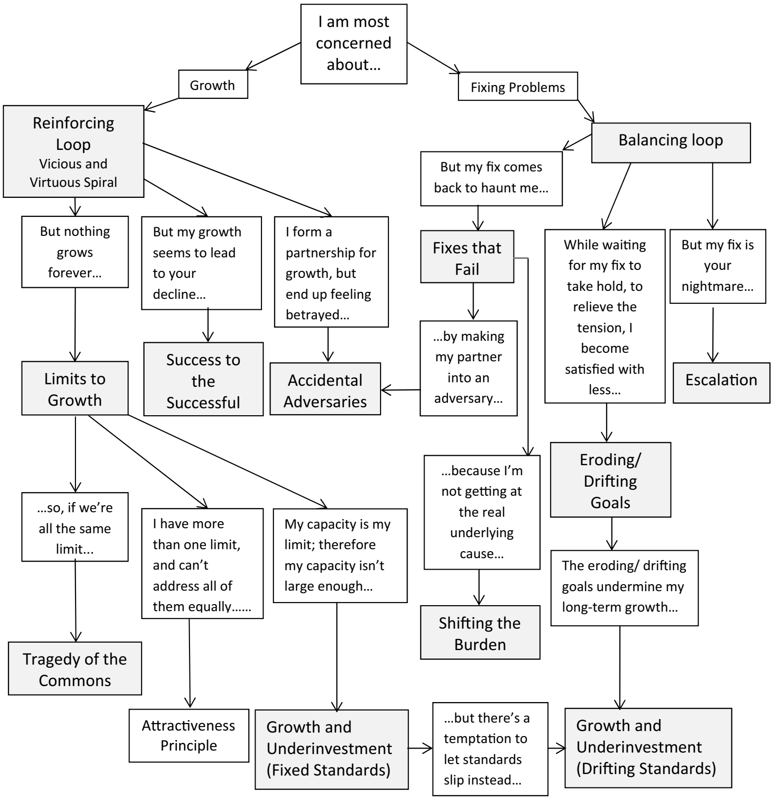

Figure 4.4. Archetype family tree showing how different archetypes are related to each other.

Source: From Senge et al. (1994). Used by permission of Doubleday, an imprint of the Knopf Doubleday Publishing Group, a division of Penguin Random House LLC.

Among all nine archetypes, the *Tragedy of the Commons* (Figure 4.5) is often used in the sustainable development literature to explain the diminishing return associated with individuals in a group who "make use of a common resource by pursuing actions for their own enjoyment or benefit, without concern for the collective impact of everyone's actions" (Kim and Anderson, 2007). The concept was originally introduced by Hardin (1968). In the causal loop diagram of Figure 4.5, two groups of stakeholders (be they two communities, two households, or two people) defined as A and B use resources to address their individual needs (reinforcing loops R1 and R2). An excess of activities by all parties (R3 and R4) may create diminishing benefits and a tragedy for *all* once resource limits have been reached (balancing loops B5 and B6). At the end, the commons are in a worse shape than if they had been managed in the first place (Gardner, 2005). This archetype emphasizes that the solution to the tragedy of the commons dilemma does not reside at the individual level but rather requires a collective decision process (a common ground) that both A and B need to address and agree upon. This archetype could be used to describe the complex web of connections between community members sharing a multitude of resources, including water, food, energy, land, infrastructure, etc. It could also be used to model the interplay between multiple communities (or larger entities such as cities and regions) sharing common regional resources.

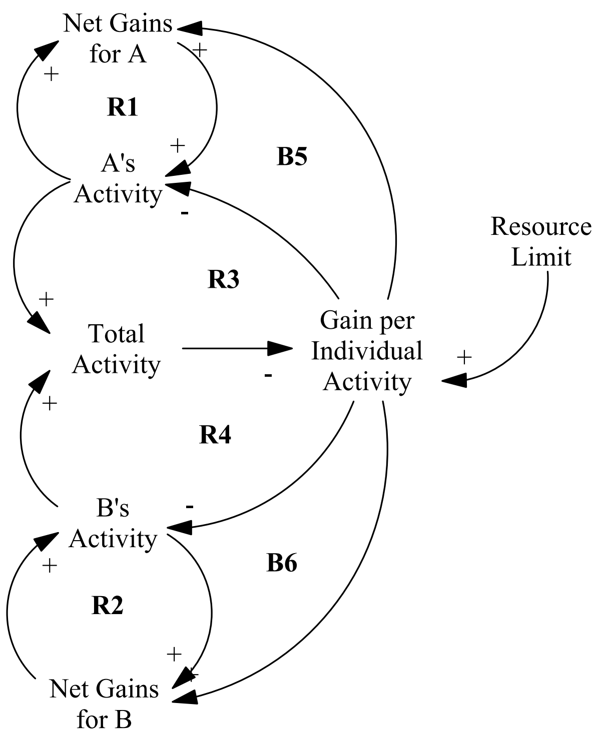

Figure 4.5. The tragedy of the commons archetype.

Note: As individuals (or groups) A and B seek actions that are beneficial to each one of them, the commons have less to offer to both A and B. A delay exists between the "total activity" and the "gain per individual activity."

Source: From "Systems Archetypes I" by Daniel H. Kim (2000), with permission from Leverage Networks, Inc. Redrawn by J. Walters using the Vensim software.

The tragedy of the commons archetype implies that there is no interaction between all parties sharing the resources and that the commons are unmanaged (Hardin, 2008). As noted by Ostrom (2007), the outcome would be quite different, and less damaging to all parties, if they were to interact and agree on how to share the common resources.

4.5 Modeling

Value Proposition

System dynamics modeling (sometimes called dynamic modeling; Sterman, 2000) can be seen as "a framework consisting of . . . a language, a set of key concepts, a process . . . supported by a toolset [software]" (Steve Peterson, mentioned by Peck, 2011). The key concepts and language were already discussed above and the software will be discussed in the next section. This section describes the specific steps involved in the modeling process.

System dynamics models are mental or conceptual models of reality that are built using the basic components (causal loops, stocks, flows, etc.) described in Section 4.3. According to Senge (1994), mental models are "deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action." We use conceptual models (but not necessarily systems models) every day of our lives. They define our individual day-to-day reality and group shared reality (Vennix, 1996).

In general, mental or conceptual models (referred to as "models" in the rest of this chapter) are used by decision makers to conduct simulations in order to better understand the dynamics of complex systems (Sterman, 2006). The models can help identify how system components act and interact, what system parts are more critical, and what and where possible system leverage points reside. Furthermore, models can help test hypotheses that decision makers may have developed after conducting some level of analysis of the systems of interest. Through multiple iterations where the predictions of the models are compared with real-world behavior and through continuous adjustments of the models, a better (but never complete) prediction of the real-world systems emerges.

This in turn can be used to make predictions of how systems would behave or react to change in the future by considering "what if" (or "what happens if") decision-making scenarios.

System dynamics models are usually built in steps of increasing complexity. However, as noted by Sterman (2000), "there is no cookbook recipe for successful modeling, no procedure you can follow to guarantee a useful model. Modeling is inherently creative. Individual modelers have different styles and approaches." This statement, however, does not imply that system dynamics modeling does not have guidelines and is a random process. To the contrary, various modeling frameworks have been proposed in the literature. For instance, Sterman (2000) recommends using a "road map" consisting of five interactive activities:

- *problem articulation,* which describes (i) existing patterns of behavior over time; (ii) the nature, scale, and boundaries of the problem being addressed and its key variables, (iii) how the problem has manifested itself and was addressed in the past, and (iv) if left unresolved, how the problem would manifest itself in the future.
- *dynamic hypothesis formulation,* consisting of mapping the current causes and consequences of the observed behavior and identifying the endogenous issues and feedback mechanisms deemed responsible for that behavior.
- *simulation model formulation,* comprising building the model, selecting the parameters that enter into its structure, deciding on initial conditions, and testing the model for consistency and other attributes.
- *testing of the model*, which is done by (i) comparing its predictive behavior with actual behavior; (ii) subjecting the model to unusual and extreme conditions (i.e. testing its robustness); and (iii) seeing how the predictive behavior changes by varying the system variables (sensitivity analysis).
- *policy design and evaluation*, which is conducted by exploring different scenarios or strategies and their consequences which leads to proposing tangible recommendations to

address the problem and foreseeing possible side effects associated with these recommendations.

Ford (2010) suggests a similar road map consisting of eight steps combined into six key activities: (i) problem familiarization (step 1); (ii) problem definition (step 2); (iii) model formulation by constructing stock-and-flow diagrams (step 3) and causal loop diagrams (step 4); (iv) parameter estimation (step 5); (v) simulation to explain the problem being addressed (step 6); and (vi) simulation analysis consisting of sensitivity analysis (step 7) and policy analysis (step 8).

Both Ford and Sterman emphasize the cyclical and iterative process between the different components of system dynamics modeling as illustrated in Figure 4.6. They also divide the modeling process into qualitative and quantitative modeling. The first two activities suggested by Sterman and the first three of Ford's plan can be seen as the qualitative and conceptual components of system dynamics modeling. The other activities emphasize the quantitative dimension of that modeling. These two dimensions of system dynamics modeling are discussed further below within the context of community development.

In general, building dynamic systems models is a learning experience for all participants involved (Vennix et al., 1997) whether as individual modelers or members of a group (Berard, 2010). They gain deeper insights about the problems themselves. According to Hovmand (2014), they go through an awareness (discovery) journey from recognizing first that they are dealing with systems to ultimately understanding, at least in part, why things happen in the systems. In between these two benchmarks, the model developers learn about (i) the components of the system and how they interact through feedback mechanisms; (ii) possible places to intervene in the system, leading to transformation; (iii) existing system archetypes; (iv) places of accumulation and forms of nonlinear relationships; (v) existing sources of dynamic behavior; (vi) possible leverage points; and (vii) the importance of boundary and initial conditions. Being able to have such a high-level awareness about a system requires that all involved in model development be trained accordingly not only as individuals but also as members of a group model-building team as discussed further in Section 4.6.

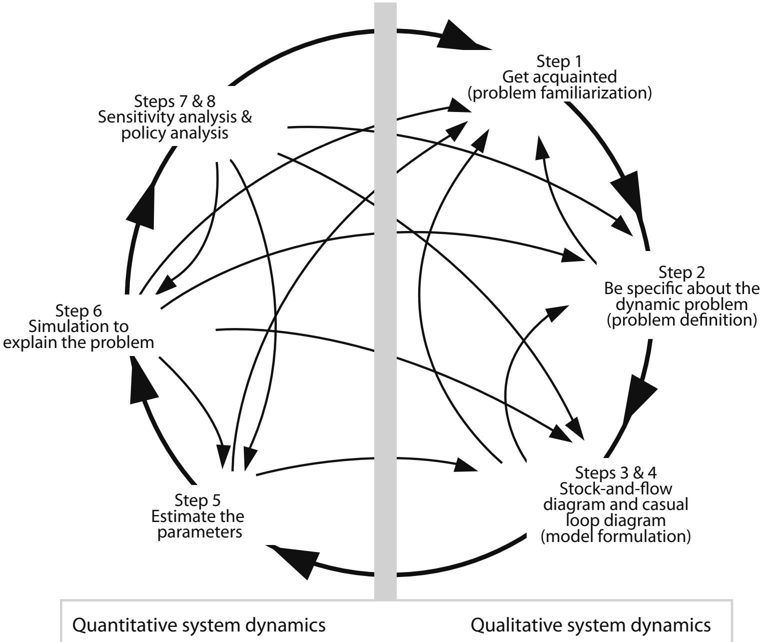

Figure 4.6. Different components of system dynamics modeling.

Note: The components are divided into those involved in qualitative modeling (right hand side) and those involved in quantitative modeling (left hand side).

Source: Ford (2010), with permission from Island Press.

Before going into the details of qualitative and quantitative modeling, a few remarks need to be made about what to expect from system dynamics models. First, one should not expect models to be validated since they are virtual representation of reality. They are not reality itself and there is no such thing as a "good model." However, there is such thing as a "useful and sound model" in the sense that the model is useful, sound, and consistent in *simulating* reality to a certain extent (Forrester, 1961; Sterman, 2000). According to Barlas (1996), the validity of a model can be described in its "usefulness with respect to some purpose" keeping in mind that "the usefulness of the purpose itself" needs to be formulated as well. Since system behavior is dictated by structure, validating a model is also about its usefulness with respect to some structure and its environment (context and scale). In development projects, the purpose would be to address any real situation that the community is facing, such as to manage the availability of drinking and irrigation water over a period of one year. The usefulness of that purpose is obvious with regard to community survival and economic development.

Second, as one goes through the different steps in the system dynamics framework, more confidence in the model's usefulness is likely to grow (Barlas, 1996). Confidence starts with having a clear understanding of what is expected in the five activities of model building mentioned above. The books of Richmond (2004a, b) and Fisher (2011) provide detailed recommendations of model building around multiple practical examples.

Building confidence in the model also requires a continuous feedback between the model itself and the real world that the model is supposed to represent (Sterman, 2000). This can be seen as an ongoing "reality check" in order to prevent the model from going astray. Finally, confidence in the model can be gained by conducting several tests that have been proposed by system dynamicists. These tests are listed in Table 4.2. A more detailed review of these tests can be found in Forrester and Senge (1980), Barlas (1996), and Sterman (2000). Most of these tests are appropriately mentioned in the following discussion on qualitative and quantitative modeling within the context of community development projects.

Table 4.2. Tests used to gain confidence in system dynamics models. This table was constructed based on the work of Sterman (2000, pp. 859-861) and Forrester and Senge (1980).

Tests	Purpose	Rationale
Boundary adequacy	Appropriateness of selected boundary to address the problem of interest. Does the outcome of the model change with the selected boundaries?	Boundaries control how systems are framed, what is in (endogenous) the model and what is out (exogenous)
Structure assessment	Assessment of how well the structure of the system has been formulated in terms of possible inconsistencies, conservation laws, unit consistencies, appropriate level of aggregation to capture the dynamic of the problem of interest	Garbage in, garbage out. Inconsistencies create confusion. Violation of conservation of mass and energy will lead to erroneous answers. More details in the model may or may not be necessary to understand the problem of interest

Tests	Purpose	Rationale
Dimensional consistency	Consistency of units between flow and stock	Inconsistencies create confusion
Parameter assessment	Making sure that model parameters are relevant and represent something real in the problem being addressed. Objective or subjective assessment of parameters and their variation is necessary	Garbage in, garbage out
Extreme conditions	Test the robustness of the model and see if it provides logical responses when parameters are given extreme values	Identify limitations of the model How far can we push the model?
Behavior reproduction	Compare model prediction (qualitative and quantitative) to reference behavior of the problem of interest. Forrester and Senge (1980) introduce four additional subtests. Helps build confidence in using model for predicting future behavior	If the prediction is not adequate, the model needs to be changed and parameters reevaluated. It makes no sense to use the model for predicting future behavior
Behavior analysis and surprise behavior	Identify unexpected forms of behavior and anomalies by changing model structure and assumptions	The model may show expected or unexpected forms of behavior, some more realistic than others
Sensitivity analysis	Test the model to see how the system responds to the variation of one or several critical parameters. The variation can be described statistically	The world is not deterministic and all parameters entering into a system are not fixed
Policy analysis	Help identify new policies that will help the system perform better in the future. Forrester and Senge (1980) introduce the policy and extreme policy tests	Old policies are responsible for the current behavior. New policies must be introduced for change to take place

Qualitative System Dynamics Modeling

Qualitative system dynamics modeling can be seen as a seamless continuum ranging from being acquainted with a problem to defining a clear problem statement (problem articulation and formulation) to developing a simulation model that best describes the problem being addressed. This conceptual aspect of system dynamics modeling is represented by the right hand side of Figure 4.6.

Before any model of any problem can be built, it is imperative that the problem and its underlying dynamic issues are clearly framed, contextualized, and described explicitly. This is referred to as developing a *reference mode of behavior* (Ford, 2010). It makes no sense to jump into the modeling phase of system dynamics if the problem of interest or at least its essence cannot be formulated, even in a simple manner.

As further discussed in Chapter 6, in community development projects, the preappraisal and appraisal phases are critical in mapping the community and creating a community baseline. The baseline helps define the reference behavior pattern of the community in its current state. The baseline describes the different forms of capacity and vulnerability of the community; its context, structure, and behavior; its boundaries and degrees of freedom; and the social rules that the community has adopted in its functioning. Once such a community baseline is established, community problems can be identified and ranked, their causes and effects explored, and assumptions and working hypotheses made with regard to the problem's dynamic. From the baseline, a conceptual model of the community (or part of it) and the issues it faces can be formulated with participation from key community leaders and stakeholders. They also need to develop some consensus as to what changes and forms of behavior they would like to see when the problems are resolved. The system dynamics model can be local and/or contain subparts associated with special issues faced by the community such as water, energy, transportation, health, economics, food, etc.

Several questions arise in the process of defining each problem, creating a dynamic hypothesis, and formulating a model. They can be framed into the *why*, *what, how, who, when,* and *where* of the dynamic modeling process. Examples are given in Table 4.3 within the context of community development projects.

At the community level, a decision needs to be made about the *endogenous* issues and components (i.e., originating from within) that need to be included in the dynamic model and those *exogenous* issues and components (i.e., originating from without) that can be set aside when trying to model and understand community behavior. Some issues may need to be excluded, at least during the first step in the iterative modeling process. They may be included later or on an as needed basis (Ford, 2010). In all cases, the decision to include specific issues needs to be made in a participatory manner with the community. Endogenous issues might be issues related to water, jobs, health, food, transportation, community dynamic, etc. Exogenous issues might be related to the influence of other communities and policy decisions dictating the community's well-being, etc.

Table 4.3. Questions that may arise when creating a dynamic hypothesis and formulating a system dynamics model.

Why	• Why is a dynamic model constructed?
What	• What problem and behavior (reference mode) is being modeled and over what time frame and spatial scale? • What methods other than (or complimentary to) dynamic modeling can be used to model the problem? • What would happen if the problem were or were not addressed? • What solutions have been attempted in the past to address the problem and what were their outcomes? • What are the components of the problem being addressed and their connections? • What range of responses can be expected from the model?
How	• How will the model complement the traditional steps of project management? • How have the components of the model interacted in the past? • How will community members be involved in building, reviewing, and updating the model? • How will the model recommendations be presented to the community members?
Who	• Who is participating in developing the model (insiders and outsiders)?
When	• When should the model be integrated into project management? • When should the model be started, evaluated, modified, and updated?
Where	• Where should model development and community interaction take place (office, community)?

A second step in building a system dynamics model is to decide on its spatial and temporal boundaries. They need to be *reasonably* defined in breadth or extension (horizontal) and in depth or intensity (vertical). In the case of community development projects, the horizontal characteristic deals with the cross-disciplinary nature of the problems faced by the community (health, water, sanitation, energy, shelter, jobs, etc.). The vertical component is associated with how deep and detailed it is necessary to go (in a reductionist manner) into each development discipline in order to address each problem. Finally, the time frame (days, months, years) simulated by the model must be selected as well as the system's initial conditions (defined by the community baseline).

Boundaries are critical to system dynamics modeling as they determine how systems are framed (Richmond, 2004a, b). They differentiate between "what is in and what is out, what is deemed relevant and irrelevant, what is important and unimportant, what is worthwhile and what is not, who benefits and who is disadvantaged" (Williams, 2008). The boundaries of system dynamics models may in some cases coincide with those in the real world. In community development projects, the spatial boundaries are likely to be geographical (community, village, household, watershed) and the temporal boundaries may include seasonal, monthly, or yearly activities. If the projects are too complex and the boundaries cannot easily be identified, artificial boundaries may need to be selected in order to simplify the complexity at stake.

It should be remembered that the conclusions reached in modeling any system depend, to a large extent, on the context and the selected boundaries. As the complexity of a model grows, boundaries may need to be expanded to see if the conclusions about the system behavior remain the same or change. This is defined as the "boundary adequacy" test by Forrester and Senge (1980) and Sterman (2000). In practice, boundaries should not be too narrow or too wide, not too shallow or too deep, and not too short or too long. According to Ricigliano and Chigas (USAID, 2011), a special effort must be made within the system boundaries to balance comprehensiveness and comprehensibility when developing models. In community development projects, decisions may be made to model a neighborhood in a community, which could be extended to the entire community, and ultimately to several interacting communities in a region. Likewise, temporal boundaries may be extended to include the community's performance over several years or a decade.

The last step in the qualitative part of system dynamics modeling is to formulate the model in terms of stock-and-flow and causal loop diagrams. According to Richmond (2004a, b), constructing stock-and-flow diagrams requires following certain guidelines. The basic building blocks (stock, flow, conveyor belts) of the model must be selected first. Selecting these components is based on (i) what is accumulating (reservoirs); (ii) what processes are flowing in and out of the reservoirs (flow); and (iii) what processes control the flow (reinforcing or balancing). Both stocks and flows can be physical or nonphysical in nature. Table 4.4 lists several types of tangible (can be measured) and intangible (cannot be measured) stocks and flows that could enter into community development projects.

Following selection of the model's building blocks, a decision needs to be made on how these blocks are connected, paired, and dependent on each other through direct (linear) causality, reciprocal causality, closed-loop causality, feedback mechanisms (reinforcing and balancing), and delay.

Table 4.4. Possible tangible and intangible stocks and flows that could enter into the system dynamics modeling of community development projects.

	Tangible	Intangible
Stocks	Populations (male, female) Food Energy Resources Land Houses Labor (jobs) Trees Roads, traffic, vehicles Water, pollutants Cash Cattle Equipment	Poverty or wealth Quality of life Happiness Health Hunger Quality Anger Satisfaction Confidence Morale Motivation Attractiveness Leadership
Flow	Hiring, layoff Saving	Learning Growing

	Tangible	Intangible
	Producing Being born, dying Constructing Depreciating Being infected Adopting Earning, spending Pumping, recharging Evaporating, infiltrating	Becoming aware Contributing Leading Managing Changing behavior Liking, disliking Becoming sustainable Understanding Assuming

It is obvious that the number of possible combinations of stocks and flows can be quite large when building stock-and-flow diagrams. However, as with the archetypes mentioned in Section 4.4, several generic stock-and-flow diagrams can be built to represent archetypical forms of system behavior. The reader will find several of these diagrams in Tables A.1 and A.2 in the Appendix. In Chapter 5, these generic stock-and-flow diagrams are combined to form modules around issues that are important to communities (e.g., population, water, housing, food, etc.). They are also used in Chapter 7 to illustrate the dynamics of community development projects.

In constructing stock-and-flow models, rules must be followed (Richmond, 2004a, b). First, care must be taken to respect unit consistency, that is, each flow in or out of a reservoir must use the same units of measure as the reservoir itself, except that flow is measured "per unit of time." Likewise, all stocks attached to a given flow path must use the same unit of measure. Second, conservation laws of mass and energy must be respected.

Causal loop diagrams, such as in Figures 2.4, 4.1, and 4.5, can provide an alternative way to conceptualize and comprehend the interaction of components at play in complex dynamic systems (Wolstenholme, 1990, 1999). They may offer additional insights about the nature and intensity of feedback mechanisms and how reinforcing and balancing processes unfold in such systems. They can be built before, during, or after constructing stock-and-flow diagrams, depending on the problem being analyzed and the modeler's preferences.

At the end of the qualitative part of system dynamics modeling, causal loop and stock-and-flow diagrams have been constructed, key model variables and their relationships have been identified (at least preliminarily), and boundaries and initial conditions have been selected. Several tests will have been conducted to build confidence in the model. According to Forrester and Senge (1980) and Sterman (2000), these include (i) evaluating the adequacy of the selected boundaries; (ii) assessing the model structure for inconsistencies with the real problem structure; and (iii) insuring a proper level of aggregation. Both (ii) and (iii) are part of the "structure assessment" test listed in Table 4.2.

From Qualitative to Quantitative Modeling

At this critical stage of the system dynamics modeling process, a decision needs to be made whether to proceed with quantitative modeling of the problem of interest. In the system dynamics modeling of social systems such as communities, it is likely that some processes involved in the problem of interest are quantitative and for which hard (objective) numerical data are available. It is also likely that other processes remain qualitative and can never be quantified. Only soft (subjective) data are available. Addressing these two process types requires alternating between critical and creative thinking, as described in Chapter 3; together, they produce the systems thinking necessary to develop these models (see Table 3.2).

As discussed by Vennix (1996), there has been a lot of discussion in the system dynamics literature about the limitations of qualitative modeling since it does not provide a complete understanding of the problem being addressed. It is clear that only quantitative modeling can provide that understanding. But, as discussed by Vennix, an argument can be made about what represents "full understanding" especially when applied to open and adaptive complex systems such as communities. Since, as discussed in Chapter 3, we are more interested in a process of "satisficing" than "optimizing" when dealing with complex systems such as communities, we can argue that qualitative system dynamics modeling provides a real-value proposition in (i) the form of a learning environment; (ii) the process of understanding communities better; and (iii) making more intelligent project management decisions. Of course, the fact that there are positive aspects to qualitative modeling should not preclude the use of quantitative modeling when data is available for some parts of the system. Doing so should lead to a fuller understanding of the problem (Vennix, 1996). In community development projects, the quantitative data collected during community appraisal can be included in the quantitative modeling of certain tangible issues faced by the community such as water, energy, and food management and job creation. However, it is likely that intangible social and cultural issues can only be qualitatively modeled.

Quantitative System Dynamics Modeling

Once a mental model is created and quantitative modeling is deemed an appropriate step forward, numerical simulations of stock-and-flow models can be run using simple input data at first in order to test the model performance, and its overall stability and equilibrium (i.e., behavior under steady-state conditions). Values are assigned to the various parameters entering into the models. These parameters need to have real-world equivalent and appropriate values that are checked using the "dimensional consistency" and "parameter assessment" tests as suggested by Sterman (2000).

The results of the simulations are compared with the behavior of the real-world problem that is being simulated. This is defined as a "behavior reproduction" test (Sterman, 2000) which can be seen as an evaluation (sometimes called validation) of the modeling process and confidence building. In community development projects, the quantitative modeling of water, energy, food, shelter, and other critical issues can be compared with existing conditions prevailing in the community or conditions that may have prevailed in the past. Based on the outcome of that evaluation, the model can be modified, restructured, and ultimately improved. Over time, more complex input data and information can then be included once confidence has been built around the model. The different steps of system dynamics quantitative modeling and their interaction are represented by the left hand side of Figure 4.6.

Through multiple simulations, the system's overall behavior is studied under various assumptions (i.e., "what if" or "what happens if" simulations), possible leverage points are identified, and possible forms of unintended consequences are explored (i.e., "surprise behavior test" according to Sterman, 2000). Ultimately, a new and better way of understanding the system emerges and the decision can be made whether the model is "robust" enough to generate meaningful patterns (Ford, 2010). The robustness of a model can be assessed using the "extreme conditions" test as suggested by Sterman (2000) where the model's behavior is tested under conditions far from equilibrium. This helps define the application range of the model, its limitations, and any surprise behavior it may engender. In community development projects, the quantitative modeling of water, energy, food and shelter issues and other critical issues can be tested under the extreme conditions that the community may have faced in the past. The response of the community to such challenges can help predict how the community may respond to more extreme conditions in the future.

Once in place, a robust model becomes a very useful tool to explore scenarios that are created by changing the values of one or several parameters. As noted by Houghton et al. (2014), the model can be tested for variables that follow certain probabilistic distributions (e.g., Monte Carlo analysis). Sensitivity analysis tests (as described by Sterman, 2000) can be carried out to analyze how a system responds to the variation of one or several critical parameters. Such analyses may, in turn, help select a decision-making process that could lead to second-order changes in a system (as discussed in Section 3.2) and have tangible impact (i.e., "policy sensitivity" and "extreme policy" tests as suggested by Forrester and Senge, 1980). Policy tests may recommend developing new models or modifying existing ones as shown in the iterative process of Figure 4.6. In community development projects, the quantitative models may be tested to assess the vulnerability of the community to a range of possible adverse events that it may encounter in the future. This may help in identifying more systemic changes that need to be in place before such events take place.

4.6 Individual and Group Decision Modeling

The sheer complexity and uncertainty of development projects raises the question of the nature of core thinking practices expected from individuals involved in making decisions in the complex adaptive context of small-scale development projects. Another way of rephrasing that question is what should the habits of practitioners interested in applying system dynamics modeling tools in development projects be within the context of the development 5.0 mindset discussed in Chapter 2. The follow-up question is how individual practices enter into project team decision making and modeling.

Individual Core Practices

It is clear that, at the individual level, development practitioners would benefit greatly by using a systems approach in their projects and adopting the habits of system thinkers shown in Table 3.1. As noted by the Waters Foundation (2014), these habits represent thinking strategies (visual, listening and speaking, and kinesthetic) that a decision maker might want to follow to address complex problems. To that general list of habits, we may want to add project specific habits such as:

- adopting an adaptive and reflective practice;
- being able to recognize community behavior patterns and infer their underlying structures;
- being able to operate in qualitative and quantitative ways as needed;
- considering the context, content, scale of projects;
- identifying and making use of feedback mechanisms;
- looking at projects as being the right ones, done right, and for the right reasons;
- considering an integrated approach to planning and design;
- embracing and welcoming community participation;
- being aware of one's own strengths, weaknesses, humility, patience, and biases;
- being willing to learn through experience;

- expecting many unintended consequences and adapting to new normal situations; and
- accepting not-so-perfect project outcomes (even failure) as a way of learning life-long lessons and gaining insights.

As noted by Vaughan (2013), the aforementioned habits help in defining generic core thinking practices that are needed by decision makers when faced with complex problems. They include (i) understanding the big picture; (ii) understanding the underlying behavior; (iii) seeking systemic change; (iv) acknowledging limiting beliefs; and (v) seeking to create a shared vision.

Group Core Practices

System dynamics modeling can be carried out by one or two modelers or by groups of individuals (Berard, 2010). The second option is likely to be more the rule than the exception since development projects are by nature participatory, multidisciplinary, and involve multiple stakeholders such as community members, government representatives, and outsiders (see Figure 2.1). If system modeling tools are used to complement traditional project management tools (see Chapter 6) for a community project, it becomes critical to ask how a multidisciplinary team of stakeholders creates a functional decision-making system and mode of operation capable of handling complexity and uncertainty.

This question has been addressed in the literature by several authors interested in the broader context of group decision making and negotiation around a problem faced by a client (e.g., a community). An excellent review of that literature can be found in Rouwette et al. (2006) and Richardson and Andersen (2010). Among the various methods of group decision making is *group model building* which explicitly uses system dynamics tools and actively involves the participation of group members in the decision-making process (Vennix, 1996; Andersen et al., 1997). In community development projects, the community members are assumed to participate in group model building. Variations of that method include the *Community Based System Dynamics* method (Hovmand, 2014) and the *Participatory System Dynamics* method (Stave, 2010).

Berard (2010) provides a detailed comparison of 16 different group modeling frameworks described in the literature. They all use essentially the same steps of system dynamics modeling described earlier in Section 4.5 and emphasize the difference between qualitative and quantitative modeling. They differ primarily in how they handle the *structural* dimension of group dynamics (i.e., group logistics and decision making) and its *process* dimension (i.e., how problems are articulated, hypotheses selected, and modeling activities carried out). To the list of the *why, what, how, who, when,* and *where* of the dynamic modeling process listed in Table 4.3, we can add several questions that relate more specifically to the dynamic of the participants in group modeling sessions in the context of community development projects:

- How many participants are included?
- Who are the participants?
- What is the distribution of participants (community, government, outsiders)?
- What skills and knowledge should participants bring to the group?
- What should be the role of each participant?
- How will be participants be trained in group model building?
- When and where should group modeling meetings take place?
- How will decisions in model building, evaluation, and change been reached and disagreement/conflict handled?

Figure 4.7 shows an example of group model building methodology proposed by Vennix (1996). It summarizes some steps that can be taken from considering a problem brought forth by a client (e.g., a community) all the way to constructing group models. The first decision that needs to be taken is whether a system dynamics model is appropriate to approach the identified problem. The parameters involved in that decision process include the dynamic and complex nature of the problem, the existence of a reference mode of behavior, the participants involved in group modeling, and the qualitative and quantitative nature of the problem being addressed. In community development projects,

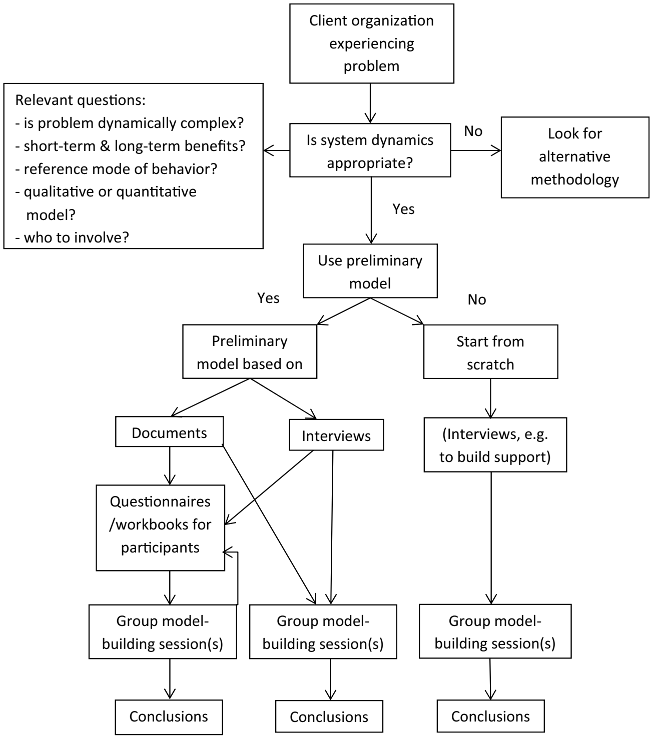

Figure 4.7. Example of group model building methodology. Following decision to use a system dynamics model to address a problem faced by a client (e.g., a community), two possible tracks are possible: bring a preliminary model to the client or "start a model from scratch" with the client.

Source: Vennix (1996), reproduced with permission from John Wiley & Sons.

once these issues are addressed, the next decision is whether to develop a system dynamics model of the community (or parts thereof). Figure 4.7 shows two possible tracks in developing such a model: bring a preliminary model to the client or "start a model from scratch" with the client.

As noted by Vennix (1996), using a preliminary system dynamics model of the problem being addressed has the advantage of starting the group discussion early and can save some time in reaching decisions. The downside is that the model is imposed onto others who were not part of its development. In community development projects, this approach would resemble more a contractual or consultative mode of participation imposed by outsiders, rather than a collaborative or collegial approach (Biggs, 1989). However, one can legitimize using a preliminary model in the prefeasibility study part of a project while accepting that the model can be abandoned and a new one built with participation from all stakeholders. In that case, according to Vennix, the preliminary model can be built based on interviews and existing documents, which represent primary and secondary data in community data collection. Other situations that legitimize using a preliminary model include, according to Vennix: (i) the group has limited expertise in model building; (ii) time is limited; and (iii) the group members are located far from each other and/or it is difficult to arrange meetings.

Whether one involved in community development uses a preliminary systems dynamic model or "starts from scratch" as suggested in Figure 4.7 by Vennix (1996), participatory action research (PAR) methods must be followed to collect information about the community. These ethnographic methods are commonly used for community appraisal in health and social sciences, agriculture, and development (Spradley, 1979; Cornwall and Jewkes, 1995; Scheyvens and Storey, 2003; Chambers, 1983, 2005). PAR methods include direct observation; participatory mapping; transect walks; interviewing; timelines; participatory diagramming; wealth and well-being rankings; and questionnaires, among many others. A combination of PAR, project management, and systems tools contributes to refining the system dynamics model until it is deemed satisfactory enough to lead to developing a project implementation plan as discussed in Chapter 6.

A Reality Check of Group Modeling

Within the context of complex adaptive systems such as communities, it is clear that group model building provides an interesting value proposition in engaging various stakeholders in making decisions in a collaborative way. The outcome of that process is of course limited by the uncertainty and complexity involved in all the systems interacting at the community level (Figure 3.1) and by how ill-defined problems at the community level are. The outcome is also limited by the bounded rationality of the group participants regardless of the culture they come from.

As remarked by several authors (Andersen et al., 1997; Vennix, 1996; Richardson and Andersen, 2010; Hovmand, 2014), group model building requires a high level of coordination from the decision-making team. This can only be done if the team members are assigned specific roles in conversation facilitation, model building, analyzing the results of the model, making decisions and recommendations, conveying the decisions to the community members, revising the decisions, dealing with disagreement and conflicts, etc. Ideally, the decision-making team needs to a come up with a "shared reality" that they can all agree on (Vennix, 1996).

Group model building also requires a willingness of the clients (i.e., the community stakeholders) to participate in that shared reality and be engaged in the multistep methodology described earlier. This assumes that the client is fully aware of the interactive nature of the methodology and its expectations and has also been trained to think using systems tools. The training is of course a very sensitive issue when dealing with local communities where some individuals have limited levels of education. Hence, the challenge for the modeling team facilitators is to be able to capture ideas from community members in various meetings and interviews and translate these ideas into the system lingo.

It should be noted that this scenario of well-functioning model-building teams holding to a fixed, long-term shared reality is very utopic. More often than not, there is a very good chance that the assumptions and preconditions in that scenario will not be fulfilled and that unexpected situations will arise. It must be remembered that the three major groups of stakeholders involved in community development and shown in Figure 2.1 (i.e., insiders, outsiders, and government representatives) are more likely to have different opinions and difficulty in reaching some form of consensus, let alone agreeing on a system model of the problems they are experiencing in common. The shared reality of a group should be seen as a dynamic concept that needs to be revisited on a regular basis through *reflection-in-action* as discussed in Section 6.4.

4.7 System Dynamics Software

Since the 1960s, several software programs have been developed to build system dynamics models in various fields of science and engineering. According to the System Dynamics Society (2014), the most commonly used software packages include *iThink/STELLA*, *Powersim*, and *Vensim.* These three platforms use a visual and graphical programming approach in the forms of icons consisting of the stocks, flows, converters, and connectors as discussed in Section 4.3. As noted by Hannon and Ruth (2001b), the graphical approach enables the users "to spend the majority of [their] time and effort in understanding and investigating the features of a dynamic system, rather than writing a program that must follow some complicated, unintuitive syntax."

The focus of system dynamics software is on modeling system behavior—linking structure to performance—rather than writing sequences of differential equations. All equations (linear or nonlinear) inherent to the model are solved in the background using the finite difference method and an integration process using the Euler's method or the Runge-Kutta methods (Chapra and Canale, 2009).

This book uses the *iThink/STELLA* software which was originally developed by Barry Richmond. Both software packages are registered trademarks of High Performance Systems Inc. (founded in 1985), now called isee Systems currently based in Lebanon, NH in the United States (http://www.iseesystems.com). iThink and STELLA are identical software packages. Richmond published two guide books both titled *An Introduction to System Dynamics*; one with business applications (2004a) and the other with applications in natural and social sciences (2004b).

All illustrative examples shown in Chapters 5 to 7 were developed using the iThink software (version 10.0.6). They could equally have been formulated using the *Powersim* or *Vensim* software packages. Powersim originated in Norway in the 1980s and is a registered trademark of ModellData currently based in Nyborg, Norway (http://www.powersim.com). Likewise, Vensim was originally developed in the 1980s and commercialized in 1992. It is a trademark of Ventana Systems currently based in Harvard, MA (http://www.vensim.com).

I would like to add a word of caution in regard to using any of the aforementioned software packages. Even though system dynamics models can be initially built in an intuitive manner, the system dynamics modeling of real problems is not easy and requires a minimum amount of training. The author highly recommends the reader to take four basic online training modules called *Introduction to Dynamic Modeling I and II* and *Dynamic Modeling I and II*, which are available (for a fee) on the isee Systems website (Chichalky, 2014). Using multiple real-life examples and the iThink/STELLA software, these excellent modules present the fundamentals of systems thinking and describe the steps necessary to build system dynamics models using the methodology discussed in Section 4.5. The illustrative examples presented in Chapter 5 require the reader to have basic knowledge in system dynamics modeling.

4.8 Mixed-Modeling Methods

Modeling complex systems such as communities is difficult and often requires using a range of modeling methods in order to address various issues (e.g., social, economic, technical, etc.); no one single modeling method can address everything. System dynamics can benefit from other modeling and decision-making methods, and vice versa, as shown in Figure 4.8.

Many modeling and decision-making methods have been proposed in various fields of science, engineering, business, etc. An excellent review of them was conducted by the *Millennium Project* (Glen, 2014). It contains a description of more than 30 methods that could be used

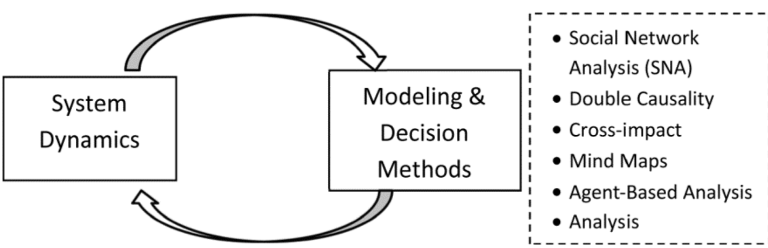

Figure 4.8. Synergy between system dynamics modeling and other modeling and decision-making methods.

separately from or jointly with system modeling when addressing global change issues. The reader will also find an excellent review of project-based analysis methods in the book *Systems Tools for Project Planning* by Delp et al. (1977) and on the website of the System Dynamics Society (2015). I present below a brief summary of four of these methods. Applications of these methods to community development projects will be discussed further in Chapter 6.

Social Network Analysis

Social network analysis (SNA) focuses on the mapping and understanding of how members of a group or several organizations interact and connect in a network (NRC, 2009). The visualization of social networks is not new and has evolved from hand drawn to computer-generated graphs (Freeman, 2000). The results of social network analysis are usually represented as a social map consisting of multiple nodes connected by links or ties that define the social fabric or web. Single or double arrowheads can be added to map how one node affects another. A generic example is shown in Figure 4.9 where nodes could represent social agents or actors (groups, individuals, or partners) and the links represent how the agents or actors are interconnected in addressing a specific issue at a given time.

In SNA maps, the size of each node can represent the importance of an agent in the network and the thickness of each link can indicate the strength of the connections between agents. The network representation could also be used to map the flow of resources and how decisions are made in any group such as a community. This may aid in identifying in that community, for instance, patterns and steps in decision making, existing clusters of decision makers, who are the critical actors in decision making, and who is being marginalized. Figure 4.9 could also be used to show infrastructure interconnectivity where the agents are systems that comprise the infrastructure such as transportation, energy, water, health, among others. Examples of application of SNA relevant to the topic of this book can be found in Moore et al. (2003), Dale (2011), Blanchet and James (2013), and Magsino (2009).

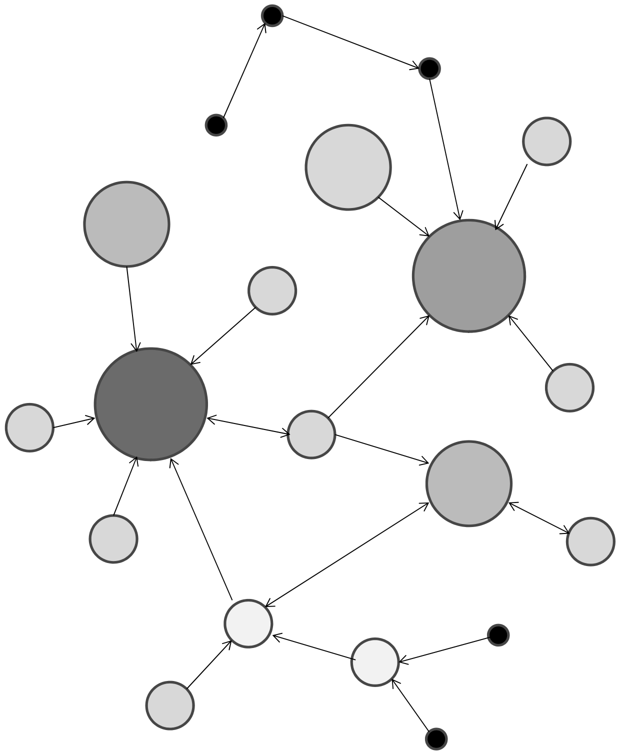

Figure 4.9. Generic social network model showing nodes and links. Nodes could represent social agents or actors (groups, individuals, or partners) and the links represent how the agents or actors are interconnected in addressing a specific issue at a given time. The size of each node is related to the importance of the agents in the network.

Various SNA tools and software are available to carry out dynamic network analysis (NRC, 2009). In a recent book, Borgatti et al. (2013) show several examples of application of SNA using the software UCINET which is available through *Analytic Technologies* based in Lexington, KY. One of the SNA tools called Net-Map was developed by Eva Schiffer for the International Food Policy Research Institute. In addition to the basic network graphical components mentioned above, Net-Map uses influence towers that are placed on the network to show the degree of influence of each node. Schiffer and Waale (2008) give an example of application of that method to model how different groups of stakeholders at the local, regional, and national levels interact in the governance of water resources in a water basin in northern Ghana.

Social network analysis tools and software not only create a quick visualization of a network and its components as shown in Figure 4.9, but also help identify the strengths, weaknesses, and patterns of interaction; identify potential attractors; make predictions; assess the network resilience; map assets and forms of vulnerabilities; conduct simulations; and plan interventions that leverage or strengthen existing network connections. Although SNA focuses more on the components of social networks and their patterns of interactions, it pays less attention to the nature of those interactions which can be handled better both qualitatively and quantitatively by system dynamics tools. In summary, SNA and system dynamics complement each other and are ideal tools to map communities and comprehend their currents and patterns of interaction.

Double Entry Causality Tables

Double entry causality tables (matrices or impact matrices) are used to display the linkage and feedback that exist between parameters when considered in pairs. Table 4.5 shows an example that summarizes possible forms of causality and cross-impact between four variables: water, energy, food/agriculture, and health. The diagonal boxes of the 4×4 table are empty since they represent one parameter influencing itself. The off-diagonal boxes in the table are nonsymmetric and indicate how two different parameters influence each other. As an example, the influence of water on energy (first row and second column) is different from the influence of energy on water (second row and first column). The off-diagonal terms can be understood as representing the feedback mechanisms that exist as two parameters interact in an interdependent manner.

Double entry causality tables can also be used to represent the relationship between various stakeholders (individuals and/or organizations) as suggested, for instance, by Biggs and Matsaert (1998) and Davies (2003). In that case, the off-diagonal terms in the tables describe the nature of the links that each stakeholder has with the others, which complements the social network analysis mentioned above. The strengths of the influence between two stakeholders can be categorized qualitatively (high, medium, or low) or quantitatively (0 for no influence, up to 5 for high influence). Analysis of these influence factors can be used to determine the consistency of various decision-making scenarios involving multiple stakeholders with different opinions (Weimer-Jehle, 2010) and their degrees of dependence and influence (Arcade et al., 2014).

Table 4.5. Double entry table showing the causality between water, energy, food/agriculture, and health.

	Water	**Energy**	**Food/Ag**	**Health**
Water		Water is used for energy extraction and production.	Water is used for agricultural production.	Water is necessary for hygiene and sanitation.
Energy	Energy is needed to run water infrastructure and desalination. Possible pollution of water bodies.		Energy is needed in mechanized agriculture.	Energy is needed to provide health services. Possible side effects of energy on public health.
Food/Ag	Agriculture requires water. Possible contamination by agrochemicals and land degradation.	Production of biofuels. Food and agricultural residues and biomass can be used in biogas digesters.		Food is needed for nutrition and health. Shortage of food creates health problems.
Health	Health services create water (quality and quantity) demand. Adequate service level must be met.	Health services create energy demand. Adequate service level must be met.	Health services create food (quality and quantity) demand. Adequate service level must be met.	

Note: Off-diagonal terms show how one row component influences the other three column components or how one column component influences the other three row components.

Double entry causality tables or matrices are useful at mapping the nature and extent of feedback mechanisms and interconnections existing in a system. This can help decide what feedback mechanisms to include in causal loop and stock-and-flow diagrams.

Mind Maps

Mind maps are graphical representations of how different components in a system are connected either as cause or effect around an individual main idea or concept. They are very useful in illustrating any system's organizational or hierarchical structure. When multiple ideas and their connections are considered, mind maps are called *concept maps* (Wikipedia, 2014c).

Mind and concept maps can be used as a visualizing and classifying aid in the early stage of system dynamics model development and in deciding what to include in causal loop and stock-and-flow diagrams. The multilayered diagram shown in Figure 1.3 is an example of a mind map showing intradependency in each layer and interdependency across layers. Various software packages for mind and concept mapping are available, a review of which can be found in Buzan (1996) and on the website (Wikipedia, 2014c).

Among the various mind maps, graphical trees are useful to represent the consequences (or effects) and causes associated with a problem. A problem tree has a trunk representing a problem. The problem has consequences (effects) represented by the branches of the tree and causes represented by the roots of the tree. A solution tree (also called result or objective tree) is created as the counterpart of a problem tree with positive roots and optimistic effects. Examples of problem and solution trees will be shown in Section 6.7.

Agent-Based Modeling

Agent-based modeling (ABM) is one of a multitude of computational methods used to simulate how a number of autonomous agents in a system interact under a certain set of rules (Wikipedia, 2014d; Wilenski and Rand, 2014). The rules apply to how agents interact among each other and with their environment; the interactions can change with time and location. In social systems, individuals or groups (the agents) are allowed to change and adapt when subjected to externally and/or internally imposed rules of behavior (Axelrod and Tesfatsion, 2014).

As remarked by Gordon (2014), simple rules in ABM can help create complex system behavior and in some cases create order in something that is apparently random. ABM has been used to model various forms of emergent behavior of social systems, such as how ideas, rumors, opinions, forms of behavior, and epidemics spread; the swarming and flocking of agents; and crowd behavior. In the field of community development, Bousquet (2002), Gurung et al. (2006), and Barreteau et al. (2010) describe several examples of application of ABM to adaptive and participatory natural resource management at nine sites in Vietnam, Thailand, and Bhutan.

Several ABM software programs and toolkits are available in the literature including StarLogo (Resnick, 1997); Netlogo (Wilensky, 2014); and AnyLogic (http://www.anylogic.com), among others. These programs are based on the Sugarscape formulation developed by Epstein and Axtell (1996).

ABM can complement system dynamics modeling but can also stand by itself as a modeling tool (Borshchev and Filippov, 2004). It provides an alternate way to explore how multiple components of a complex adaptive system or subsystem (such as a community or part of it) behave and interact *at the individual level* and how forms and patterns of behavior could emerge from that interaction. ABM is not limited by the high aggregation inherent to system dynamics. It can be used, for instance, to consider the behavior of individual components within a system dynamics stock or reservoir. The stock could represent a specific population, a group, or an institution. Finally, ABM can help explain how a SNA social network is generated and how it could be modified if new rules (e.g., rules of behavior change) were introduced in systems or subsystems that are part of that network.

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CHAPTER 5

Examples of Community Development System Modules

Several stock-and-flow diagrams are presented to model the dynamics of some core issues that are operating in small-scale community development projects. This chapter was written to show development practitioners how to build simple but comprehensive system modules once they have acquired some basic training in systems modeling. The modules can be assembled as building blocks of larger system or subsystem models.

5.1 Introduction

As discussed in Section 4.5 and summarized in Figure 4.6, system dynamics modeling is carried out in steps. They include problem familiarization, problem definition, model formulation (stock-and-flow and causal loop diagrams), parameter estimation, simulation to explain the problem being addressed, and simulation analysis (sensitivity analysis and policy analysis). A fair number of feedback mechanisms exist between these steps. This chapter looks at the simulation part of the modeling framework (steps 3 and 4 in Figure 4.6) and presents various modules that could be of relevance to small-scale community development projects. Chapter 6 discusses how these modules fit into the broader methodology of integrating systems thinking into the different management stages of these projects. Finally, Chapter 7 explores how combining various modules can help in understanding better the complex interactions and associated behavior of communities at different scales.

Section 1.3 mentioned several large scale and comprehensive system frameworks that have been developed over the past 40 years to explore global change and futures scenario planning (e.g., World3-03, International Futures, TARGETS, etc.). These global frameworks are complex and consist of multiple modules, submodules, and feedback mechanisms that can quickly become challenging to the user. It should be noted that these frameworks were specifically developed to address regional, country, or global issues and rely on comprehensive statistical databases. Even though these global frameworks cannot be directly applied to address small-scale community issues, they can serve as a guide when deciding on the components and connections that need to be included in system dynamics models of small-scale communities. This will be further discussed in Chapter 7.

The system dynamics modules presented in this chapter are built on the generic stock-and-flow diagrams listed in Tables A.1 and A.2 in the Appendix. In writing this chapter, it was not my intent to present an exhaustive list of modules that could be used in community development projects. First of all, this would be impossible due to the wide range of issues and processes at stake in such projects. Second of all, there is no need to build modular stock-and-flow and causal loop diagrams from scratch as the literature contains many excellent publications in which such diagrams have been developed to model generic forms of behavior (e.g., archetypes) in various fields of science and engineering. The reader will find such generic models in the books of Richmond (2004a, b), Hannon and Ruth (2001a, b), Fisher (2011), the three "system zoo" books of Bossel (2007a, b, c), and the more recent book by Pruyt (2013). Web searches on system dynamics models will also reveal many useful resources. Reference to some of these models will be made in the modules presented below.

The reader should be reminded that the goal of system dynamics modeling of community development projects is not about cranking out system modules for the sake of it. Development practitioners need to comprehend first the state of a community and its multiple patterns of behavior before jumping into assembling stocks, flow, converters, and connectors. They also need to acquire the individual and team core practices discussed in Section 4.6. To a certain extent, putting system dynamics model building blocks together is likely to appear easier to engineers than trying to understand either social behavior patterns unfolding at the community level or the interaction between social systems and their environment. It is tempting, therefore, to jump head first into the modeling pool, so to speak, without a clear understanding of context. However, such an approach is of limited value. The best practice is first to identify and understand the behavior patterns of communities in a participatory manner, and then to select, modify, and assemble appropriate generic system structures in an effort to reproduce the observed patterns in a given context.

5.2 About the Modules

Several system dynamics modules are presented below to simulate the issues that are most likely addressed by insiders and/or outsiders in small-scale community development projects. These issues include population dynamics, water, food and agriculture, energy, shelter, etc. The modules are presented in a stock-and-flow diagrammatic format and were created using the iThink software (version 10.0.6) discussed in Section 4.7. Even though no numerical simulations are presented in the modules, they were designed assuming that all rates of change (flows) are expressed in units (e.g., of people, food, jobs, construction, adoption, etc.) per year unless mentioned otherwise.

Some of the modules presented below stand by themselves and address only one issue (e.g., population), whereas others involve the combination of closely related issues (e.g., food, population, jobs, etc.). Modules can quickly become overwhelming because of multiple connections between stocks and flows. In the iThink software, this can be simplified somewhat by using the “Ghost” icon function which is a useful tool in creating shortcuts to stocks and flows at several locations in the model. It is described further on the isee Systems website (www.iseesystems.com) along with other modeling tips.

It should be noted that one can add more complexity to the proposed modules by adding additional stocks, flows, converters, and connectors. One rule of wisdom that I have learned from reading the system dynamics modeling literature, listening to teachers, and creating models on my own, is always to start with simple models and make sure that they pass the equilibrium (or steady state) test and all the other tests listed in Table 4.2. As confidence in the models increases, sophistication can always be added to the models in due time.

5.3 Population Modules

Module PM1

The module shown in Figure 5.1 consists of one stock representing the total population of a community. The population increases through birth and immigration and decreases through deaths and emigration. The flows "being born," "dying," "immigrating," and "emigrating" (expressed in people per year) depend on the current population and some rates of change.

This simple stock-and-flow diagram is often the starting point for more sophisticated ones where birth and death rates are related to other issues such as access to water (quality and quantity), food, shelter, education, health clinics, etc. The "Goal Seeking" module shown in Table A.1 could also be added to the stock-and-flow diagram if one is interested in determining how long it would take for the population to reach a desired target. Likewise, the module defined as "Carrying Capacity" in Table A.1 could be added if one is interested in including the carrying capacity of the community (expressed in a maximum number of people) as a limiting constraint in the population growth.

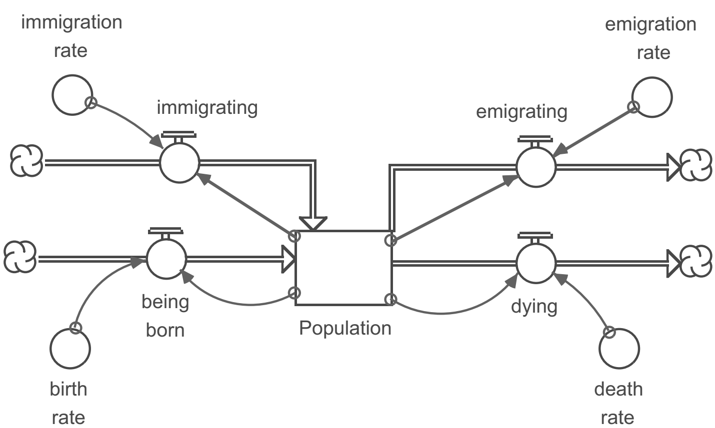

Figure 5.1. Stock-and-flow diagram representing population dynamics.

Module PM2

Figure 5.2 shows how the distribution of the population of a community can be represented using a so-called stock-and-flow diagram "chain" (Richmond, 2004a, b). Five age groups were selected: 0 to 19; 20 to 39; 40 to 59; 60 to 79; and above 80. Different death rates can be assigned for each age group. These rates can themselves be functions of other parameters and be time-dependent. The workforce consists of adults between the ages of 20 and 59 who represent only a fraction of the population. Only a fraction of females in the community is assumed to give birth. That fraction and the number of children born per female may depend on other parameters (e.g., health and education) and be also time-dependent. As discussed by Richmond (2004a, b), this stock-and-flow diagram requires special attention when assigning initial values for each age group population.

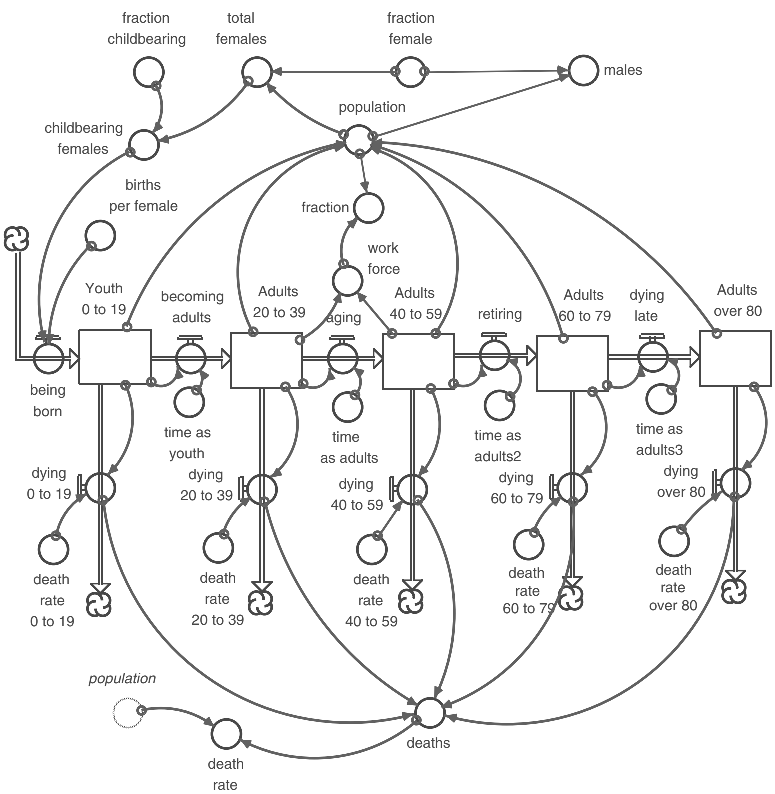

Figure 5.2. Stock-and-flow diagram representing the distribution of a population by age groups.

One can easily build additional components to this stock-and-flow diagram. Examples include (i) breaking down each age group in terms of gender, health, and education; (ii) distinguishing between adults around employment and literacy; and (iii) distinguishing between marginalized and nonmarginalized populations in each age group. More advanced and detailed versions of this module can be found in Bossel (2007c; modules Z601, Z602, Z604, and Z609).

Module PM3

In module PM1, the converters that feed into the four flows (being born, dying, immigrating, and emigrating) are assumed to be constant. This is rarely the case as they may depend on other state and control variables. The immigration rate may depend, for instance, on national policy decisions or health issues. The emigration rate may be related to a lack of job opportunities in a community where younger people move to urban areas. As suggested by Forrester (1971), the birth and death rates may depend on variables such as "food, material standard of living, crowding, and pollution" and other factors such as availability of health clinics and education, among others. The birth and death rates in Figure 5.1 may also depend on the population itself (e.g., birth rate decreases as population decreases). This variability can be handled using the graphical functionality available in the iThink software where each converter can be defined as a function of another converter or time.

Figure 5.3 shows an example where the birth rate depends on the density of a population over an available land area. Comparison between the current density and a normal population density (expected over the land area) affects the population birth rate. The population cannot grow forever and is limited by a certain capacity, which depends on the population density (e.g., population capacity decreases as population density increases). The population follows the logistic S-shape model of Table A.1.

In Figure 5.3, the death rate is assumed to depend on several factors such as the availability of food per person (e.g., death rate increases as food is less available); the access to clinics; the environment; and the availability of public transportation, among other possible factors. The

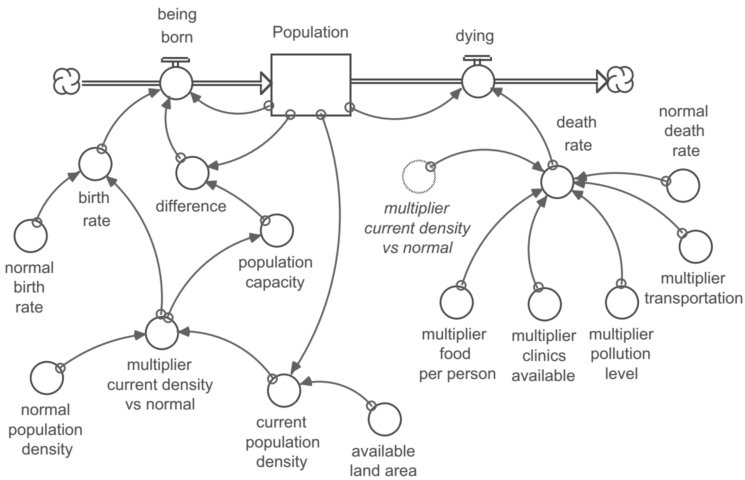

Figure 5.3. Stock-and-flow diagram showing the effect of multiple factors on the birth and death rates.

effect of these parameters on the death rate is accounted for by using various multipliers using the methodology proposed by Forrester (1971) in the *World Dynamics* model and by Bossel (2007c, module Z610a). The population density is assumed to affect the death rate as well.

5.4 Water Modules

Module WM1

The availability of water for domestic, agricultural, and industrial use is critical to community development. Figure 5.4 shows a simplified breakdown of the water cycle from precipitation to different forms of community water supply. The population is assumed to get its water from precipitation falling over a certain watershed area. Part of the water is lost through evapotranspiration. Some water enters and saturates the ground and ultimately recharges the aquifer after soil saturation. The rest of the water is considered as runoff.

Part of the runoff is stored in lakes or man-made reservoirs, some is collected in local catchment systems (e.g., roofs and ground level catchments), and some is taken directly (e.g., pumped) from the rivers. An unassigned amount of water flows into the environment and can be determined by subtracting the cumulative stored water, the catchment water, and the taken-from-river water from the total runoff. More advanced and detailed versions of this module can be found in Bossel (2007b; modules Z301, Z310). The flows out of the various water stocks are not shown and will be considered in Figure 5.5.

As runoff takes place, some soil is eroded which reduces the vegetation cover. Less soil also reduces the growing rate of the vegetation cover, which depends on the amount of soil water. The dynamic of this module has further consequences on crop yield and deforestation and surface vegetation used for cattle feed.

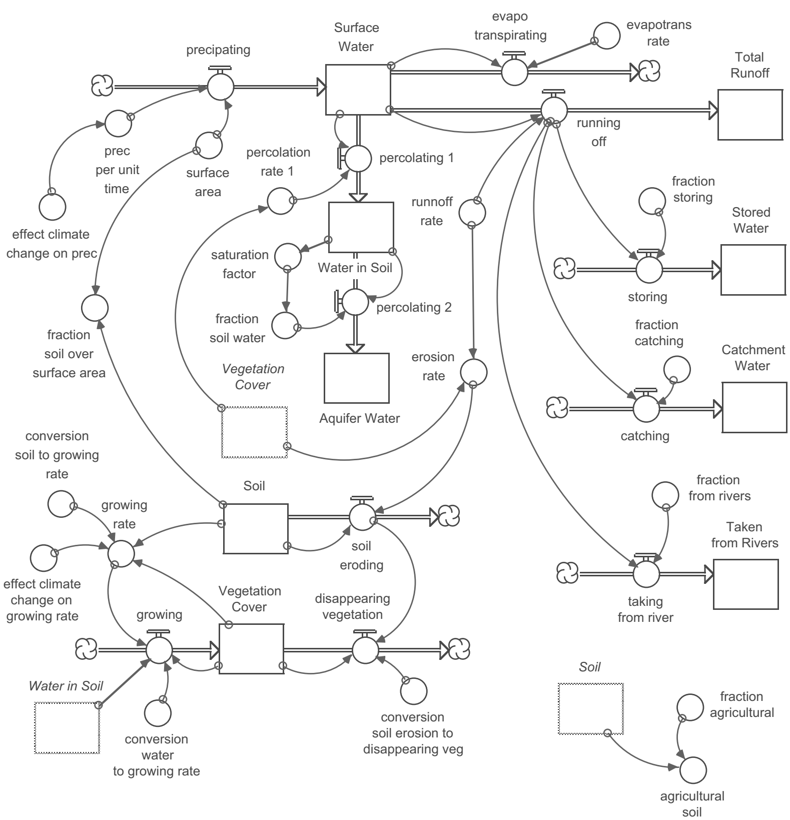

Figure 5.4. Stock-and-flow diagram showing the life cycle of water from precipitation over a watershed area to usage by a population.

Module WM2

As described in the previous module and shown in Figure 5.4, the water available to the community can come from various sources. A community is likely to use some or all of that water for several purposes (WHO, 2011a): (i) domestic including drinking water (DW) and nondrinking water (NDW) used for hygiene, personal washing, cooking, cleaning homes, gardening; (ii) agricultural (crops and cattle); and (iii) industrial. To that list, one could add water used for energy production (e.g., micro-hydro), recreation, and other areas that contribute to the well-being and economic development of a community. Per capita water requirements standards have been proposed and can be used as a guide to determine what is a normal water supply (Chenoweth, 2008; WHO, 2011a, b).

In Figure 5.5, the total amount of water available to the community is determined from the supply sources of Figure 5.4 minus the demand to meet the community needs; the different supply sources can be consumed at different rates. These needs depend on many factors such as "climatic conditions, lifestyle, culture, tradition, diet, technology, and wealth" according to Gleick (1996). They may also depend on the level of community development phase and on the type of sanitation used in households. For instance, flush toilets use much more water than pit latrines. In general, all these variables make it difficult to determine an exact and unique basic water demand.

In Figure 5.5, a certain amount of domestic water assigned as drinking water is treated using various methods such as chlorination, slow sand filters, boiling, or ultraviolet light. An effectiveness factor is introduced to account for how effective the treatment is in providing water quality according to international standards (WHO, 2011a, b). The amount of treated drinking water available per person is compared with standards (Chenoweth, 2008). This is then related in functional form to the death rate. This comparison may help in deciding whether the drinking water demand is met, and if not, what policies need to be put in place to reduce the consumption; assign more water as domestic drinking water; and/or improve the water treatment effectiveness.

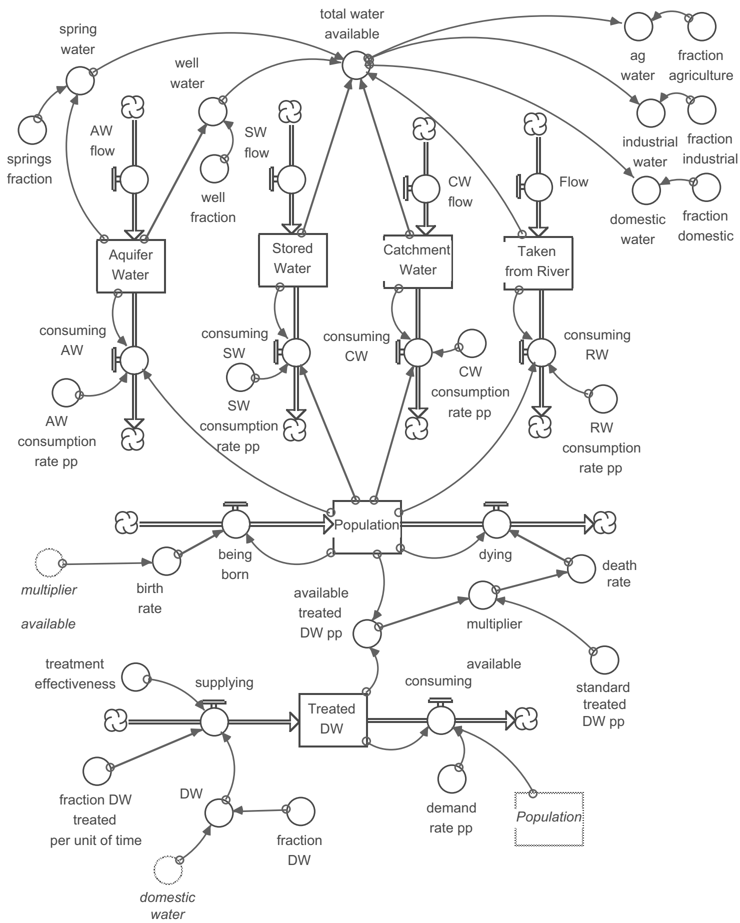

Figure 5.5. Stock-and-flow diagram showing water availability and consumption. A certain amount of domestic water is available as drinking water.

5.5 Food Module

Figure 5.6 shows a stock-and-flow diagram related to food consumption and production similar to the one proposed by Hannon and Ruth (2001a). Food is assumed to be produced locally by local labor which represents a certain fraction of the population. A fraction of the total food is imported as well and is based on the ratio between the consumed food and the available food. Comparison between the amount of food available per person and some standard affects the birth and death rates of the population.

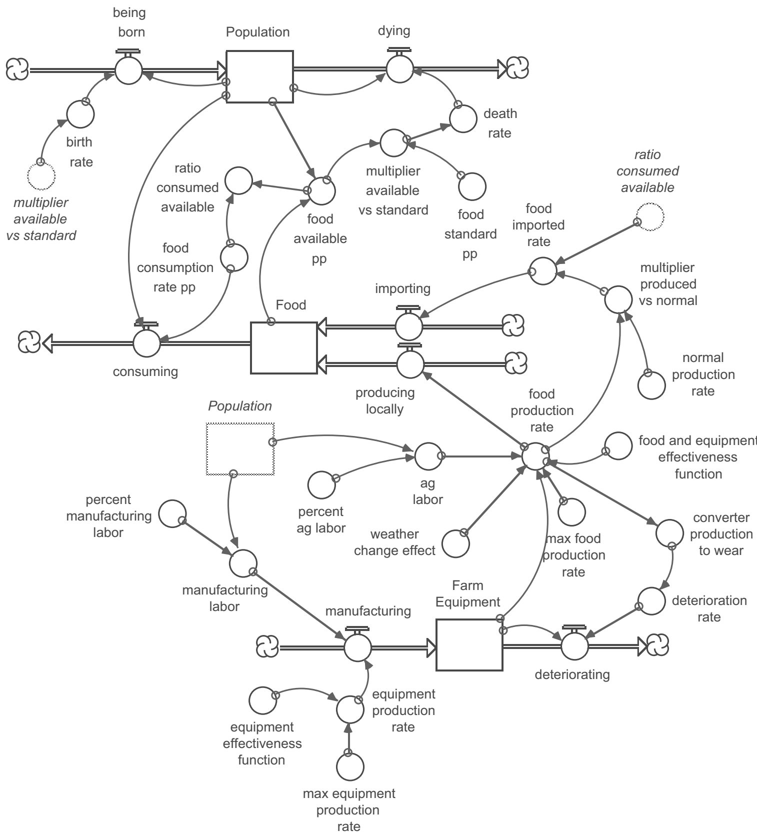

Figure 5.6. Stock-and-flow diagram showing the relationship between a population, food production and consumption, and jobs related to food production and the making of agricultural equipment.

The food consumption, importation, and production rates are expressed in mass of food per unit time. Using a recommendation by Hannon and Ruth (2001a, pp. 52), the rate of food production is assumed to be a product between a maximum value and a function that varies between 0 and 1 and depends on the labor and its effectiveness in producing food.

A fraction of the population is involved in agriculture and another fraction is involved in the manufacturing of equipment used in agriculture. As suggested by Hannon and Ruth (2001a, pp. 56), the equipment production rate (expressed in amount of equipment produced per unit time) follows the same functional form as the food production rate mentioned above. The amount of equipment produced is also assumed to enter into the food and equipment effectiveness function.

Finally, the agricultural equipment is assumed to deteriorate at a rate that depends on the food production rate. The total food production rate is compared to a normal rate of production. The ratio between these two values is assumed to have an impact on the rate at which food needs to be imported.

5.6 Health Module

Among all the possible health modules that can be created, I have selected one that describes the fecal-oral transmission of pathogens from fecal matter to a population. In the field, that transmission can occur along five possible pathways: fluids, fingers, flies, food, and floods. It is often represented in the water, sanitation, and hygiene literature by the F-diagram (Wagner and Lanoix, 1958).

The example shown in Figure 5.7 starts with a healthy population consisting of two groups of individuals based on whether they use sanitary practices (SP) or unsanitary practices (UP). Both groups are exposed to fecal pathogens but are infected at different rates to account for the impact of sanitary practices on health. The infection rates depend on many parameters, one of which is the exposure of the population to fecal matter (amount and proximity). This is expressed in the form of an infection multiplier in Figure 5.7.

The size of the population affected by fecal transmitted diseases (e.g., cholera, giardia, hepatitis, etc.) depends on the fraction of the healthy population becoming sick and how many people are cured by treatment. The treatment rate depends on many parameters including availability of health education, clinics, doctors, and medicine. The "being cured" rate depends on the rate of treatment and its effectiveness. Once cured, people may decide whether to adopt sanitary practices.

The production of fecal matter responsible for the diseases is assumed to originate from animals and open human defecation. Some of that fecal matter decomposes over time and some fraction can be used to feed biogas digesters. These digesters produce energy for cooking and heating. The number of people openly defecating over time is assumed to decrease as access to health education and latrines (and other forms of sanitation) increases.

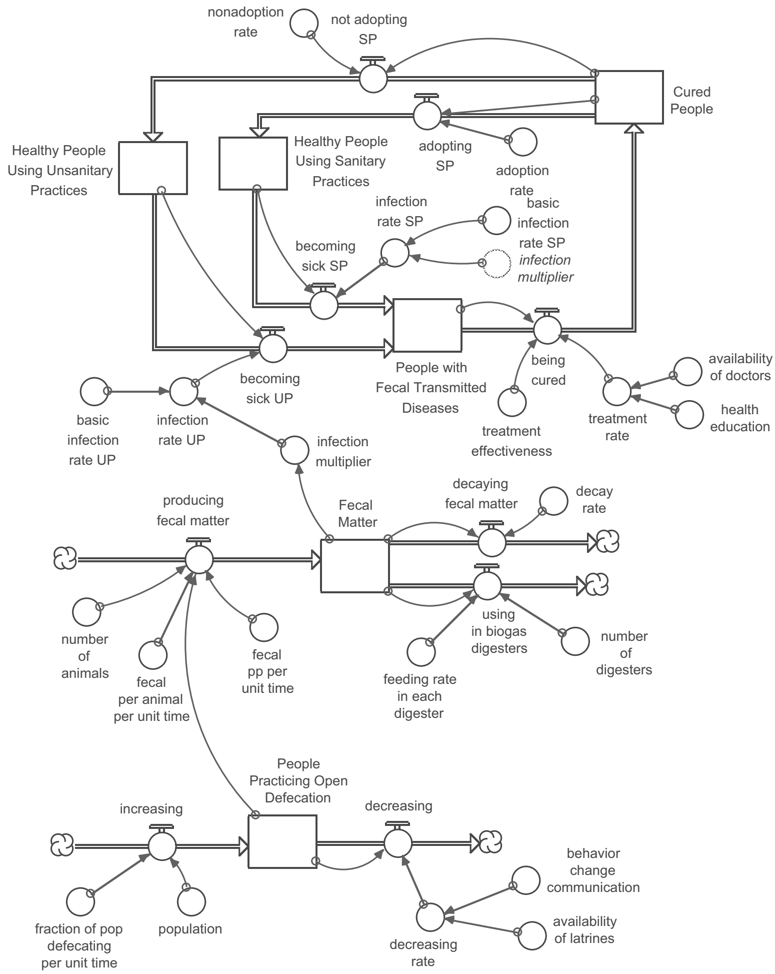

Figure 5.7. Stock-and-flow diagram describing the dynamic of transmission of disease from fecal matter to a population.

Note: UP and SP stand for unsanitary and sanitary practices, respectively.

Many components can be added to this module. For instance, development practitioners may want to differentiate between the different ways healthy people can become sick. The infection rates may be different for the different pathways of fecal-oral transmission mentioned above. In return, this would help identify the nature and extent of primary and secondary barriers to reduce or prevent the transmission.

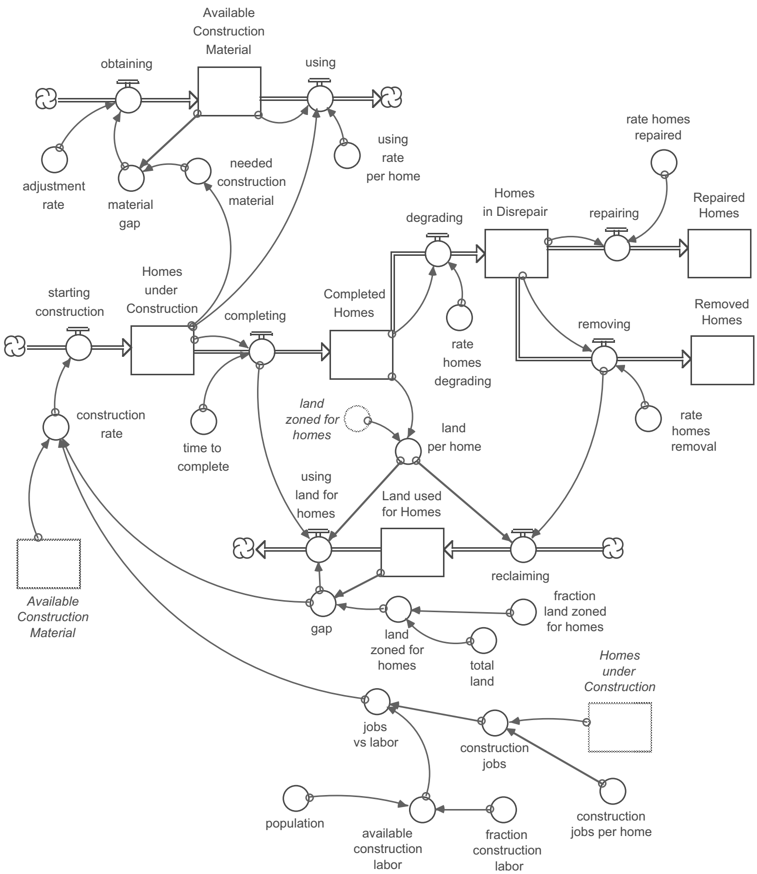

Figure 5.8. Stock-and-flow diagram showing the dynamic between land, home construction, and jobs related to home construction.

5.7 Housing Module

Figure 5.8 shows a stock-and-flow diagram that describes the dynamic between four main variables: homes (under construction, completed), land occupied by the homes, available construction material, and the labor part of a population responsible for constructing the homes. This model was adapted from an example proposed by Fisher (2011, pp. 8-3).

A certain number of homes are assumed to be constructed in a community. After completion, some of these homes are degrading over time but are repaired. Other homes are removed. The land zoned for home development decreases with home construction and increases as homes are removed. The total land used for homes cannot exceed the total land zoned for homes (i.e., land capacity). The gap between these two land values creates a “carrying capacity” feedback loop which affects the construction rate (e.g., the construction rate decreases as the gap becomes smaller).

A fraction of the total population is considered as available local construction labor. The ratio between available labor and the number of construction jobs is assumed to influence the construction rate.

Finally, construction of the homes requires material. The available construction material is compared to what is necessary to build the homes. The gap between the two and the time it takes to obtain construction material (adjustment rate) drive the rate at which the material becomes available. The amount of construction material available to build the homes affects the construction rate as well.

5.8 Behavior Change Module

Communicating behavior change is important in development projects. In most cases, a new form of behavior (e.g., washing hands, drinking treated water, etc.) may be adopted by some members of a community whereas others refuse to do so. Those who adopt the new forms of behavior (called *existing adopters*) and those who could adopt (called *potential adopters*) interact on a daily basis in a community. Some individuals or groups may decide to adopt a new form of behavior through that interaction.

The dynamic between existing and potential adopters is shown in Figure 5.9. This model was adapted from an example proposed by Fisher (2011, pp. 12-17). Figure 5.9 shows a third group of adopters called *permanent adopters* who have decided to adopt the new form of behavior for a certain time, hopefully forever. However, some of these adopters may lose interest over time and fall into the *lost interest* group. Some of the members of that pool may decide to reconsider their behavior and join again the pool of potential adopters. They are classified as *renewed adopters*.

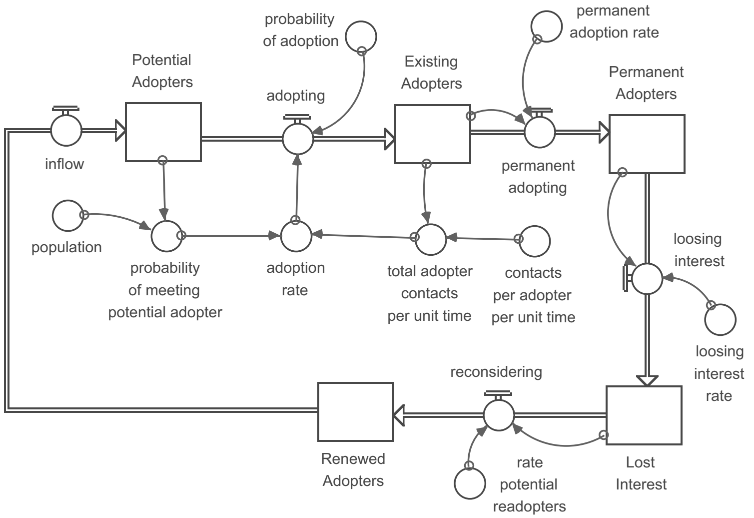

Figure 5.9. Stock-and-flow diagram showing the dynamics of communicating and adopting change in a community. The same diagram can be used to model the spread of rumors, diseases, etc.

The dynamic of Figure 5.9 is sometimes referred to as the *Bass Diffusion Model* in the literature (Bass, 1969; Wikipedia, 2015). It can also be applied to model the transmission of a disease in a community where "adopting" is replaced by "being infected" and "probability of adoption" is replaced by "infectivity." The different groups become the susceptible population, the infected population, and the recovered population. Some of that later group may become susceptible again as they lose some capacity to stay healthy or decide to go back to an older form of behavior that may induce more infection.

Other parameters such as education and access to health services could be added to this module. The type of behavior that is promoted does not necessarily have to be the same over time and can change. For instance, if behavior change communication is initially successful in one community, more advanced forms of behavior can be promoted or the successful behavior can be scaled up to other communities.

5.9 Concluding Remarks

The modules presented above represent a small fraction of potential modules that could describe the dynamic between the various tangible and intangible issues that are at play in communities. They can also be combined with the complimentary modeling and decision-making methods discussed in Section 4.8. As we will see in the next chapter, these various tools fit well into the broader methodology of integrating systems thinking into the different management stages of these projects.

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CHAPTER 6

A Systems Approach to Small-Scale Development Projects

The last three chapters presented an overview of what constitutes systems thinking and the tools of system dynamics that can be used to simulate complex systems. This chapter discusses how to integrate systems thinking and systems tools in the various stages involved in the management of small-scale community development projects. The stages include appraisal and assessment of community needs, selecting appropriate solutions, and designing and planning solutions to community problems that hopefully will provide long-term benefits (i.e., sustainability) to community members. As discussed in Chapter 2, this new systems approach represents a new paradigm (development 5.0) in community development. This chapter presents the different components of system- and complexity-aware community project management and emphasizes the importance of reflection-in-action in all phases of the management process.

"There are no perfect people. There are no perfect projects. We are not measured against perfection, only called to do what we can, to set out on an exploration to an imagined destination, an imagined good. So forget about the fear, forget about the guilt, forget about the fact that the doorway makes no promises. Just step through." (Westley et al., 2007, pp. 229).

6.1 Project Life-Cycle Management

As discussed in the previous chapters, many fields of science, engineering, and technology have promoted the use of systems thinking to address complex problems. Interestingly enough, a systems approach to community development projects has not received as much enthusiasm from development agencies, even though it has been recommended by various groups and individuals in the development literature (e.g., Chambers, 1997; Breslin, 2004; Bossel, 2007; Scoones et al., 2007; Williams and Britt, 2014; Fowler and Dunn, 2014). An excellent review of that literature can be found in Ramalingam and Jones (2008) and Ramalingam (2014).

A systems approach to small-scale development projects requires a good understanding of systems theory, systems tools, and the process of system dynamics modeling discussed in Chapters 3 to 5. It also requires a familiarity with the different steps and substeps that enter into the life-cycle management of small-scale projects which are reviewed in this chapter. Finally, a systems approach to community development projects implies that development practitioners are continuously aware and reminded of (i) the value proposition of systems thinking in each phase of a project; (ii) how systems tools are implemented in a participatory manner with all project stakeholders; (iii) the importance of continuous project assessment through reflection-in-action as projects unfold; and (iv) the importance of context, scale, structure, and boundaries in all aspects of system dynamics modeling.

Community Development Projects

Community projects in developing countries come in different shapes and sizes. From an engineering perspective, a project can be seen as "a temporary endeavor undertaken to produce a unique product, service, or result" (PMI, 2008). Well-executed projects, whether in the developed world or in the developing world, require following a methodology and a management structure. They also demand trained and competent project leaders and managers. However, possessing these characteristics does not necessarily guarantee successful projects as projects may not perform as planned for a multitude of reasons even in "ideal" conditions. In the field of International Development Project Management (IDPM), it is commonly accepted that "many internal and external, visible and invisible factors . . . influence the environment and create a high amount of risk in accomplishing the project objectives"

(Kwak, 2002). Issues may be related to politics (local, regional, or global), hazards at different scales, priorities of development agencies and donors, etc.

The fundamentals of managing community projects in the developing world differ from those in Western countries in the "how" of project management, more than in the "what." In the context of developing communities, small-scale project design, planning, and execution take place in uncertain and complex environments that involve a multitude of interacting technical and nontechnical issues. Absent in such projects are predefined and detailed blueprints that ensure the kind of control and predictability that are found in large engineering projects. As a result, managers of small-scale development projects have to be able to manage challenging and sometimes seemingly competing tasks, a role to which they may not be accustomed. Such challenges may arise, for instance, in the way project managers ensure that work is completed "on time, within budget and scope, and at the correct performance level" (Lewis, 2007). In development projects, these parameters need to be considered within the context of a different culture and in uncertain and complex adaptive environments. Hence, project managers "must be willing and able to make significant changes and to challenge the status quo" that is expected in traditional project management in the Western world (Laufer, 2012). This obviously assumes that they are permitted to adapt to changing conditions by their employing agencies and donors.

I summarize below 10 guiding principles which I think require special attention when considering a methodology for the management of small-scale projects in developing communities:

1. *Context and Scale of Projects.* Understanding context and scale (in addition to content) is critical in the life-cycle management of projects. As remarked by Nolan (1998), projects that fit with their surroundings are more likely to succeed. Too often, projects that are successful in one context and scale are imposed into another environment with limited or no success.
2. *Right Projects, Done Right, for the Right Reasons.* Development projects have to be done right from a performance and technical

point of view. They must also be the right projects for the community and the environment that interact with the projects (ISI, 2012). Furthermore, projects must be conducted for the right reasons: to address the *needs* of communities and not their wants or to satisfy outsiders.

3. *Community Stakeholders' Participation and Accountability.* Project management must be respectful of the way community decisions are made and allow community members to "generate information to solve problems *they* have identified, using methods that increase *their* capacity to solve similar problems in the future" (Narayan, 1993). According to Barton (1997), stakeholders include "all persons and groups who have the capacity to make or influence decisions that have impact on project design or implementation." They also consist of those who do not have a voice and who will be impacted by the project. Community participation works well when all stakeholders are accountable for their decisions and actions (Taylor-Ide and Taylor, 2002).
4. *An Integrated Approach to Project Design.* Development needs to be understood well beyond providing just value-free technical solutions. Engineers interested in development projects need to be particularly sensitive to nontechnical issues and be educated accordingly in order to propose solutions that have both depth (technical) and breadth (nontechnical).
5. *Following Adaptive Project Logic.* There is a need to follow, *as closely as possible,* some form of project logic based on a cause-and-effect hierarchy. Projects have an overall impact that depends on reaching goals, which themselves require meeting objectives by carrying out activities, which in turn necessitate different forms of input and resources. These various steps need to be monitored and evaluated and require that assumptions and preconditions are met. When not met, assumptions and preconditions have the potential for putting projects at risk. Without logic, it would be difficult to plan any project. But this does not mean that the logic is written in stone. As projects unfold, it needs to be adjusted as needed.
6. *Adaptive and Reflective Practice.* Adopting an *adaptive* and *reflective practice* (Schön, 1983) as projects unfold will assist in arriving at

satisficing (good enough) solutions and *not* necessarily the best (optimal) solutions (Simon, 1972). In development projects, rationality is bounded by complexity and uncertainty. An adaptive and reflective practice through learning-by-doing contributes to making sounder management decisions as the project is unfolding (reflection-in-action) or after it has been completed (reflection-on-action). That practice must also take into consideration lessons learned from previous completed projects whether successful or not, and how such projects have performed over time.

7. *Leveraging Existing Success Stories.* A community development practitioner needs to leverage local knowledge and learn from individuals and households in a community who "succeed against all odds" despite being exposed to the same conditions and constraints as everyone else (Pascale et al., 2010). Building on people's existing strengths is the foundation of the *Asset-Based Community Development* approach developed by Kretzmann and McKnight (1993) or the *build from success* recommendation of Taylor et al. (2012). Existing change-makers (sometimes called positive deviants) represent leverage points in the community and can accelerate change though participation and interaction. Their solutions are already proven within the context of the community and are easier to scale up across the community than solutions that originate from external experts. As shown by Taylor et al., the combined effect of building on success with promoting behavior change, adopting a reflective and adaptive approach and encouraging stakeholder partnership is likely to yield tangible and long-term results at the community level.
8. *Long-Term Benefits.* Projects need to be able to provide long-term benefits (sustainability) to communities. These benefits include tangible services provided by technical solutions but also intangible things such as inclusion of rights-based issues, inclusiveness, and respect of human dignity, diversity, and equity. Too often, projects fail in the long-term because they have not been designed correctly right from the start. In other instances, they tend to divide people as they become entangled in geopolitical issues (whether local, regional, or national) that benefit one group or individual at the

expense of others. In other cases, project assessment (monitoring and evaluation) and an exit strategy have been not incorporated into the project from the beginning and are seen as an afterthought.

9. *Attributes of Proposed Solutions.* Solutions to community problems need to be compatible with the community members. They must be accessible, affordable, available, sustainable, reliable, and scalable. They also need to be appropriate, contextual, and equitable.
10. *Results/Outcome versus Activity Driven Management.* There is more to a community project than a list of technologies and activities and how many pumps, PV panels, and other artifacts have been installed. Projects are defined by the quality and outcome of the solutions that unfold from their implementation, and not just by the nature and quantity of technical stuff.

The aforementioned guidelines clearly show that the management of projects in developing communities requires a *different approach* from that used in traditional projects in the Western world. The multidimensional and interconnected nature of such projects makes systems tools more appropriate to address various sociotechnical feedback mechanisms, causality, and interaction mechanisms that are common in social systems (Sterman, 1992). Such mechanisms are not usually accounted for by conventional management tools (i.e., tools for scheduling, cost estimating, planning, etc.).

Simply put, traditional management tools are necessary but not sufficient to capture the dynamic character of project management in complex and uncertain environments. Hence, we can add one more guiding principle to the aforementioned list: that the management of small-scale community development projects must be conducted in a system- and complexity-aware (or mindful) manner. The results and recommendations that emerge by integrating systems thinking into the various phases of project life-cycle management are more likely to contribute to second-order changes at the community level; that is, changes that make a big and long-term difference in the livelihood of the community and its households as discussed in Section 3.2.

Project Management Processes

It is commonly accepted that project management represents a key factor in securing the delivery of meaningful and quality projects. It involves a multitude of technical and nontechnical (socioeconomic, political, etc.) steps that ensure project success. These steps are particularly critical in community development projects.

The Project Management Institute (PMI, 2008) defines project management as "the application of knowledge, skills, tools, and techniques to a broad range of activities in order to meet the requirements of a particular project." According to PMI, project management is usually done through the integration of processes divided into five main groups: initiating, planning, executing, monitoring and controlling, and closing. A brief definition of each process group is as follows:

- *Initiating* focuses on defining the project, determining the nature and scope of the project, how many phases it will contain, the project environment, the stakeholders, the risks, the context, and whether the project can realistically be completed. The project scope includes goals, budgets, and timelines. A vision and mission for the project are developed. At the end of the project initiation phase, a *project charter* (or project hypothesis) is established.
- *Planning* is where a project plan is outlined that includes the planning team, the work to be performed, goals, procedures, budget, schedule, resources needed, risk analysis, deliverables, work breakdown, and activities needed to achieve the deliverables. The planning team creates a specific list of tasks to be carried out in order to meet goals and objectives in a logical manner. The output of this phase is a *project management plan.*
- *Executing* corresponds to putting the project management plan to work. This phase involves coordinating resources and people, and integrating and performing project activities in accordance with the project plan. The output of this phase consists of completing *deliverables*.

- *Monitoring and controlling* is keeping track of and *evaluating* the various phases of the project, its operation, how the tasks are executed, how the outputs compare to the plan, and monitoring and evaluating the main project variables (i.e., performance, cost, risks, quality, schedule, resources, scope, etc.).
- *Closing* is the last phase which depends on the satisfaction of the client. It also includes a reflective component looking at lessons learned (what went well and what could be improved for the next project). The output of this phase consists of *archived project documents*.

Figure 6.1 illustrates how these five processes overlap during the lifetime of a project. There is enough practical evidence that following these processes in a context that can be defined as simple or complicated (as discussed in Section 3.1) can lead to (but not always guarantee) successful and predictable quality projects. However, in complex situations, such as in small-scale communities, the same level of project success and quality cannot be predicted. System- and complexity-aware project management requires system- and complexity-aware project initiating, planning, executing, monitoring and controlling, and closing. These processes need to be managed by system- and complexity-aware individuals and groups following well-defined core practices as discussed in Section 4.6.

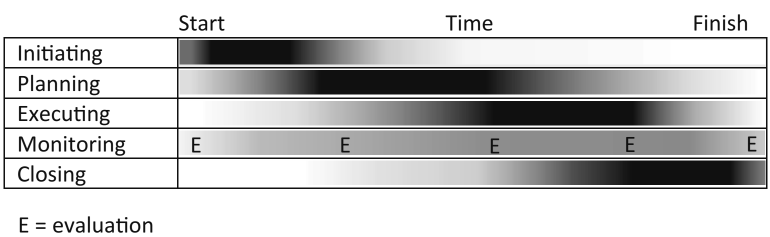

Figure 6.1. Five overlapping processes involved in the management of projects from start to finish.

Source: Amadei (2014), reproduced with permission from ASCE.

6.2 Project Life-Cycle Frameworks

Project life-cycle frameworks for the management of development projects in developing countries have been proposed by various development agencies such as CARE, Mercy Corps, UNDP, EuropeAid, DFID, Oxfam, USAID, etc. A review of some of these frameworks can be found in Amadei (2014). In general, agencies and their partners have developed frameworks with the intent to:

- provide and deliver high-quality projects that improve people's lives and give them healthy choices and opportunities;
- enable the measurements of project outcomes and impacts;
- provide documentation for future projects and develop a database of projects;
- create a platform for discussion and exchange;
- assure accountability to donors; and
- educate their respective staff.

All of these frameworks share common features. First, they all emphasize the need to include community participation in all project phases. Second, the frameworks borrow many of the processes of project management mentioned above. Third, they recognize the cyclical nature and the sequential and hierarchical structure of projects, and the need to have a coherent information system in place in project planning, execution, monitoring and evaluation, and closing. Projects are broken down into stages whose duration and importance vary with each project. Each stage implies activities where decisions need to be made, monitored, and evaluated; reporting is required; and specific responsibilities are assigned. This linear way of thinking does not always allow for the integration of feedback mechanisms, and reflective and adaptive practice.

Participation

As observed by Barton et al. (1997), participation is about mobilizing and employing "local knowledge, skills, and resources" and recognizing that there is inherent talent and capacity at the local level. Participation has been shown to add benefits when considering decision making and project sustainability, effectiveness, and efficiency. Ultimately, as summarized by Taylor-Ide and Taylor (2002), a desirable final outcome of a community development project consists of solutions that (i) are achieved by mobilizing the community into collective action; (ii) mobilize local knowledge, skills, and resources; (iii) make the community proud of itself; and (iv) enhance the community's capacity and ability to become self-reliant. In the context of this book, the term "participation" is synonymous to "mobilization" (Howard-Grabman and Snetro, 2003) or "co-creation" (Prahalad, 2006).

Participation can take different forms depending on the dynamic that exists between outsiders and insiders (i.e., beneficiaries) and the sociocultural context in which it takes place (Figure 2.1). Different cultures look at human interaction differently. For instance, in some cultures, participation is based on building trust while others are more competitive. In other cases, some cultures do not promote participation or even discourage or limit it to certain genders, castes, or social, political, and economic groups. Participation can be motivated by individuals, groups of actors (organic participation), or institutions (induced participation) as noted by Mansouri and Rao (2012). Participation will also vary during the life cycle of a project.

The style of participation has evolved with the history of development itself over the past 50 years from being originally mostly *contractual* (decisions made exclusively by outsiders), then *consultative* (insiders are asked for their opinion), to more *collaborative* (projects managed by outsiders in collaboration with insiders), to ideally being *collegial* (or collegiate) where insiders have control over the process and are not subjected to precooked expert recipes (Biggs, 1989; Hazeltine and Bull, 1999; UNDP, 2009). A collegial approach to participation implies that insiders are involved in the assessment and analysis of the problems they have identified and are active contributors in the design of the solutions. Their knowledge is critical in that process. In general, this type of participation is more likely to translate into skills, confidence, equity, gender equality, transparency and accountability, and efficiency through ownership.

As noted by Biggs (1989), the type of participation depends on the type and components of a project. For instance if the emphasis of the project is oriented toward technology testing, the contractual or consultative approach might be more appropriate. At other times, when identifying problems and coming up with solutions, a collaborative and collegial approach is more appropriate. Rather than being rigid on the mode of participation, one should recognize that it is a process that evolves over time from contractual to collegial. It is noteworthy that transitioning from a contractual mode to a collegial mode with a given community takes time (expressed in years) and relies heavily on building relationship and trust with that community; such activities are not necessarily of a highest priority in development agencies and to donors. For that reason, participation historically has been predominantly contractual and consultative in development projects.

Project Logic

Existing major development frameworks recognize that good project management delivery depends on adopting a strategic combination of steps that follow a cause-and-effect hierarchy or so-called project logic. It provides clear definitions of what represents vision, mission, goals, and objectives in a project and how, when combined, these key components yield a clearer road map in addressing identified problems.

In many current development frameworks, a logical framework approach (LFA) is used to describe the logic involved in conducting a project. LFA asks project managers to see a solution to a problem as emerging from a strategic combination and logical progression of identified *inputs* (resources) that are necessary for conducting various activities. These *activities* deliver outputs and help meet specific objectives. These *objectives*, in turn, produce *effects* and reach *goals* which ultimately have an overall *impact* (outcome, or overarching goal). In order to be meaningful, these different components of the framework have targets (benchmarks) and verifiable indicators (measurements) that are used to qualify and quantify the progress of development projects. The LFA also clearly outlines the assumptions and risks involved in all steps of the project.

As shown in the bibliography compiled by den Heyer (2001) and a literature review of 18 agencies by Bakewell and Garbutt (2005), LFA has become standard practice in development projects and is often required by donors. It is important to note that the terminology used to describe the key components in the project logic (i.e., inputs, activities, outputs, effects, outcome, and impact) can differ from one development agency to another (Mercy Corps, 2005). Despite those differences, the underlying idea is always to have in place a structured approach to a project and a common platform of understanding and communications between different project stakeholders.

Table 6.1 shows the basic components of the LFA in the form of a generic logical framework matrix. The matrix can be interpreted from the bottom-up and/or the top-down (vertical logic). In all cases, the impact (sometimes called outcome) represents the end-state and the overall changes the project is expected to make (i.e., tangible development changes). It often includes the type of improvement in human conditions after the project has been completed, the identification and number of beneficiaries, and an estimation of when change is expected to occur. A summary of the LFA can be expressed in the form of a *causal hypothesis statement* or narrative (RHRC, 2004): "this set of INPUTS and ACTIVITIES will result in these products and services [OUTPUTS], which will facilitate these changes in the population [EFFECTS], which will contribute to the desired IMPACT."

As an example, consider again the Water of Ayolé example described in Section 3.3. The causal hypothesis statement for that example could read as follows:

> External funding and expertise will be used to train governmental representatives to provide health and hygiene education of community members and training in the installation, operation and maintenance of water pumps. This will result in better health and supply of clean and reliable water sources. In turn, this will lead to an improvement of community wellbeing and economic development.

Table 6.1. Basic components of the logical framework analysis in matrix form.

Steps	Explanation	Examples	Indicators Benchmarks	Means of Verification	Assumptions
Impact (outcome/aim)	Long-term fundamental changes in human well-being, organizations, and systems resulting from meeting goals	o Improved health status/well-being o Increased gender equity	Meaningful indicators of tangible outcome and impact	Tangible modes of verification that the outcome is satisfactory and impact is real	o Assumptions needed to go from meeting goals to tangible outcome and impact o Assumptions about expected outcome and impact
Effects (goals, purpose)	Short-term and intermediate changes in human behaviors and systems resulting from meeting objectives	o Safe behaviors practiced o Improved health care and WASH o Improved services	Meaningful indicators of meeting goals	Tangible modes of verification that goals are met	o Assumptions needed to go from outputs to meeting goals o Assumptions about meeting goals
Outputs (objectives)	Deliverables, products, and services created by conducting project activities	o Physical structures o Trained individuals o New institutions	Meaningful indicators of outputs delivery	Tangible modes of verification that outputs are delivered	o Assumptions needed to go from activities to outputs o Assumptions about meeting objectives
Activities	Processes, technology, tools,	o Construction	Meaningful indicators	Tangible modes of	o Assumptions needed to

Steps	Explanation	Examples	Indicators Benchmarks	Means of Verification	Assumptions
	and actions necessary to convert inputs into outputs and meeting objectives	o Installing equipment o Recruiting/training o Developing curriculum o Producing materials	of activities undertaken	verification that activities are undertaken satisfactorily	go from resources to activities o Assumptions about conducting activities
Inputs	Resources necessary to undertake activities	o Money o Materials o Time o Personnel (expertise)	Meaningful indicators of resource quality and quantity	Tangible modes of verification that resources are available	o Availability of resources

The logical framework matrix (Table 6.1) shows a horizontal logic in addition to a vertical logic. Indicators, benchmarks, and modes of verification are used to assess (monitor and evaluate) how each project component (input, activities, outputs, goals, and overall impact) progresses, whether the assumptions and preconditions require some updating, and whether risks may unfold if the assumptions and preconditions are not met (Caldwell, 2002). In Table 6.1, the indicators are observable events and changes which provide evidence or proof that what has been claimed has actually occurred (Bakewell and Garbutt, 2005). They apply to a wide range of project components including personnel, resources, funding, etc. According to Caldwell (2002), the indicators must have the following eight characteristics in order to be meaningful: (i) measurable; (ii) technically feasible; (iii) reliable; (iv) valid; (v) relevant; (vi) sensitive; (vii) cost-effective; and (viii) timely.

In general, the LFA can be seen as an executive summary of the strategic component of project planning and expected changes. Once in place, it provides the necessary information to develop the project logistics (i.e., activity and resource scheduling and procurement) and tactics (i.e., the what, who, when, where, and how, of a project). The information detailed within the logic model provides insight into what the project is expected to achieve, what activities and resources are needed for the project, how results will be achieved, which factors are crucial for success, how success can be measured, and the corresponding time frames of activity and resource delivery.

The Paradox of Project Logic and Uncertainty

Promoting a logical (and mostly linear) cause-and-effect approach such as the LFA for the management of projects in developing communities seems contradictory to the context in which such projects take place. After all, as emphasized throughout this book, projects in developing communities take place in very uncertain and complex situations, which at a first glance should not lend itself to following a rigid, linear, and methodological ladder from inputs, through activities, objectives, and goals, to impact. Since its inception in the late 1960s, there has been a lot of discussion about the strengths and limitations of the LFA (Bakewell and Garbutt, 2005; Oxfam, 2008; and Jensen, 2010).

Objections to using project logic within an LFA framework arise from its apparent lack of flexibility. LFA is sometimes seen by opponents as:

- too formal and rigid with linear cause and effect (linear causation);
- not truly reflecting the uncertain and flexible nature of development projects;
- not working well with complex situations and unintended consequences;
- hard to identify meaningful indicators;
- time and resource consuming to the detriment of the rapidly changing environment itself;
- hard to change and adjust once in place;
- culturally specific, meaning that it can be hard to implement in some cultures;
- hard to explain to others and to be put into practice;
- often treated as a contract document; and
- imposing rigid development ideas on communities.

On the other hand, proponents of LFA cite several compelling reasons for using it. They assert that the framework:

- makes development projects more effective and accountable;
- provides rigor in all phases of a project;
- represents a clear way of communicating;
- is a good road map for setting expectations and reporting on progress and accountability;
- can be seen as a uniform way of thinking;
- helps simplify the complexity of projects by providing a rigid structure;
- represents a consistent way of communicating across organizations;
- forces people to think through the various components that may influence the project; and
- can easily be combined with a monitoring and evaluation plan.

From a global perspective, the LFA has strong attributes that clearly warrant its use in project management. The developing world is littered with too many projects that failed because they were poorly (or not at all) planned and/or executed. As remarked by Lewis (2007), planning is necessary to control and guide how projects unfold. The LFA provides a proven form of much-needed project control which is necessary (but not sufficient) to ensure project quality. As noted by Earl et al. (2001), it can be seen as a road map toward reaching specific goals and outcome. Without that map, one could easily get lost in the process (Patton, 2001).

In the context of community development projects, however, control should not be necessarily understood as "rigid" control, but rather as "adaptive" control using planning methods that (i) are flexible and realistic; (ii) allow for change and include feedback mechanisms; and (iii) still have performance indicators and modes of verification in place. According to Mowles et al. (2008), this type of adaptive control requires complexity-aware project managers to (i) regularly act and reflect on the actions taken and (ii) be simultaneously *involved in* but *detached from* predetermined solutions.

It must be kept in mind that project planning methods vary with the circumstances and context in which project managers make decisions. As a project unfolds, the planning is likely to vary from *objective* planning in situations that show more certainty and less complexity to *subjective* (i.e., intuitive) planning when facing more complex and uncertain situations. Elms and Brown (2012) remark that using dominantly subjective methods seems to lead to better decisions "for problems at the interface between straightforward technics—the traditional province of engineers—and the environments (natural, social, economic, political, and so on) surrounding them," which are likely to be found in community development projects.

In his book *Projects that Work*, Nolan (1998) divides project planning methods into two groups of methods: *interactive* methods and *directive* methods (Table 6.2). Interactive methods are used when "the elements of the project evolve as time goes on, and as new learning occurs." Schön (1983) calls this approach *reflective practice* which is more in line with the intervention of *self-reflective practitioners* than experts (Caldwell, 2002). Interactive and reflective methods account better for uncertainty, are more flexible and adaptive, and require preplanned adaptability and more subjective decision making. They are better suited for a learning environment in which patterns emerge and need to be detected. Finally, interactive planning methods emphasize a need for creative thinking in decision making (Table 3.2) and involve inductive reasoning (Axelrod, 1997).

Table 6.2. Comparison between interactive and directive project planning methods.

Directive Planning	Project Features	Interactive Planning
The impetus for the project comes from above.	Origin of the project	The impetus for the project comes from below.
Interventions are temporary.	Nature of the intervention	Involvement is long-term.
The environment is stable and familiar.	The environment	The environment is unstable or unfamiliar.
Projects center on things rather than people.	Focus of the project	Projects emphasize growth in human capacity rather than material things alone.
Detailed knowledge of techniques, outcomes, and contingencies is assumed to exist at the start of the project.	Role of existing knowledge	Incomplete knowledge is assumed; learning about what to do becomes a major project goal.
Little learning or new knowledge is assumed to be necessary to make the project work.	Role of new knowledge	Learning and new knowledge are seen as central to the success of the project.
Overall strategies and objectives are spelled out in advance.	Strategies and objectives	Objectives and strategies emerge gradually from on-site study of the situation.
The research, decision-making, and action functions in the project are separated and done by different groups.	Integration of effort	Research, decision-making, and action are combined and done by essentially the same group of people.
All resources, activities, and timetables are spelled out in advance.	Choice of resources, activities, and timetables	Resources, activities, and timetables are determined as the project proceeds on the basis of experience gained in this field.

Directive Planning	Project Features	Interactive Planning
Project decisions are relatively "pure" and can be made in terms of a few controllable variables, preferably of a quantitative nature.	Decision making	Project decisions are "impure" and are made in terms of shifting often qualitative factors.
Implementation is routine and involves the application of pre-specified solutions. Tasks are relatively routine and repetitive.	Implementation tasks	Implementation is creative and experimental and changes as the project evolves. Tasks are not routine, but may need to be done differently at different times.
Few modifications of the project plan are possible at later stages.	Modifications of plans	Continual modification of the project plan is necessary to take account of new learning.
Little local initiative or participation is required.	Local input	Local participation is necessary to shape the project.

Source: Nolan (1998), reproduced with permission from the author.

In contrast, *directive planning* methods are more rigid and linear, require predetermined accurate information and objective decision making, and rely on the input of experts. Most civil engineering projects (e.g., building a bridge) that deal with man-made materials rely on directive planning or *blueprint planning*. Such planning methods have their place in community development projects for specific technical tasks. Directive planning methods emphasize a need for critical thinking in decision making (Table 3.2) and involve deductive reasoning (Axelrod, 1997).

In summary, the logical aspect of project management and how to deal with the uncertainty and complexity encountered in community projects may appear as incompatible as suggested by Mowles et al. (2008). This represents, however, a *paradox* ("a statement or proposition that seems self-contradictory or absurd but in reality expresses a possible truth," dictionary.com) that can be reconciled by recognizing that complexity-aware project managers need to simultaneously follow a planning road map and be flexible, reflective (on action), and cognizant of the context and the dynamic of that context as projects unfold. At times, interactive planning is better and provides a breadth of thinking. In other situations, directive planning is more appropriate and requires more in-depth thinking. According to Patton (2001), this is all about "situation recognition [or awareness]" and expecting that in projects "some of what is planned will go unrealized, some will be implemented roughly as expected, and some new things will emerge." Hence, project logic needs to be flexible and dynamic and be revised accordingly as projects unfold.

Complexity- and system-aware development practitioners must recognize that each project is unique and requires a specific approach. This flexible approach requires thinking in a systemic way with a mix of creative and critical thinking (Table 3.2) and inductive and deductive reasoning. Failing to recognize the uniqueness of project planning and execution by using the same tools and the same mode of thinking irrespective of the project context may create more harm than good and deliver projects that are rigid, ill-conceived, ill-executed, and fall short of what was (or could be) expected.

6.3 Proposed Framework

In my recent book (Amadei, 2014), I proposed a framework for the management of small-scale development projects called ADIME-E (*Appraisal, Design, Implementation, Monitoring and Evaluation, and Exit strategy*). The framework uses the CARE project design framework (Caldwell, 2002) as its backbone and is supplemented with tools used by other agencies (UNDP, Mercy Corps, and EuropeAid) and analysis tools more commonly used in engineering practice. A simplified version of the framework is shown in Figure 6.2. The reader will find more details of the framework in Chapter 4 of *Engineering in Sustainable Human Development* (Amadei, 2014).

The following sections of this book describe briefly the different stages of the framework, their input and output, and more importantly the challenges and opportunities in integrating systems thinking and system dynamics modeling across the framework. In describing the different framework stages, I make the assumption that there is one core team of outsiders involved in all the stages shown in Figure 6.2. The team may seek opinion and participation from other outsiders, but ultimately is responsible for working in close collaboration with the community and will carry out the project from inception to completion. I also make the assumptions initially outlined in Chapter 1 that

(i) adequate funding is available to carry out the project; (ii) community participation can be expected in all stages of the project; (iii) there are no critical project deadlines; and (iv) skills and resources are available from insiders and outsiders of the community. Finally, I do not discuss the various documents and deliverables that may be expected by development agencies at the end of each stage of the framework.

Community development projects do not always unfold in a linear and predictive way that always moves forward as idealized in Figure 6.2. Indeed, there will be times as a project unfolds when decision makers have to cycle or iterate within a project stage or between a current project stage and one (or several) of the many previous ones following some form of monitoring and evaluation. Examples include more data are needed to identify community problems; some information is missing; some issues were ignored or overlooked; the design must be improved; community capacity needs to be increased before a particular solution can be implemented; the project cannot end until some long-term issues are addressed; etc. Needless to say, this cyclical process may create delays in the project execution. These delays must be expected in the overall project management.

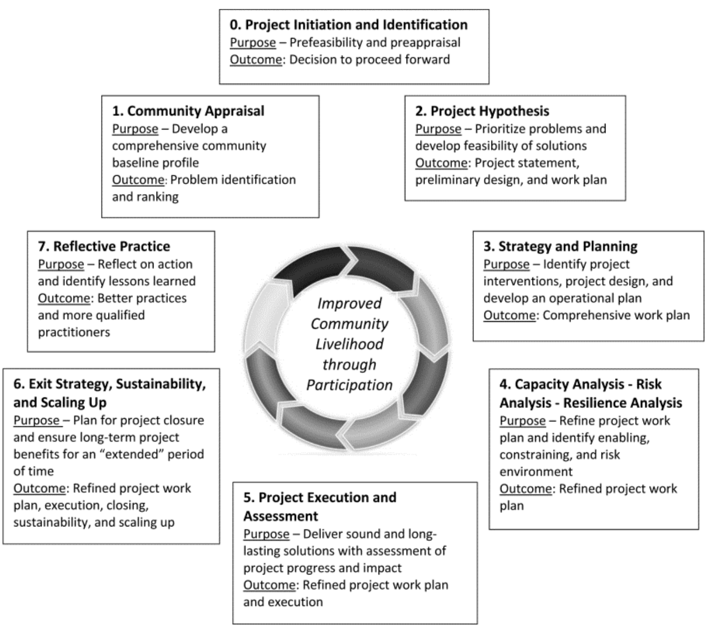

Figure 6.2. Basic components of the ADIME-E framework.

Note: This is a simplified version of the framework proposed by Amadei (2014, pp. 149).

The iterative and cyclical dynamic between the different stages of the framework is captured in Figure 6.3. It has the same components as in Figure 6.2 with the main difference that project assessment (monitoring and evaluation) is now located at the center of the model and is reframed as *reflection-in-action*. Figure 6.3 implies that each stage of the framework undergoes one or several rounds of reflection-in-action (as needed), which dictates whether the project can proceed to the next stage (outer clockwise path) or go back to one (or several) of the previous stages for further information (inner counterclockwise path). It must also be remembered that each stage of the framework in Figure 6.3 is itself comprised of several tasks that have their own internal feedback mechanisms. These mechanisms can also contribute to project delays. These tasks and their interconnections are further discussed in the following sections.

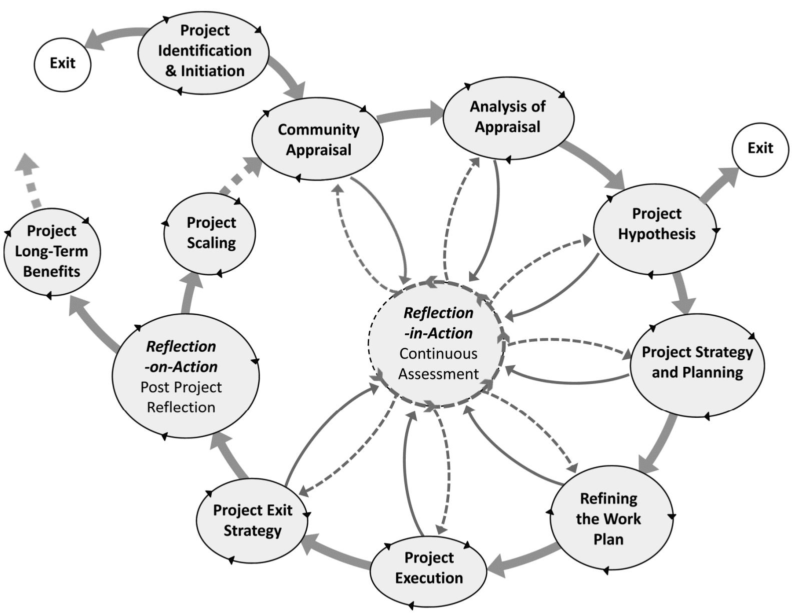

Figure 6.3. Modified version of the ADIME-E framework showing the importance of reflection-in-action and the cyclical nature of project management.

Note: Based on continuous project assessment through reflection-in-action, a project can proceed to the next stage (outer clockwise path) or go back to one (or several) of the previous stages for further information (inner counterclockwise path). This figure was developed in collaboration with Tamara Stone.

Upon project execution, closure, and reflective practice (*reflection-on-action*), a decision can be made whether (i) to leave the community while staying in contact with the project beneficiaries for a certain length of time in order to ensure follow-up and long-term benefits and/or (ii) go to scale. If the latter option is selected, project managers may want to reenter the framework but at a scale that is larger than the previous one. It should be noted that the framework of Figure 6.3 can be used to describe the stages of a project unfolding in a given context and over a certain scale. Extrapolation to different contexts and larger scales needs to be dealt with extreme caution as it is usually nonlinear.

6.4 Reflection-in-Action

In the context of Figure 6.3, reflection-in-action refers to the act of reflecting on the project by both internal and external stakeholders using assessment (monitoring and evaluation) methods as the project unfolds. By placing reflection-in-action at the center of the project life cycle in Figure 6.3, project assessment is seen as a critical component to the delivery of successful projects. Using the analogy of a wheel with hub and spokes to describe Figure 6.3, reflection-in-action (the hub) is critical to keeping the project together and moving through its different connected stages (wheel turning). The concept of reflection-in-action is in line with observations and recommendations made by several authors about the systemic and dynamic nature of development in general. As best summarized by Barder (2012) and Ramalingam (2014), development practitioners need to include "more experimentation, adaptation, and learning" in their programs and projects and strive to combine a traditional "results-based management" approach with an "adaptive management" approach.

Reflection-in-action is seen as a continuous process of monitoring *and* evaluation. Throughout the entire life cycle of any project, development practitioners need to track and assess how each stage of the project is unfolding, learn in real time, and answer the question of how well the project and its components are doing. This is done in partnership with the community. If necessary, corrective actions need to be taken to ensure that the project will deliver what it promises in the short, medium, and long-term (Nolan, 2002).

As with all other stages of the framework, the methods used for reflection-in-action need to adapt to the complex and uncertain context in which community development projects unfold. The methodology used to integrate systems thinking in the reflection-in-action part of a project can be borrowed from that proposed by Britt (2013) and Williams and Britt (2014) in what they call the *complexity-aware monitoring* of development projects. It was suggested by these authors as an alternative to the traditional performance monitoring of USAID projects in order to account for the uncertainty and “complex aspects of projects and strategies.”

Britt (2013) and Williams and Britt (2014) emphasize that traditional performance monitoring “which relies on predictive practices built on known or hypothesized cause-and-effect relationships” is better suited for predictability and “the simple and complicated aspects of a strategy or project.” In that context, results can be compared to clear indicators, benchmarks, and targets integrated into the LFA. It is clear that the traditional performance monitoring approach is of limited value to address the complex and uncertain situations encountered in community development projects. System- and complexity-aware monitoring is better suited for that context.

System- and complexity-aware assessment (not just monitoring) uses many of the same tools of monitoring and evaluation used by development agencies. For instance, monitoring is seen a continuous process that provides real-time information and data about how a project is unfolding and whether goals and objectives are likely to be achieved or not. It is a formative form of assessment where no values and judgments are imposed on the collected information.

Likewise, evaluation follows monitoring and is a discrete event which provides assessment at the end of a specific project phase or activity. It serves as a tool to diagnose (i) completed and ongoing activities (performance or process) and (ii) the value of the results (positive and negative) obtained by conducting specific activities and the extent to which goals and objectives are achieved (impact). Values and judgments are placed upon the information. Evaluation helps decision makers understand how and to what extent an initiative is responsible for particular measured results, whether intended or not.

Unlike traditional evaluation which is often done at a limited number of specific times in a project life cycle (e.g., mid-term and end of project) in a predictable context and assuming strict cause-and-effects links, complexity-aware evaluation is done more frequently at the end of each phase of the project as shown in Figure 6.3. Many project components can be evaluated, such as activities, tools, strategies, policies, project impact (environmental, social, cultural, economic, and institutional), project quality, response of beneficiaries to the project, etc. Evaluation can be qualitative and quantitative and be conducted at various scales ranging from individuals to households to the entire community. It is obviously limited to the scale at which the community appraisal has been conducted and the baseline survey established.

Following the recommendations by Britt (2013) and Williams and Britt (2014), a system- and complexity-aware assessment plan during the reflection-in-action phase of a project must be designed to:

- keep up with the rate of change and progress in all stages of the framework by including three types of project indicators: (i) leading indicators that foresee change; (ii) coincident indicators that keep track of ongoing change; and (iii) lagging indicators that look back at how change has evolved over time;
- account for different outcomes in all stages of the framework other than just meeting (or not meeting) specific targets by considering possible unintended consequences, nonlinear behavior, and other possible unexpected outcomes emerging from the unique characteristics of adaptive complex systems (see Section 3.3);
- include an assessment of system dynamics in all stages of the framework, which means an assessment of not only each system component but also how they interact, their feedback mechanisms, the role of endogenous and exogenous issues on the system dynamic, and how the stakeholders contribute to the feedback mechanisms;

- articulate needed change (change steering) in all stages of the framework and what represents performance and impact in a dynamic context where low certainty and low agreement are the rule; and
- accommodate what project success actually represents (e.g., meeting optimized and definite goals and objectives or creating satisficing patterns of change) and how it may change as projects unfold.

Similar recommendations were proposed by Preskill et al. (2014) in an excellent report titled *Evaluating Complexity: Propositions for Improving Practice*. In this report, the authors provide nine propositions for evaluating complexity: "(i) design and implement evaluations to be adaptive, flexible, and iterative; (ii) seek to understand and describe the whole system, including components and connections; (iii) support the learning capacity of the system by strengthening feedback loops and improving access to information; (iv) pay particular attention to context and be responsive to changes as they occur; (v) look for effective principles of practice in action; (vi) identify points of energy and influence; (vii) focus on the nature of relationships and interdependencies within the system; (viii) explain the nonlinear and multidirectional relationships between the initiative and its intended and unintended outcomes; and (ix) watch for patterns, both one-off and repeating, at different levels of the system."

As noted in the discussion in Section 6.2, the paradox between systems thinking and the logical structure of the LFA makes system- and complexity-aware assessment plans complementary to traditional monitoring and evaluation plans. They still need to be consistent and in line with the overall strategy and project logic expressed in the LFA. The latter provides clear definitions of what represent vision, mission, goals, and objectives in a project and how, when combined, these key components yield a clear implementation road map to address the identified problems (Table 6.1). Assessment plans must, however, go one step further in looking at how much change is occurring in the logical framework during project implementation (horizontal logic), and what to do about change, especially if unintended consequences arise.

As a result, system- and complexity-aware assessment plans, like conventional assessment plans, can use many of the same verifiable performance indicators and means of verification, and rely on the same assumptions as those in the logical framework. It must also be kept in mind that all assessment plans, whether conventional or not, require that reasonable and appropriate project *targets*, *benchmarks*, and *performance criteria* be established.

Unlike traditional assessment plans, system- and complexity-aware assessment plans require adopting a more flexible and adaptive methodology that incorporates stakeholder participation. It can be seen as an "*evidence-based*" form of decision making where decisions are based on the field reality rather than on predetermined opinions from outsiders (Taylor et al., 2012). The targets, benchmarks, and performance criteria need to be able to change as a project unfolds and the various systems involved in the project change. The traditional indicators in the logical framework need to be supplemented with others to capture that change. Britt (2013) recommends using multiple so-called *sentinel indicators* (a term used by ecologists) to capture and communicate change and "signal the need for further analysis and investigation." Britt (2013) and Williams and Britt (2014) also suggest exploring other methods such as *Process Monitoring of Impacts*, *Most Significant Change*, and *Outcome Harvesting* as additional system- and complexity-aware methods when assessing predicted and emergent change. Finally, Fowler and Dunn (2014) recommend using the *Developmental Evaluation* method proposed by Patton (2011) to evaluate progress and make decisions in complex and uncertain settings in social innovation. Development evaluation is about "exploring the parameters of an innovation and, as it takes shape, changing the intervention as needed (and if needed), adapting it to changed circumstances, and altering tactics based on emergent conditions" (Patton, 2011).

In general, by placing reflection-in-action at the center of Figure 6.3, project managers and decision makers become aware of how well each stage of the project is doing in an adaptive manner. They can assess whether one project stage can progress to the next stage, or whether it requires additional information, analysis, or design, or whether it necessitates revisiting any of the previous stages. Finally, it must be kept in mind that reflection-in-action at each stage of the framework takes time. In other words, some delays need to be accounted for in any system model in order to account for the time it takes, for instance, between comparing expected performance with actual one and between observation and implementation of corrective actions. In short, reflection-in-action is not an instantaneous process.

6.5 Identification and Initiation

The initiation/identification phase of a project is used to establish a rough project description and whether the project will receive a green light to proceed. It can be seen as the *prefeasibility* or *preappraisal* phase and is usually carried out by a small team of development practitioners.

Based on preliminary interviews with the stakeholders and those requesting the project, combined with possible site visits and data gathering, and drawing upon past experience with similar projects, development practitioners decide whether the project is viable and can move into the appraisal phase, or whether the project should be rejected. In this evaluation phase, great care must be taken to assess whether the organization that will intervene in the project has the capacity to manage and complete the project or if it needs to bring in other partners to supplement that capacity.

This project stage, which can be seen as *reflection-before-action*, serves to prepare the community for action in collaboration with some community leaders. According to Howard-Grabman and Snetro (2003), this phase is about orienting the community, informing the community about the project and inviting participation, building trust and relationships, and identifying a core group that will represent the community through the life of the project. According to EuropeAid (2002), this project phase is done to "help identify, select or investigate specific ideas, and to define what further studies may be needed to formulate a project."

A traditional reductionist tendency at this stage of the project framework is for development practitioners to hone in, often too quickly, on a particular problem that may seem to resonate with them. In some cases, the problem may have actually been emphasized by a small number of community leaders who have a vested interest in having it addressed. Caution needs to be taken to avoid developing such a narrow mindset that early in the project and coming to expedited conclusions about the needs of the community. It is not uncommon for preappraisal teams to conclude, for instance, that the project is a water project, an energy project, etc. Such early conclusions have potential to derail projects altogether by forcing them into compartments. They can also undermine the community participation process right from the start.

Even though one cannot expect to have a system dynamics model in place at this stage of the project framework since community problems have not yet been fully identified (although preliminary causal loop diagrams can be sketched), it is important for the project team to adopt and encourage an open, flexible, and systemic mindset as it acquires the skills and resources necessary to carry out the community appraisal in a systemic way rather than looking at various systems independently from each other. At this stage of the framework, it is critical to address the various components of group model building discussed in Section 4.6 and start building a strong team that will see the project from its inception to completion.

6.6 Community Appraisal

Community Baseline

The main goal of the appraisal phase is to learn as much as possible about the community through the collection and analysis of data and the transformation of these data into useful information. Community appraisal provides a local context consisting of the community's operating environment, its cultural setting, and its level of development. It also provides information about the more global context of the country and region in which the community resides. In general, at the end of the appraisal phase, a *baseline profile* of the community is established. It defines the overall *state* of the community, its multiple *patterns of behavior*, and its structural components. The baseline profile data and information are critical to building various system dynamics modules such as those described in Chapter 5. These modules may represent the dynamics surrounding several tangible or intangible issues that were observed during appraisal.

Overall, community appraisal should be developed with full participation of the community members and different community stakeholders, individuals, households, and institutions. Ideally, the baseline profile defines the community as it sees itself, not as outsiders see it, through its strengths, weaknesses, opportunities, challenges, threats, capacity, vulnerability, resources, and the hazards or adverse events it might be exposed to. In summary, the baseline profile helps identify the enabling and constraining factors in the community in which projects unfold.

The methodology used to carry out community appraisal comes from the social sciences and uses tools from *Participatory Action Research* (PAR). More information about PAR tools can be found in Spradley (1979), Cornwall and Jewkes (1995), Park (1999), Fals-Borda and Rahman (1991), Chambers (2005), Scheyvens and Storey (2003), among others. PAR tools focus mostly on collecting and analyzing primary and secondary, and qualitative and quantitative data dealing with sociocultural issues. In addition to these issues, other community attributes are observed and mapped: environmental, economic, technical, human resources, etc. The results of the appraisal phase are usually presented in matrix or tabular form or by other means of data representation (sketches, drawings, videos, etc.) around the following topics: stakeholders and beneficiaries, gender, partnership, capacity, vulnerability and vulnerable groups, social network, and uncertainty.

Figures 6.4a and 6.4b show the different tasks involved in carrying out and analyzing the appraisal, respectively. It should be noted that the tasks are themselves interconnected with various feedback mechanisms that contribute to reflection-in-action *within* that stage of the project. For instance, during data and information collection, it may become apparent that the appraisal team must supplement its expertise with that of other individuals in specific areas of study or involve key members of the community. More information may be needed as a gap is observed in a specific area during the reporting process. Another feedback example is a need to change the way the team is operating due to cultural or other issues that are emerging in the appraisal process.

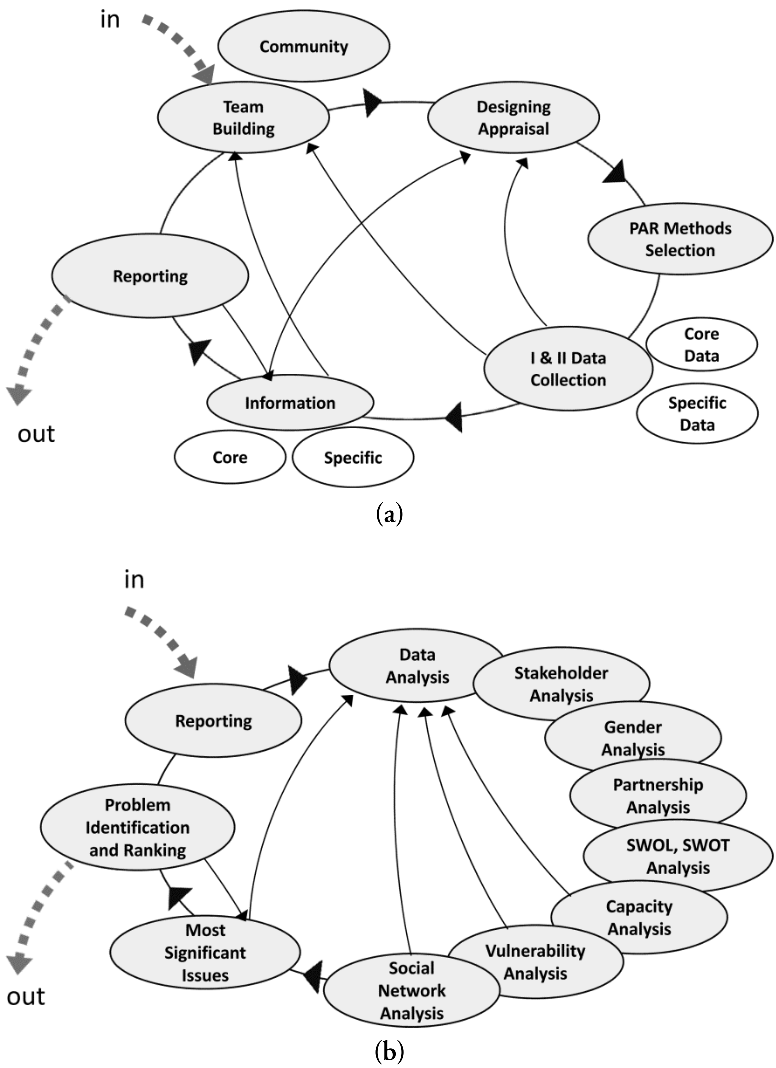

Figure 6.4 Different tasks involved in (a) Conducting the appraisal, and (b) Analyzing the results of the appraisal.

Note: This figure was developed in collaboration with Tamara Stone.

The Appraisal Team

The collection of community data requires that a professional support team be established. It can be seen as an extension of the team (or be the same team) that carried out the preappraisal or feasibility study.

The team must demonstrate a variety of qualifications that match the type of community appraisal to be conducted, as well as showing proper qualifications in PAR tools. Team members need to be selected based on their sensitivity to culture, technical expertise, community appraisal experience, personal attributes, gender, and the unique skills they bring to the group. To that list, and as discussed in Section 4.6, one would expect the members to be able to work as a team and in a systemic way while being responsible for specific roles such as facilitator, modeler/reflector, recorder, translator, gatekeeper, or simply observer (Richardson and Andersen, 2010).

It is common for team members to receive training from sponsoring agencies before going into the field. They should especially be made aware of biases and challenges that they bring with them (Cornwall and Jewkes, 1995). According to Chambers (1983), biases can be categorized into six groups: (i) spatial (data are collected in easily accessible places); (ii) project (ignore data from failed projects and emphasize those from successful projects); (iii) person (preference to collect data from more educated people); (iv) season (preference to collect data during traveling season); (v) diplomacy (certain issues are not raised because they are not deemed important or as matter of courtesy); and (vi) professional (data from selected individuals). Finally, the appraisal team members also need to be trained in group decision, negotiation, and consensus building which are basic components of group model building (Richardson and Andersen, 2010; Hovmand, 2014).

It is noteworthy that the appraisal team's perception of the baseline profile (or its "shared reality" according to Vennix, 1996) is likely to change during the entire appraisal phase. It may be limited in scope at the start when few data are available and become more comprehensive as the appraisal proceeds and the community members are more trusting of outsiders. Furthermore, its refinement does not stop at the end of the appraisal phase, and continues well into the project execution. As remarked by Nolan (2002), "gaining an insider's view of another culture takes time and effort, as patterns fall into place one piece at a time." But even the best appraisal will never be complete since, as mentioned earlier in this chapter, there is always some form of uncertainty about the community.

Baseline Profile Information

The information that emerges from community appraisal can be divided into two groups core and specific. In general, *core information* is a combination of qualitative and quantitative information about:

- the community itself: location, demographic, geographic, socioeconomic, political, cultural, environmental, health, education, beliefs and practices, attitudes, feelings, human rights, power distribution, forms of behavior, and positive deviance;
- the community dynamic including social groups, vulnerable groups, government, institutions, the decision process and leadership roles, marginalized groups, rights assessment, gender equality, support groups, connection and social networks, community vision, and priorities;
- how people with different identities (tradition, gender, patriarchy/matriarchy, ethnicity, race, caste, childhood, aging, disability) experience poverty, violence, or oppression;
- existing change-makers in the community who do things differently and successfully using uncommon behavior and attitude;
- the range of stakeholders and groups in the community (through stakeholder and partner analysis) as well as their interests, resources, and levels of influence (positive or negative);
- the community resources, skills, strengths, and capacity (institutional, human resources, technical, economic/financial, energy, environmental, social, and cultural) and the quality, quantity, and state of those resources and skills;
- the range of adverse events (small, medium, and large) the community has experienced in the past—these events need to be mapped in terms of type, location or extent, intensity, severity, duration, surprise effect, probability of occurrence, risk drivers, and how they impacted the community;

- the community concerns, priorities, sense of vulnerability, and risks (real and perceived) that could harm people, property, services, livelihoods, and the environment people are dependent on;
- the community needs, which according to Caldwell (2002) can be broken down into normative needs, felt needs, and relative needs;
- the community dynamic across various seasons (in rural areas, seasons define community and household activities); and
- in-country governance, policy, and socio-political-economic issues at the regional and national levels that the community needs to consider in its development—regional and national policies in public health and sanitation, education, job creation, shelter, transportation, energy, poverty reduction, and others need to be identified as they may facilitate community development in some cases or create impediments to development in other cases.

In addition to core information about the community, the appraisal phase will also provide *specific information* about the capacity (or vulnerability) of the community to deliver special services to its members related to energy, WASH, health, shelter, education, food, transportation, etc. Using appropriate indicators, the quality and quantity of existing services can be appraised and compared with existing international standards (e.g., World Health Organization) to identify *service gaps*. Being able to carry out a strong capacity and vulnerability appraisal for various types of service delivery is essential in selecting future correcting options, implementing appropriate solutions, and monitoring and evaluating the long-term well-being of the community. More specifically, the appraisal needs to identify for each type of existing service: what works well; what does not work well; and what could be improved.

Data Collection and Analysis

Community data are collected and converted into information that is necessary to understand the project environment. They can cover multiple areas such as the environment, people (individuals and households), the existing infrastructure, available resources, issues and concerns in the community, how people live, and constraints that they have on a daily basis. Table 6.3 lists several sources of information in the mapping of communities. Forbes (2009) considers more than 200 parameters that can be appraised at the community level.

Table 6.3. Sources of information in community mapping.

Aspects	Examples of Information Needed
People	Who lives in the area? What is their structure and composition? What divisions exist? What is the basic profile in terms of things like health, education, employment, income, and so forth? What are the patterns of leadership? What aspects of their belief systems, values, and practices seem important? Do some groups have more power or influence than others?
Environment	Where are the physical and social boundaries of the community? What aspects of climate, topography, natural resources, or seasonal variations seem important? What outstanding natural features mark the area? How is environment connected with livelihood?
Infrastructure	What institutions, organizations, facilities, or services exist? What is their relationship to local populations, now and in the past? What is likely to change in the future?
Resources	What important assets does this community possess or have access to? These might include financial resources, intellectual resources, human resources, and informational resources. How are these assets held and managed? What rules govern their use?
Modes of livelihood	What are the principal bases of the economy? How are people organized for work? How are they connected and/or differentiated? Are there extremes of wealth and poverty? What are current economic trends? How are resources and benefits distributed? How is time patterned?
Issues and concerns	What things have engaged the time, thought, and energy of people here? What are people's main concerns or issues? How do they see these issues? Are there differences of opinion regarding these? What sorts of options are seen as acceptable or workable for dealing with them?
Principal constraints	What factors or conditions lying largely outside the control or prediction of the community are important for understanding what is happening inside the community itself? How do people see these things? Have they changed over time?

Source: Nolan (2002), reproduced with permission from Westview Press.

Community data can be primary or secondary and both can be qualitative or quantitative. Primary data are new data obtained directly by the appraisal team from the community and stakeholders whereas secondary data are those that previously exist about the community, the region, or the country, and were collected by someone else. They are available in various forms and indirect sources: articles, reports, websites, maps, censuses, individuals who may have visited the community in the past, previous studies, etc. Some additional data may also be obtained from in-country governmental agencies (local, regional, and national).

In general, community data can be collected using a combination of the PAR tools mentioned above. Regardless of the tools used, a key priority in data collection is to make sure that the data are authentic, valid, appropriate, meaningful, inclusive, truthful, and accurate; in other words that we have confidence in using them to draw conclusions about the community. According to Barton (1997), good quality data and information must show the following attributes: accuracy, relevance, timeliness, credibility, attribution, significance, and representativeness. In general, quantitative and qualitative data collection methods differ in terms of types of data collected, the methods used, the skills required of those collecting the data, and the scope and scale of data collection. A review of the different methods of data collection can be found in Barton (1997), Caldwell and Sprechmann (1997a, b), and Chambers (1983, 2002, 2005).

The analysis of the data is expected to reveal:

- the most significant issues, concerns, and needs that the community is facing and their prioritization, as well as possible leverage points in the community;
- perceived core problems and cause-and-effect relationship for each problem including possible feedback mechanisms;
- the community's available resources and assets (natural, human, social, economic, and infrastructure capital);
- issues important to different groups and different areas of service: what works (or has worked) well, does not work well, what could be improved, and what are current road blocks to improvement;

- ranking and importance of issues based on gender, age, employed/unemployed, caste, belief systems, married/single individuals, etc.; and
- areas where the appraisal team needs to come back and address issues that require more information and/or clarification. This iterative process needs to continue until a general consensus is reached.

In order to obtain a profile of the community, the data analysis can be broken down into several categories: stakeholder, partnership, gender, capacity (resources, assets, and services), vulnerability and vulnerable groups, social networks, etc. The results of the analysis can be presented using descriptive statistical methods for the quantitative data and anecdotal summaries for the qualitative information. Examples of data analysis can be found in Chapter 5 in Amadei (2014).

Among the various categories of data analysis presented in my other book, determining the capacity of a community to provide a given service to its members is very important. This is illustrated in Figure 6.5. This radial representation was originally proposed by Professor Garrick Louis and coworkers at the University of Virginia (Louis and Bouabib, 2004). For a given type of service (e.g., energy, water, sanitation, shelter, health, etc.), eight categories of capacity are evaluated: the service level (compared to some standard), institutional, human resources, technical, economic and financial, energy, environmental, and social and cultural. As indicated in Figure 6.5, each capacity category is itself broken down into basic components that are then rated based on an agreed-upon metric. The latter can be quantitative or qualitative (high, medium, low) or based on an arbitrary scale ranging from 1 to 5, for instance. A radial diagram similar to Figure 6.5 can be developed to summarize the vulnerabilities of a community as well. Examples of capacity and vulnerability analyses for actual projects can be found in Louis and Bouabib (2004) and Amadei (2014).

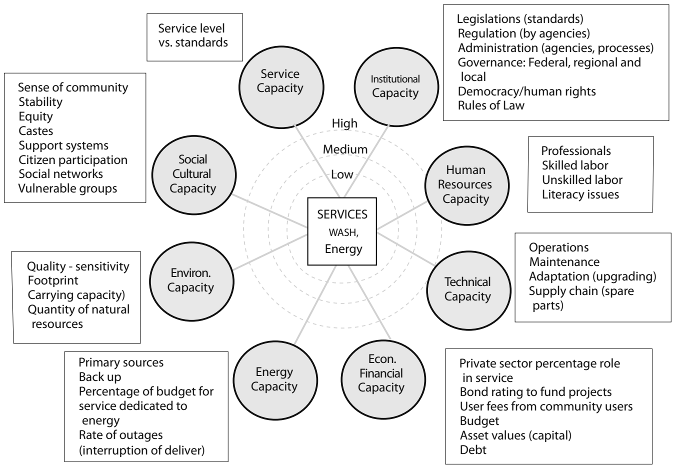

Figure 6.5 Components of capacity analysis for a given type of service.

Source: Louis and Bouabib (2014), reproduced with permission from Garrick Louis.

Problem Identification and Ranking

Following data collection and analysis, the appraisal team should be in a position to formulate the different problems that the community is facing in the form of well-defined problem statements. Once identified, and before proceeding any further, the team needs to confirm and validate those problems with the community. Caldwell (2002) recommends clearly identifying the "what, who, and where" in the problem statement. The "what" defines "the condition the project is intended to address" whereas the "who" defines "the population affected by the condition." Finally, the "where" states "the area or location of the population." As an example, consider the following narrative: *No toilet of minimum hygienic standards (what) are available for 70% of the rural population (who) of Loreto, Peru (where).*

Once formulated and acknowledged by the community, the appraisal team needs to be able to describe the causes and consequences of the problems as part of the narrative. Consider the following example: *Community xyz is exposed to high levels of turbidity and E. coli due to a broken water treatment system.*

The next stage is to involve the community in deciding whether the identified problems are (i) real and clear to all; (ii) the most critical ones;

(iii) capturing the needs of men and women and marginal and vulnerable groups; and (iv) addressing the needs of the community (UNDP, 2009). Once these issues are addressed, the problems are ranked by order of priority. This can be done by asking various groups of stakeholders (e.g., married or single men and women, various age groups, associations, village council, key decision makers, etc.) to identify their top three or four problems. Ranking can also be carried out by examining the added value (for both insiders and outsiders) in solving each identified problem in terms of improving people's quality of life compared to associated costs (cost-benefit analysis). Often times, the cost of an activity and whether it is justifiable for the expected project outcomes must be addressed. Other criteria may include assessing the level of local support available to solve the problems and existing comparative advantages.

A Systems Approach to Appraisal

There are many ways that development practitioners can integrate a systems approach in the aforementioned phases of community appraisal and ultimately when agreeing on a community baseline that best describes the present state of the community and the issues it faces, and deciding on the changes that the community would like to see in the future. From a systems point of view, the community baseline, which is the principal outcome of the appraisal phase, can be seen as defining the *initial* and *boundary conditions* of any future systems model of the community.

A system- and complexity-aware approach to community appraisal is about collecting and analyzing data and information in a systemic way. More specifically, this means (i) seeing and seeking connections in the data; (ii) engaging multiple stakeholders in system model building; (iii) managing different opinions; (iv) seeing and encouraging social networks; (v) using reflection-in-action to assess the appraisal and the results of the appraisal; (vi) formulating the community problems in a noncompartmentalized manner; and (vii) recognizing that the appraisal team is itself a system with all the characteristics that entails.

Seeing and Seeking Connections in the Data

Traditional community appraisal tends to favor a pigeonholed approach to data collection whether it is about people's needs, infrastructure, or specific issues, such as water, energy, food, hygiene, transportation, health, education, etc. The aforementioned PAR tools of participatory and nonparticipatory data collection (e.g., focus group interviews, surveys, observations, mapping, etc.), as comprehensive as they may be, often fail to explore potential connections. It is important for development practitioners to adopt a multi-issue approach when collecting and analyzing community data. As an example, the issues of water, energy, and food/agriculture are more often than not interconnected. The collection and analysis of data about these three issues needs to address the following questions: How are these issues interconnected? What are the connections? And why are some connections stronger than others? The "where" and "when" (i.e., scale) of these connections needs to be addressed as well. These issues can be mapped using causal loop and stock-and-flow diagrams to indicate the components that are responsible for one or several issues faced by the community. Various system modules, such as those presented in Chapter 5, may emerge from this exercise. As data are being analyzed, the stock-and-flow diagrams become helpful at making sense of the data and visualizing their inter- and intraconnections and potential feedback mechanisms. As these diagrams are being built, it may become necessary to collect more data to clarify some emerging issues that are being mapped.

Stock-and-flow diagrams can be supplemented with some of the tools discussed in Section 4.8 such as double entry causality tables, mind maps, and layered diagrams. An example of layered diagram was shown in Figure 1.3 where the issues of energy, water, transportation, information and telecommunication, and emergency services are interrelated during a flooding event. In this layered diagram, each issue possesses its own intraconnection. For water, it could be issues of water availability, quality, quantity, distribution, wastewater collection, and the functioning of basic water infrastructure systems. As an example, Walters (2015) shows how to combine PAR tools, causal loop diagrams, social network analysis, and impact matrix analysis to identify key community issues and their interconnections for two rural water projects in Nicaragua.

Likewise, for energy projects, the following issues need to be assessed: energy sources, needed energy, energy use and patterns of use, and renewable versus traditional energy systems. For health, the type and location of health risks, child nutrition, and the capacity and vulnerability of health services need to be mapped. Finally, for food security projects, the issues of food availability, food access and distribution, and food usage and preparation need to be identified. In these circumstances, a double entry causality table such as Table 4.5 can be built.

Participatory Group Model Building

As community data are collected, it is important that community members be involved in the modeling process and become increasingly aware of how various community issues are connected. As discussed in Section 4.6, group model building methods have been suggested in the literature for groups to reach more holistic decisions. Recall, for instance, the example of the Costa Rican neighborhood discussed in Chapters 1 and 2 where a development worker trained in building models created a causal loop diagram with a group of local women leaders (Figure 2.4).

Dealing with Different Opinions

Groups of stakeholders and organizations in a given community are likely to have different opinions about the nature and importance of key issues in the community, how they are connected, what drives the issues, how they should be addressed, and who is responsible for addressing them. An example is shown in Figure 6.6 for a municipality in Nicaragua (Walters, 2015). In this example, two groups of stakeholders (a community water committee and a government agency) were asked "what are the most important issues that lead to the sustainability of rural water infrastructure in the municipality."

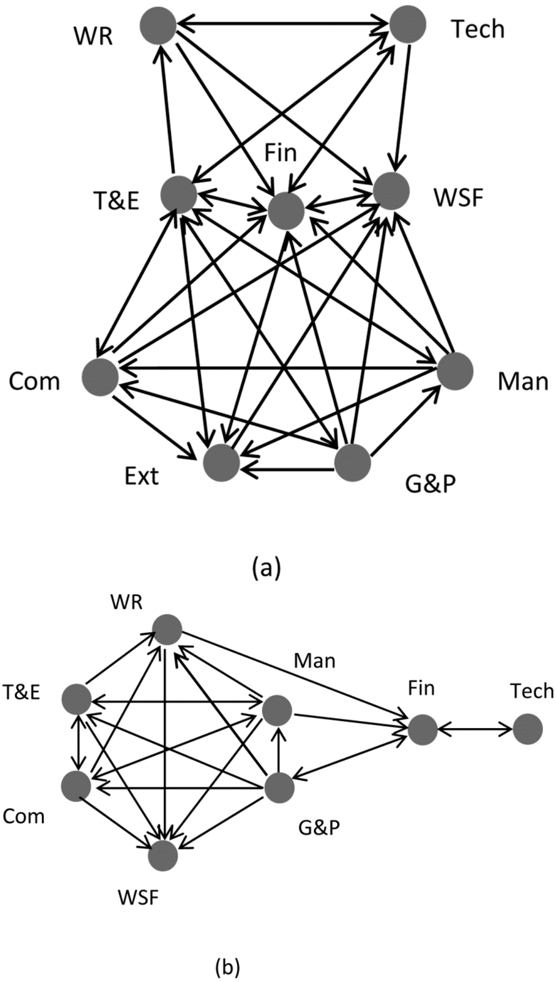

Figure 6.6. Diagram showing a network analysis of issues that are of value to two groups of stakeholders involved in deciding on the sustainability of rural water infrastructure in a municipality in Nicaragua. Arrows show how issues are connected according to (a) a community water committee and (b) a government agency.

Note: G&P: Government & Politics; Man: Management; T&E: Training & Education; Com: Communication; WSF: Water System Functionality; WR: Water Resources; Fin: Finances; Ext: External Support; Tech: Technology; and Com: Community.

Source: Walters (2015).

Figure 6.6 indicates that the two groups have different opinions about the issues and how each issue drives the others or vice versa. The challenge becomes one of making sense of and reconciling the different opinions, creating "stakeholder alignment" (Walters, 2015), and possibly reaching a common ground among all stakeholders. Etienne (2014) gives several practical natural resources examples where common ground could be reached by using multiple systems tools such as multiagent systems, agent-based modeling, adaptive management, role-playing games for collective decision making, and collective learning process.

Recognizing Social Networks

Individuals, households, associations, village councils, and other community groups all have different levels of importance and influence in a community which may vary over time. As adaptive and evolving social agents or groups of them, they are parts (some more than others) of a social network of relationships which can be represented as a social map consisting of interacting nodes and links (or ties) that define the social fabric or web (see Figure 4.9). In communities, nodes could represent groups, individuals, or partners of relative importance, and links represent how various stakeholders are interconnected in addressing a specific issue (water, energy, health, education, etc.)

The same representation could also be used to create social maps that describe how decisions are made at the community level and who is involved in making these decisions. Some members in a network are more critical than others in terms of skills, knowledge, resources, and decision making. They possess more "centrality" (Freeman, 1977; Borgatti, 2005) and can help in developing more effective and efficient solutions whereas others can block progress. Some members may have skills that others in the community are not aware of and therefore need to be brought into decision making. Finally, social networks are not only indigenous to a community. Social maps such as Figure 4.9 can help visualize exogenous connectivity between a community and other institutions within a broader environment (Mitleton-Kelly, 2003).

As discussed in Section 4.8, social network analysis not only provides a quick visualization of a community network and its components, but also maps (i) existing relationships and network communication in the various community systems; (ii) how the components of community interact, already work (capacity) or don't work (vulnerability); (iii) who makes decisions, who could block decisions, who are key players or threats, and who could be brought into the decision process; (iv) what are possible attractors in the community; (v) who are the reactive and passive agents in the community; and (vi) what are the community's weaknesses and vulnerable populations. Unlike system dynamics models, social network analysis does not pay much attention to the nature of interactions in a network, focusing instead on the interactions themselves.

Reflection-in-Action

While carrying out the community appraisal and analyzing the data, the feedback mechanism between the outer and inner paths in Figure 6.3 is critical to developing the community baseline. The reflection-in-action requires a joint effort and multiple feedbacks between project insiders and outsiders. All stakeholders need to decide whether the appraisal phase is adequate or needs more work and whether the problems identified are realistic. This is not an instantaneous process and it may create some delay in reaching any form of agreement.

Problem Formulation

The problems outlined and ranked at the end of the appraisal phase need to be formulated in a systemic way rather than in the form of a laundry list of issues to address. From a systemic perspective, the problem formulation should be more than just "the what, who, and where" of a problem as suggested by Caldwell (2002). For instance, the aforementioned problem narrative "*No toilet and minimum hygienic standards (what) are available for 70% of the rural population (who) of Loreto, Peru (where)*" may want to include how other problems such as health, jobs, the economy, education, or lack of national policies are linked to this one.

Special attention needs to be focused on whether solving one problem may help address another one or create new ones due to nonlinearities, synergy, and emergence. An attempt should be made to use causal analysis and stock-and-flow-diagrams to summarize the problem and its many components.

The Appraisal Team as a System

It should be noted that the appraisal team is itself a system that needs to remain *somewhat* functional as projects unfold. As mentioned earlier, the team needs to be knowledgeable in various traditional PAR tools of qualitative and quantitative data collection. The team also needs to be trained in system dynamics tools and systems thinking in general.

The team must also recognize that in decision making, its members must be ready to go through multiple feedback mechanisms that may reinforce agreement or division, or may help reach a common ground. A node and link social map such as the one shown in Figure 4.9 can also be used to map the connectivity between the members of the project management team which in turn may help resolve team dynamics issues. The map may show different individuals clustered around major community issues, how the clusters interact with each other, and how information flows from one cluster to another via other clusters. Such mapping can help in building more efficient decision processes, avoid roadblocks to team productivity, and reduce information and intervention delays.

6.7 Causal Analysis

Problem and Solution Trees

Once the data have been analyzed and the problems identified and ranked, there is a need to further analyze each problem in terms of cause and effect. Causal analysis acknowledges the complex cause-and-effect relationships (linear or circular causation) that characterize the dynamic of systems such as communities. These relationships are often the reason why problems exist in the first place and why the problems do not always have easy solutions. It is indeed not uncommon for a problem in a community to actually be the consequence or cause of another problem. Direct and indirect issues with macro- or microlinkages may contribute to a given problem. Comprehending all these connections can be difficult for the human mind, in particular for those who are more comfortable with linear thinking tools. The causal loop and stock-and-flow diagrams discussed in Chapters 4 and 5 along with the various visualization and decision techniques summarized in Section 4.8 may help development practitioners capture the macro- and microlinkages and make sense out of them.

One of the many visualization techniques that I have found useful in identifying the causes and consequences of a given problem is the *problem tree* (Delp et al., 1977). The core problem is represented by the tree trunk. The consequences (or effects) of the problem are represented by a network of tree branches, the visible part of the tree. Branches may have smaller branches to simulate effects and associated subeffects. The causes, subcauses, and other associated linkages are represented by the tree roots, the hidden part of the tree. Several core problems can be represented by several trees which in turn can share roots and branches. Figure 6.7 shows an example of a problem tree for a community in eastern Nepal where "low crop yield" was identified as the problem of interest (Glover et al., 2011).

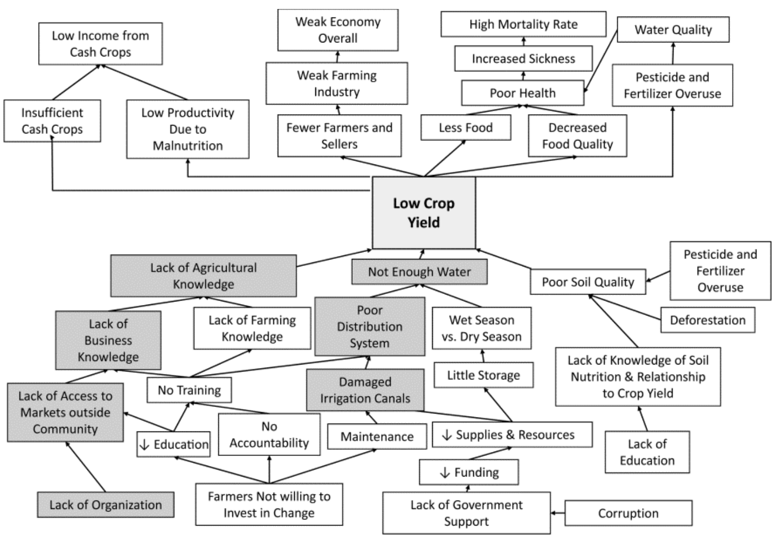

Figure 6.7. Example of problem tree for crop yield for a project in Nepal.

Note: The shaded boxes are arranged in two themes that need to be considered: education of farmers and water infrastructure.

Source: Glover et al. (2011), reproduced with permission.

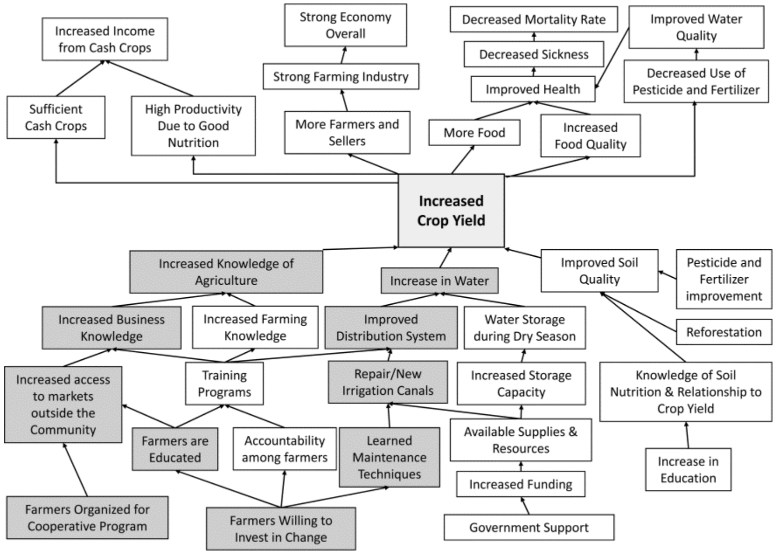

Figure 6.8. Example of solution tree for crop yield for a project in Nepal.

Note: The shaded boxes are arranged in two themes that need to be considered: education of farmers and water infrastructure.

Source: Glover et al. (2011), reproduced with permission.

The problem tree leads to its counterpart: a *solution tree*, also called a *result tree* or an *objective tree* (Delp et al., 1977). Instead of showing negative causes and effects of a major problem, a solution tree has positive roots and optimistic outcomes. The solution to the problem is now at its center and contributes to reaching the project outcome or overarching goal. The solution tree gives a comprehensive picture of the future desired solution in a hierarchical format and helps define project objectives. Figure 6.8 shows the counterpart of the problem tree for the same community in eastern Nepal.

From a systems point of view, problem and solution trees help visualize the hierarchical cause-and-effect dynamic that drives complex systems such as communities. It has been my experience that the concept of a tree can be understood by all (since most people have seen a tree) and can be a useful tool to help people visualize the causes and consequences of community problems; they may be aware of the issues but not of their connections. However, problem trees have limitations as suggested by Davies (2003). They only show links in one direction and in a hierarchical manner and as a result do not capture the complexity inherent in community projects. This could be remedied by constructing causal loop diagrams side by side with problem trees in order to capture various forms of connectivity among different causes or effects, or between causes and effects.

The challenge in using problem and solution trees is to prioritize which causes and effects to tackle once they have been identified. Figures 6.7 and 6.8 show multiple causes and effects and many places of possible intervention. Not all interventions are possible due to project constraints (time, financial, expertise, etc.) According to Caldwell (2002), priority should be given to causes that (i) show good potential to make a significant impact and contribution if eliminated; (ii) community members can relate to; (iii) provide substantial impact through synergy, collaboration, and partnering; (iv) match the capacity of the community; (v) are recurring in the community; and (v) can be measured and verified. In Figures 6.7 and 6.8, two tracks (or themes) were identified as propriety root causes and are shown by the shaded boxes: education of farmers and water infrastructure.

Project Hypothesis

Once key interventions are selected to address a given problem, a project feasibility study is carried out. This is the output of the preliminary phase of project design. In that study, various options are proposed and actions considered for each option. The challenge is to match the options with the community characteristics identified in the appraisal phase (capacity, vulnerability, and resilience). In order to help with the selection and decision process, various mathematical methods can be used (Delp et al., 1977; Decision Sciences Institute, 2014; Glen, 2014).

Existing mathematical decision tools such as the *Multi-Criteria Decision Analysis* (MCDA) method can be used to rank decisions based on several key criteria deemed important in the decision process (Delp et al., 1977; Mendoza and Macoun, 1999; Figueira, 2005; Nathan and Reddy, 2011; Huang et al., 2011). An excellent review of different multi-criteria analysis techniques was published by the Department for Communities and Local Government (DCLG, 2009) in the United Kingdom.

In the book *Systems Tools for Project Planning* (Delp et al., 1977) and the CARE *Project Design Handbook* (Caldwell, 2002), a variation of the MCDA method is referred to as the *Multi-Criteria Utility Assessment* (MCUA) method. In this method, the decision process is presented in a matrix form. The MCUA matrix ranks alternative solutions based on their worth for each problem identified and their appropriateness which can be defined in terms of decision criteria (or attributes) such as cost-effectiveness, social acceptability, required management support, community support, sustainability, technical feasibility, political sensitivity, and level of risk (Caldwell, 2002). Other criteria that may enter into the ranking process include cost-benefit analysis, transport and delivery costs, operation and maintenance, energy needs, replacement parts and costs, life expectancy, payback period, maintenance, and timing (Forbes, 2009). To this list, we can also add social acceptability, political sensitivity, administrative feasibility, community sustainability, community participation, and environmental sustainability, among others.

For each alternative solution in the MCUA matrix, a score is calculated based on subjectively assigned weights for each selected decision attribute or criterion. Several methods have been proposed in the literature and include the rank order centroid method; the ratio method; the swing weighting method; and the analytic hierarchy process pairwise comparison method (Barron and Barrett, 1996; Molenaar, 2011). A sensitivity analysis can also be conducted to explore how different ratings and weights affect the decision scores. Table 6.4 shows an example of MCUA matrix for the community in eastern Nepal considered in Figure 6.7 and 6.8. Criteria were used to compare different solutions for two issues: water for irrigation and energy. Note that the solution with the highest ranking in Table 6.4 is when both issues are addressed simultaneously.

At the end of the decision process, one alternative solution with a higher score may clearly stand out in the MCUA above the rest as in Table 6.4. However, this is more often the exception than the rule. More often than not, solutions rank close to each other since there is a fair amount of uncertainty at this stage of the project. Even solutions that have smaller scores should not be discarded as they may later on become feasible if more data become available as projects unfold.

Table 6.4. Example of multi-criteria utility assessment matrix for a project in Nepal.

		Train Maintenance Person for Old Canals		Irrigation Canals		Implement Drip Irrigation		Water Storage Facilities for Year-Round Water Supply		Electrical Transmission Lines from Existing Hydro Plants		Pico-Hydro Plants		Photovoltaic Panels on Individual Homes		Combined Irrigation Canal/ Pico-Hydro System	
Criteria	Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight
Cost effectiveness	3	3	9	2	6	1	3	1	3	1	3	2	6	2	6	3	9
Social acceptability	5	2	10	3	15	1	5	2	10	2	10	2	10	2	10	3	15
Operations & maintenance feasibility	4	2	8	2	8	1	4	2	8	2	8	2	8	1	4	2	8
Environmental sustainability	5	3	15	1	5	3	15	2	10	3	15	3	15	3	15	2	10

		Train Maintenance Person for Old Canals		Irrigation Canals		Implement Drip Irrigation		Water Storage Facilities for Year-Round Water Supply		Electrical Transmission Lines from Existing Hydro Plants		Pico-Hydro Plants		Photovoltaic Panels on Individual Homes		Combined Irrigation Canal/ Pico-Hydro System	
Criteria	Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight	Score	Score x Weight
Community participation	4	1	4	3	12	2	8	2	8	3	12	3	12	2	8	3	12
Impact on community health	4	1	4	2	8	2	8	1	4	1	4	2	8	1	4	2	8
Economic impact	3	1	3	3	9	2	6	1	3	2	6	2	6	2	6	3	9
Number of people impacted	4	2	8	2	8	2	8	2	8	3	12	2	8	3	12	3	12
Total			61		71		57		54		70		73		65		83

Source: Glover et al. (2011), reproduced with permission.

The reflection-in-action process in Figure 6.3 may require a reevaluation of the alternative solutions in the MCUA matrix. After all, it must be remembered that this is still the preliminary phase of project design. Further analysis is therefore needed to narrow down the most appropriate solutions and interventions.

The MCUA decision process involves a combination of objective decision making when selecting the various alternative solutions to a problem and subjective decision making when selecting the weights of the different criteria. It is therefore critical that the team making such decisions consists of qualified individuals. The team members must possess the technical expertise to conduct the exercise and suggest recommendations which can be technical or nontechnical (e.g., behavior and/or policy change). Additional expertise may be sought, as necessary, from the local communities, government agencies, and other groups and individuals who have experience and have developed practices in the past.

The solutions that emerge from this phase of the project need to be brought to the attention of the entire community, its stakeholders and partners, and validated through various mechanisms such as feedback meetings, nominal group process, and prioritization exercises (Delp et al. 1977). This step helps with information sharing, external validation, and building support and acceptance among the community members. From this exercise, certain solutions will emerge as more appropriate to some community members than others. This may confirm the conclusions reached with the MCUA method. In other cases, it may contradict those conclusions and require reexamination of the attributes and criteria used in the initial ranking. Although several alternative solutions may still need to be considered at the end of this selection exercise, there are likely to be fewer options than those listed in the initial MCUA matrix.

This stage of the overall ADIME-E framework is where the focus of the project has shifted from appraisal and identification of community problems to developing a preliminary action plan. A *project hypothesis* (or project statement) can now be laid out in terms of anticipated outcome and the problems being addressed, the connections between problem causes and effects, the impact of possible interventions, how the interventions rate, the assumptions and preconditions necessary to support the project hypothesis, and the risks involved if these assumptions and preconditions are not fulfilled. At this stage of the ADIME-E framework, project managers may decide whether to move forward and develop a full action plan, put the project on hold, or terminate the project.

A Systems Approach to Causal Analysis

As with the community appraisal, the causal analysis needs to be carried out in a systemic way. This can be done by considering the connections between the different tasks involved in this stage of the project as shown in Figure 6.9. Another way is to subject the results of the causal analysis to reflection-in-action as discussed in Section 6.3. The feedback mechanism between the outer and inner paths in Figure 6.3, when carrying out the causal analysis and developing the project hypothesis, is critical to ensuring a sound preliminary project design. At this stage of the project, there may be a need to go back to the community and collect and analyze more data if a data gap is noticed or in order to strengthen the selection of a preliminary solution.

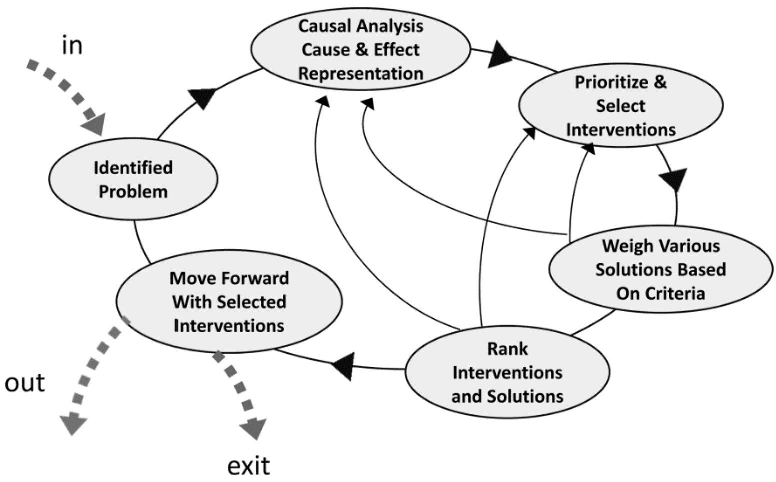

Figure 6.9. Different tasks involved in the causal analysis phase of project management.

Note: This figure was developed in collaboration with Tamara Stone.

Reflection-in-action during the causal analysis phase of a project may raise the following questions: (i) Does the project hypothesis truly address the root cause(s) of the problem? (ii) Are the proposed solutions appropriate within the community context? (iii) Does the community agree with the project hypothesis and the proposed alternative solutions? It may also happen that despite multiple feedback mechanisms, reflection-in-action may recommend that the project be stopped altogether and an early exit strategy needs to be outlined.

A systems approach is critical to the success of this phase of the project as solutions need to be well-thought out and their impact estimated accordingly. The causal loop and stock-and-flow diagrams described in Chapters 4 and 5 combined with problem and solution trees and multi-criteria decision tools can help identify the most promising solutions to one or several community problems and explore the "what if" (or "what happens if") of these solutions. An attempt should be made to account for relationships between the various criteria in the MCUA matrix and how they may influence the overall option ratings.

6.8 Comprehensive Work Plan

Strategy and Operation

A comprehensive work plan is now developed that includes project strategy, logistics, and tactics. It can be seen as "a collection of documents that communicates essential information about a project to everyone who is involved in the project" (CH2MHILL, 1996). Strategy refers to the overall game plan or method that will be followed to conduct the work. Tactics and logistics are related to the implementation part of the work. Tactics refer to the what, who, when, where, and how of a project. Logistics refer to activity and resource scheduling and procurement. Tactics and logistics represent the operational component of project delivery.

As discussed in Section 6.2, project strategy is expressed in terms of a logical framework (LFA) that summarizes the structure of the project and its internal logic in terms of impact, goals, objectives (outputs), activities, and inputs. The LFA must translate into an operational (implementation) plan ready to be executed with well-defined indicators, modes of verification of success, targets, and taking into account assumptions and preconditions. The plan contains detailed tactical and logistical information describing (i) how the goals, objectives, activities, and input in the LFA will be implemented; (ii) how, where, and when the activities and tasks will be conducted (scheduling); (iii) who will conduct these activities and tasks; (iv) what resources are necessary; and (v) what contingency plans need to be included for different levels of expected success.

The work plan is usually presented in the form of activity and resource scheduling graphs, responsibility charts, work breakdown structures, budgets, resource plans, and Gantt charts (used to describe the human, material, and financial means necessary to undertake the activities). Multiple project life-cycle costs are considered and may include start-up, installation, energy, operational, maintenance and repair, downtime, environmental, decommissioning, and disposal costs depending on the nature of the project. In addition to planning the project activities, there is also a need to plan the management of project activities and various tasks such as quality control, reporting, budget control, and staff. As with the project activities, human, physical, and financial resources necessary to undertake the management activities need to be outlined, procured, and mobilized.

In this phase of the project cycle, the planning of project quality needs to be addressed as part of a quality management plan. This includes defining quality standards and the characteristics of those standards. This will help define a strategy for project quality assurance, quality control, and quality improvement. Another aspect of project planning has to do with assessing the impact (local, regional, and global) that the project's activities and solutions could create on people's health and well-being, as well as the environment (IAIA, 2014). Issues may include noise, land, water, and air pollution, deforestation, and reduced biodiversity. Special precaution must be taken to ensure that local and/or national regulations are respected. A final aspect of project planning is taking care of zoning issues and permits that are necessary prior to project execution.

As the final work plan is developed, both capacity analysis and risk analysis need to be further carried out in order to refine and confirm the decisions outlined in the work plan. Another equally important issue is how likely community members are to change their behavior when adopting the recommendations outlined in the work plan.

Behavior Change

Success of the operational plan does not rely on engineering solutions alone. More often than not, the success of implementing the components of the action plan depends on necessary changes in community behavior. A *Behavior Change Communication* (BCC) strategy may need to be introduced in order to promote positive behaviors and create a supportive environment so that the behaviors are sustainable in the long-term and eventually become habits. According to Booth (2013), the *BCC strategy* includes (i) identifying the motivators for change in behavior and barriers that have the potential to prevent or slow down change; (ii) reviewing existing forms of behavior including possible competing ones and their levels of penetration; (iii) weighing the benefits of alternative forms of behavior, their impact, and their possible levels of penetration; (iv) outlining the dominant methods of communication that are most likely to be effective within the target audience, its components and their probability of success; and (v) identifying resources available and needed to reach out to the target groups.

Once a BCC strategy has been agreed upon, a *BCC plan of intervention* needs to be established for each form of behavior that needs change. The plan needs to outline who is responsible to implement the BCC plan, where and how BCC activities should take place, and over what time frame. The plan must also include provision for monitoring and evaluation of the actions taken and how to implement corrective and remedial actions if the target behavior is not in place over a certain physical and temporal scale. It must be stressed that the behavior change sought in the community is to be encouraged and promoted through the BCC plan, but never coerced.

Capacity Analysis

Within the context of community development, capacity has to do with the ability of community members to achieve certain development goals and satisfy their needs. It defines the *enabling environment* of the community. Capacity is also about the ability of community members to cope with various situations (inherent capacity) and to adapt to new needs, challenges, changes, and opportunities (adaptive capacity). Capacity is a strong attribute of communities that are resilient to hazards and adverse events.

In the overall ADIME-E project framework shown in Figure 6.3, capacity analysis is conducted to ensure that the community has the ability to move forward with the preliminary work plan. More specifically, there is a need to assess whether the community has the strength, knowledge, resources, and capability to (i) accept the proposed solutions and recommendations outlined in the planning stage of the project; (ii) implement those solutions; and (iii) carry out the corresponding action plan in a sustainable way with long-term benefits. Capacity analysis helps ensure that the solutions in the proposed work plan match the level of community development. Capacity analysis helps identify the weakest links in the community (part of the constraining environment) and determine the necessary steps in eliminating them through community capacity building so that the community can achieve a higher level of development and success over time. In summary, capacity analysis provides an understanding of what the community can do, what it cannot do, and what it could be doing if it were to reach a higher level of development through strengthening.

The capacity of a community increases through capacity building and capacity development. This process is multidimensional since there are many forms of capacity that can be addressed in a community such as financial, technical, social, intellectual, leadership, environmental, institutional as shown in Figure 6.5. Often times, the different categories of capacity are linked to each other due to the systemic nature and complexity of communities. Furthermore, capacity building and capacity development at the community level are likely to depend on what takes place at other scales within the community, across communities, and at the regional or national level. As a result, capacity development needs to be considered "from a systems perspective, with an appreciation of the dynamics and interrelationships among various issues and actors in different dimensions" (Bolger, 2000).

Risk Analysis

Communities must not only identify and increase their capacity; they must also identify and reduce their vulnerabilities. The balance between capacity and vulnerability defines to a great extent the risk environment in the community. In general, risk is the possibility that an undesired outcome (or the absence of a desired outcome) associated with an event has "adverse effects on lives, livelihoods, health, economic, social and cultural assets, services (including environmental), and infrastructure" (NRC, 2012). Risk depends on the magnitude of the event, the exposure to that event, and the difference between the vulnerability and capacity to handle that event.

According to Smith and Merritt (2002), at the project level, risks can be seen as unanticipated surprises that could jeopardize the success of a project or parts of it. In systems lingo, these unintended consequences emerge from the project itself and/or the environment in which the project unfolds. In general, risks can stop a project at its inception, delay it, and/or lead to failure if not properly accounted for. In turn, risks have the potential to affect the life of the community, its health, its economic well-being, its social and cultural assets, and its infrastructure.

The risk environment at the community level is twofold. The first risk environment is defined by risks that exist before any project is conducted. These are risks associated with a wide range of adverse events or hazards that the community could face and over which community members have limited control. They can be internal or external to the community, small or large. They range between everyday events (e.g., lack of water and sanitation, poor shelter, living conditions, livelihood, illness, economy, etc.) and extreme events (e.g., floods, volcanoes, earthquakes, landslides, wildfires, hurricanes, etc.) Several small-scale or periodic medium-scale events may arise as well such as drought (periodic, chronic), soil degradation, deforestation, epidemics, health risks, and hazards, etc. Another class of adverse events deals with those associated with war or the breakdown of governments that may have disastrous consequences at the local and global levels.

The second risk environment is associated with the project itself. Risk may arise in all phases of the ADIME-E framework due to the prevailing uncertainty and complexity of the project environment. They can be internal or external to a project. For instance, in the appraisal phase of the ADIME-E framework, there is a risk that some stakeholders may create roadblocks to the execution of a project. There is a risk that the collected data are inaccurate, incomplete, poorly analyzed, or strongly biased. There is a risk that the data analysis leads to an incomplete project hypothesis. There is a risk that the project may fail because of unintended consequences resulting in loss of life and/or resources, whether right after the project is completed or during the project life cycle. There is a risk that in the logical framework and project planning phase, assumptions and preconditions necessary to meet goals and objectives are not (or are partially) met or there is negligence or cutting corners in project management. These situations may lead to negative results, project delays, or cost overrun. Finally, there is a risk that the project is no longer what the community needs, or, in some cases, was never needed in the first place.

It should be noted that both risk environments are not necessarily independent of each other. They may be situations where one feeds onto the other and even accentuates the severity of situations in a cascading manner; new risks may even be created.

Since risks are an integral part of projects in developing communities, they need to be managed. Risk management contributes to protecting and preserving security, well-being, and quality of life for the households within its scope. An added value of risk management is that it helps communities become more resilient over time and creates better projects overall. As discussed by Smith and Merritt (2002), risk management consists of several steps: (i) risk identification (risks, drivers, impacts, probability); (ii) risk analysis and prioritization (mapping in terms of impact and probability); (iii) development and implementation of risk management strategies (avoidance, transfer, tolerance through mitigation, contingency plans); and (iv) monitoring and evaluation of strategies (measuring progress and effectiveness, identifying new risks, and eliminating those risks no longer of concern).

A Systems Approach to Developing the Work Plan

As in the community appraisal and causal analysis stages of the project, the different aspects of the work plan need to be carried out in a systemic way. Figure 6.10 shows how the different tasks involved in the strategy and planning stage of a project are related through various feedback mechanisms. Each task in turn consists of additional internal connections and feedback mechanisms. For instance, the different forms of capacity listed in Figure 6.5 are themselves interconnected for a given type of service. Likewise, risks existing prior to a project and those created by a project can be related as the project may actually increase or decrease the existing risks.

The feedback mechanism between the outer and inner paths in Figure 6.3 influences the comprehensive work plan. During this stage of the project, there may be a need to reconsider the interventions outlined at the end of the causal analysis stage and select one that (i) provides a better value now than at the time of the preliminary design; (ii) creates less risk; (iii) fits the community capacity better; (iv) has less environmental impact; (v) is more cost-effective; (vi) has a higher cost-benefit; and/or (vii) is more promising from a behavior change point of view. There may also be a need to collect additional data that may have been ignored during the appraisal phase. The comprehensive work plan is an important component in the project life cycle since upon its completion, project execution can start.

Reflection-in action while developing the comprehensive work plan may raise several questions such as: (i) What is the importance of meeting the assumptions and preconditions in the work plan? (ii) Will the community members be able to play an active role in the project execution? (iii) Will they be able to deliver a project of quality, with tangible benefits, and in a cost-effective way? (iv) Does the community have the capacity to handle the project? (v) What are the risks involved? and/or (vi) What kind of behavior change is expected of the community?

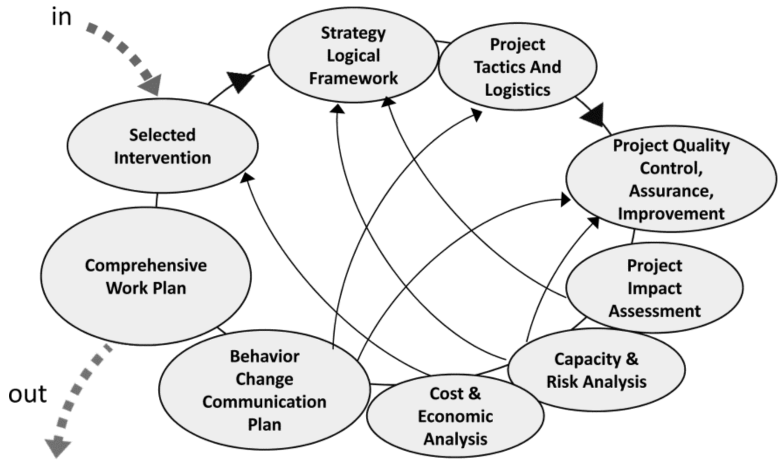

Figure 6.10. Different tasks involved in the strategy and planning stage of project management.

Note: This figure was developed in collaboration with Tamara Stone.

Systems models can be used to visualize the various strategy, tactics and logistics components of the work plan in greater depth. Stock-and-flow diagrams such as those shown in Chapter 5 can help in visualizing connections far beyond the traditional tools such as Gantt charts and the like. They can also be used for scenario building and explore "what if" (or "what happens if") situations and their consequences in each critical part of the work plan.

6.9 From Implementation to Long-Term Sustainability

Following the same recommendations as for the other stages, all project stages following the implementation plan need to be carried out in a systemic way and not as separate tasks. During project implementation, it is likely that changes in the operational decisions will be dictated by logistical and tactical changes and vice versa. This feedback mechanism extends beyond project closure, although the intensity of the feedback is much less after project closing than before. At this stage of the framework, the project managers may have enough causal loop and stock-and-flow-diagrams to predict the medium- to long-term performance of the project, suggest alternatives if conditions change or the project does not perform as planned, and foresee any future intervention if needs arise.

As the project comes to an end (planned or unplanned), lessons learned must be evaluated and a final evaluation of the project must occur. Project sustainability (i.e., its long-term performance) must be ensured once the project has ended (postevaluation). The project must be able to continue delivering benefits to the target community which requires that measures and processes must be in place should problems arise and decisions need to be made (e.g., *reflection-post-action*).

Criteria for project sustainability are mostly subjective as discussed in Chapter 7. According to the World Wildlife Fund (Gawler, 2005), "a project can be said to be sustainable when it continues to deliver benefits for an extended period, after the main part of external support has been completed." According to Nolan (2002), project sustainability depends on whether the project is "compatible with its surroundings." Good design, along with community participation, sound financial support and economic environment, and fitting policy are great attributes of sustainable projects. In my previous book (Amadei, 2014, Chapter 15), I discuss at length the different recommendations that have been proposed in the literature to ensure the sustainability of Water, Sanitation, and Hygiene (WASH) projects.

A recent study conducted by Walters (2015) on using systems tools to determine the factors that are most critical to ensure the long-term sustainability (performance) of rural water projects is worth mentioning. Using a combination of stakeholder interviews, graphical modeling, and social network analysis, Walters found that eight critical factors and their interconnections influence the outcome of rural water projects. They include: government, community, external support, management, financial, technology construction and materials, environment and energy, and water system functionality.

Going to Scale

In order to ensure long-term success, projects should be evaluated for replicability and scaling up (i.e., expanding the project scope and implementation toward a greater impact within the community or other communities). If community development projects could be approached in a linear and predictable way, their replicability could be easily planned.

This is obviously not the case and scaling up in a complex and uncertain setting is difficult. There are no effective recipes to guarantee that what works at one scale will work at another scale. This has to do with all the characteristics of complex systems discussed in Section 3.3. Any change in one component of a system will have unpredictable consequences somewhere else in that system or in other systems connected to that one.

As noted by Taylor et al. (2012), communities evolve through adaptation and change. Hence, according to these authors, scaling up in that context cannot be seen as a "growth in numbers" which would be like "viewing humanity as a mass of bodies and forgetting that they can interrelate one to another. It is from their interaction that the truly important dynamics evolve." Taylor et al. see this evolution occurring under a framework which they call *Systems for Communities to Adapt Learning and Expand* (SCALE). It recognizes that community development takes time and that with the availability of resources and skills, community well-being can emerge from multiple interactions and lead first to an increase in the number of people benefiting from development, followed by an improvement of the quality of life at the level of the community, and to creating an environment for collaboration and expansion.

The bottom line is that scaling up cannot be predicted by doing this or that. Like many forms of behavior in systems, it emerges when the right conditions are in place and a "tipping point" (Gladwell, 2002) has been reached. We may never know when that takes place but all parties involved in development projects (insiders and outsiders shown in Figure 2.1) can contribute to making the environment fertile for that tipping point to sprout and grow. Necessary (but not sufficient) conditions for that process to take place include having a fertile community environment with the unique attributes discussed in Section 2.3 and decision makers that are aware of the systemic and complex nature of development projects.

Reflective Practice

It is important for community development practitioners to reflect on a project once it has been completed. This reflection-on-action, or "debriefing" process, represents a valuable learning exercise in identifying what has worked and not worked in a project (Figure 6.3). It helps incorporate changes in future projects and explore areas of potential improvement. Reflective practice is also a valuable tool for the practitioners as it promotes self-learning, enhanced skills and knowledge, increased confidence and understanding, self-motivation, and professionalism. Reflective practice may also give some insights into the applicability of systems tools and provide possible changes for future projects.

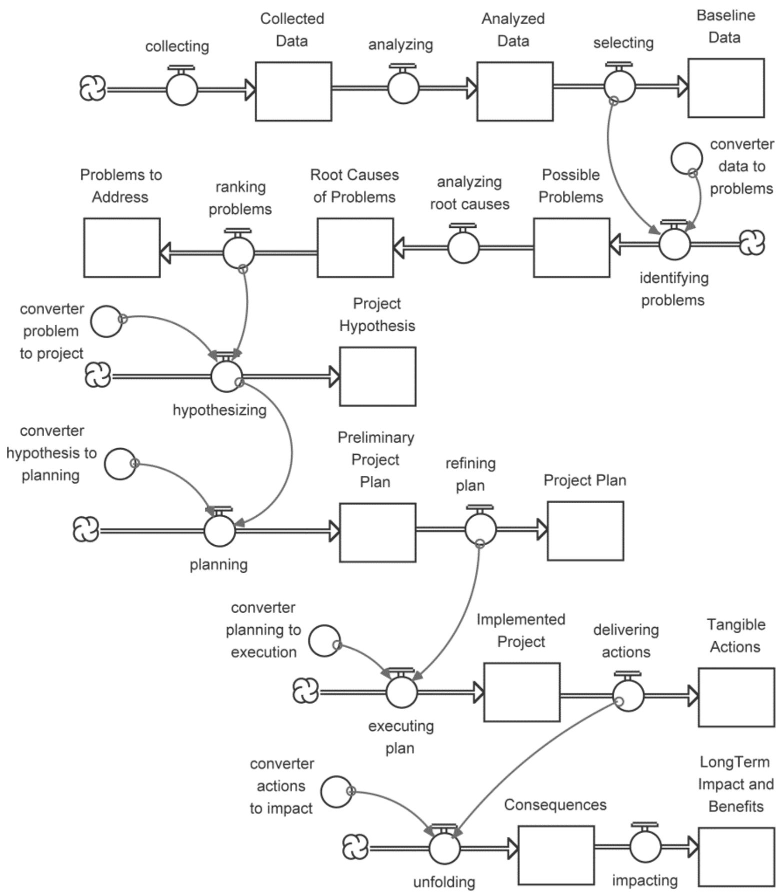

Figure 6.11. Stock-and-flow diagram representing the different stages of the ADIME-E framework.

Note: This figure was inspired by Figure 1-3 in Introduction to Systems Thinking by Richmond (2004, pp. 8).

6.10 Stock-and-Flow Representation

Figure 6.11 shows the aforementioned stages of the ADIME-E framework using a stock-and-flow diagram. It consists of six variables: data, problems, hypotheses, plans, actions, and impact/benefits. Converters are used to transition from one variable to the next. Note that the feedback mechanisms shown in Figure 6.3 were not included in the stock-and-flow diagram for the sake of clarity.

The stocks associated with the six aforementioned variables are the key components of development projects. They can be inserted at the center of Figure 2.1 to illustrate that the key components require participation and involvement from the community, governments, and outsiders.

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CHAPTER 7

Dynamic Modeling of Community Development

In systems such as small-scale communities, structure controls behavior in a given context. Existing patterns of community behavior and their associated issues can be analyzed to determine their underlying structure. In turn, this reverse form of analysis helps in deciding what building blocks need to be included in system dynamics models of communities. This chapter provides guidelines for selecting the components and modules that need to be included in system dynamics models of small-scale communities. Models may not be able to reproduce in depth the complexity associated with the interaction of social systems with other systems. Nevertheless, simple but integrated system dynamics models combined with traditional methods of community development can provide valuable tools in understanding the underlying structure behind the state of a community and duplicating some of its associated behavior patterns and ongoing issues. Once the underlying structure is understood and associated parameters are determined, system simulations and sensitivity analyses can be conducted and recommendations can be proposed so that the community can solve some issues and reach a more desirable state or even a so-called state of sustainability. This methodology needs to consider multiple scales and multilayers of analysis at the system, subsystem, and modular levels.

"As complexity increases, precise statements lose meaning and meaningful statements lose precision" (Lofti A. Zadeh).

7.1 Introduction

As discussed in Section 2.1, human development is about "creating an environment in which people can develop their full potential and lead productive, creative lives in accord with their needs and interests"

(UNDP/HDR, 1990). It can also be seen as a process of providing the services and resources necessary for people to address their basic human needs, which in turn can lead to subsequent economic growth. Successful human development encompasses multiple attributes as discussed in Section 2.3. Broadly, a positive sign of human development occurs when communities are able to evolve over time from their *current state* to a more *desirable state* where health, prosperity, peace, stability, and resilience are prioritized and hopefully become the norm. These positive characteristics usually emerge from the interaction of multiple stakeholders and multiple interventions and projects that increase the capacity of communities and decrease their vulnerability. Obviously, the transformation does not happen overnight and requires patience and dedication from all involved in community development, especially the community members. In short, successful development takes time.

In development projects, the state of a community is determined during the appraisal stage of project management (Section 6.6) and is included in the community baseline along with the various issues a community faces. The community state expresses itself in distinctive behavior patterns. Since, as discussed in Chapters 3 and 4, the behavior of systems is controlled by their structure and how they interact with their environment, analysis of the community baseline data may help identify possible structural components that are responsible for the current state of the community. A dynamic hypothesis (Sterman, 2000) emerges from that analysis. In turn, the structural components can be included in the problem identification and ranking stage of the project, the project hypothesis formulation, the design of solutions, the development of an appropriate work plan, and the laying out of long-term solutions as discussed in Chapter 6. Finally, understanding patterns of behavior and being aware of their underlying structure can help in constructing system dynamics conceptual models that are more representative of the actual community and better address the issues faced by the community or any part of it. The models can also be used to envision one or several possible desirable states for the community.

It is clear that being able to recognize the behavior patterns of communities and infer their underlying structures in a given context is a unique skill and one of the many core competencies or practices that system- and complexity-aware development practitioners should possess as discussed in Section 4.6. At the same time, they should also realize that it is practically impossible to account for all the structural components that are responsible for all the different forms of behavior occurring at all scales in a community. Based on experience, one can only *guess* at the current state of a community, infer some of the structural components that are responsible for its behavior, and propose simplified but integrated conceptual models to explain that behavior. Hopefully, as projects unfold, a better picture of the community emerges, its dynamics becomes less confusing, and system dynamics modeling becomes more comprehensive. In short, development practitioners need to remember that understanding and modeling the state of a community takes time, requires awareness (mindfulness), a lot of patience, and is never complete.

Out of all desirable states for a given community, one state that has become popular to talk about in the field of development (which can be interpreted as the "holy grail" of all states) is for a community to be sustainable. As discussed in Section 2.4, many interpretations of sustainability have been proposed in the literature. That state is often seen as balancing people, planet, and profit. Using the more sophisticated model of Ben-Eli (2011, 2012), the sustainability state is characterized by a "healthy" dynamic equilibrium between humans and the carrying capacity of the environment they depend upon (Figure 2.2). As shown in Figure 2.3, the five interconnected domains at play in that equilibrium are the material, economic, life, social, and spiritual (value) domains.

The dynamic of reducing the gap between the current state of a community and any desirable state (assuming both can be defined) can be represented using a stock-and-flow diagram as shown in Figure 7.1. The *goal-setting* archetype shown in Table A.1 in the Appendix was selected to model that dynamic. Community development can be seen as an "adjusting" process that is occurring at a certain rate (AR1) and over a certain time (delay). This is done through continuous *reflection-in-action* as discussed in Section 6.4. The rate of adjustment depends on many factors (social, economic, political, etc.) and can also be a function of the gap between the desirable state (DS) and the current state (S) of the community.

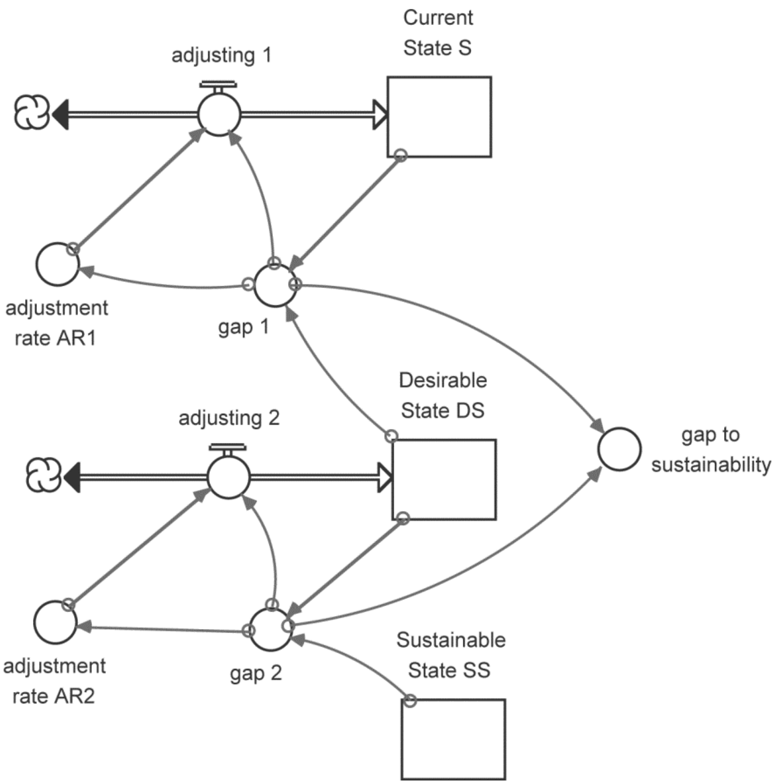

Figure 7.1. Dynamic between current state, desirable state, and sustainability state of a community using a goal-setting archetype. Bi-flows are used to model possible increase or decrease of the current and desirable states.

Another adjusting process running in parallel to the first one can be introduced between the desirable state and the ideal sustainability state (SS) of the community and at a different rate of adjustment (AR2), which could be slower or faster than the first one. The two processes shown in Figure 7.1 can be formulated mathematically as follows:

$$\frac{dS}{dt} = AR1 \times (DS - S)$$

$$\frac{dDS}{dt} = AR2 \times (SS - DS)$$

The difference between the two gaps in Figure 7.1 defines how far the current state of a community (S) is from the sustainability state (SS). Solving these two first-order differential equations would give an expression for (S) and (DS) as a function of time, if we knew their functional forms and associated parameters and variables (dependent and independent).

It is noteworthy that Figure 7.1 contains two bi-flows instead of two uni-flows feeding the current and desirable state stocks. This was used to model an increase or decrease of the two stocks. The current and desirable states may actually decrease if the adjustment rates become negative and the community state degrades over time. Including delays and adjustment rates in the stock-and-flow diagrams of Figure 7.1 is likely to create an oscillation mode of community behavior around the desirable and sustainability states.

A question arises as to who defines the (S) and (DS) states in Figure 7.1; we will talk about the (SS) state in Section 7.4. An obvious and idealistic answer to that question is "the community insiders, of course." The problem in development projects, however, is that community outsiders often have a different opinion than the insiders. That difference in opinion between insiders and outsiders needs to be reconciled over time through participation and collaboration. An attempt to model that dynamic is shown in Figure 7.2 where the *oscillation* or *two interacting population* archetype of Table A.1 in the Appendix has been used to model that process.

Figure 7.2 explains that insiders have their own opinion about the current state and the desirable state of their community. They have some level of awareness about the gap between the two, and are working at reducing that gap over time. As outsiders enter into a collaborative framework with the insiders and learn about the community, they forge their own opinion about its current state and offer recommendations about a more desirable state. Through exchange and collaboration with insiders, outsiders gain insight by comparing the insiders' opinion with their own. Over time (delay), they adjust their opinion about the current state and the desirable state of the community (adjustment rate ARo). Likewise, insiders adjust their opinion over time (delay) about the current and desirable states by interacting with the outsiders (adjustment rate ARi).

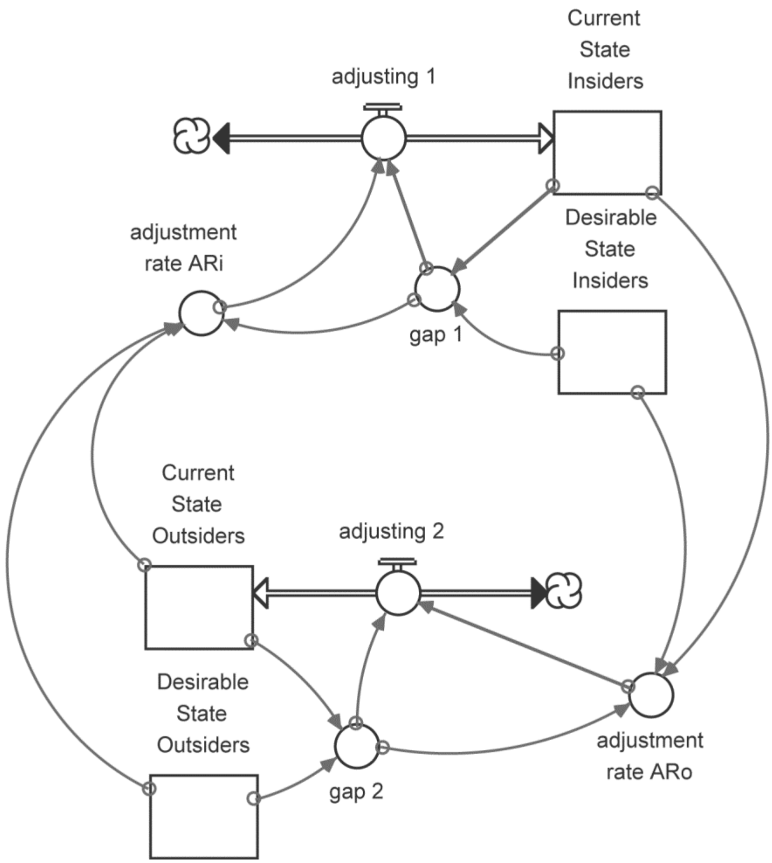

Figure 7.2. Dynamic of interaction between insiders and outsiders using an oscillation archetype. Bi-flows are used to model any positive or negative adjustments in the interaction between insiders and outsiders.

The interaction model of Figure 7.2 reaches convergence when outsiders and insiders agree on what the current state and the desirable states of the community are, and on a plan of action to achieve the desirable state. If the convergence does not take place, there is the risk that the solution implemented by outsiders will not last long and become unsustainable due to the lack of community buy in. Note that in Figure 7.2, the two adjustment rates, ARo and ARi, are not constant and depend on the two gaps, which also change over time. Finally, as in Figure 7.1, bi-flows have been used to model any positive or negative adjustments in the interaction between insiders and outsiders.

7.2 Reverse Analysis of Community Behavior

Now that the dynamic between current and desirable states of a community has been established and formulated in a system dynamics manner, let's explore how to identify the structural components that drive the behavior patterns of a community and are responsible for existing issues in that community. Once an adequate and somewhat realistic structure has been developed and is deemed "good enough" by all stakeholders to reproduce existing observed behavior patterns and explain the issues, it can be tested further by conducting parametric studies and sensitivity analysis. This overall methodology is directly consistent with that proposed by Sterman (2000) and Ford (2010). This corresponds to steps 5 to 8 in the overall modeling process of Figure 4.6. Upon finishing step 8 of that process, predictions can then be made about the future of the community, leverage points identified, and recommendations proposed in regard to what structural components need to be changed in order for the community to solve its ongoing issues and reach a more desirable state, even a state of sustainability.

Inferring the structure of something from its emerging behavior (or performance) can be seen as *reverse analysis* (the term reverse engineering is used instead in many engineering disciplines). However, there are no specific existing methodologies for how to do so, much less one that would guarantee a definite and successful answer. Reverse analysis of community patterns of behavior and associated community issues is likely to be done in an iterative, trial-and-error manner using the various feedback mechanisms shown in Figure 4.6. It also requires making assumptions and laying out multiple preconditions, which, if not fulfilled, could make the inferred structure far from reality. This does not mean, however, that reverse analysis is a random process. Several recommendations can be made to guarantee some *satisficing* (i.e., good enough) levels of success.

- There are common patterns of human behavior called archetypes that have been identified around the world and modeled using systems tools as discussed in Section 4.4. The dynamic behind these archetypes is relatively well understood although it cannot be generalized to represent all forms of human behavior. Nevertheless, archetypes represent a great place to start in community projects and reverse analysis. Some, but not all, observed forms of community behavior patterns can be matched with existing known archetypes for which system dynamics structures can be inferred.

- There are basic human needs that are common to all human beings on the planet. Although needs may vary from one culture to the next and change with scale, a good place to start is to incorporate in the reverse analysis the broad categories of needs identified by Maslow (1943). They include physiological needs, safety and security, love and belonging, self-esteem, and self-actualization.
- Reverse analysis of technical community issues such as water, energy, food, transportation, and health can be handled in a rational way. Solutions to these issues can be carried out quantitatively. Nontechnical sociopolitical and economic issues are more difficult to analyze, require more time to resolve, and solutions to these issues are qualitative.
- Inferring structure from behavior and current community issues is not a problem with a unique solution which can be linearly extrapolated from one scale to the other. There can be many system dynamics models and structures that can reproduce the same form of behavior and explain ongoing community issues.
- It is impossible to account for all the dynamic processes, components, and links between components that are responsible for a type of behavior and associated issues. The task is not to get lost in a complex web of causal loops and stock-and-flow diagrams but rather to find models that balance complexity and simplicity, explain observable patterns of community behavior, and can be understood by all.
- Reverse analysis of behavior patterns can only go so far in terms of scale and level of disaggregation. It is "relatively easier" to infer the structure underlying the average behavior of a small community than that of multiple individual households and their constituents.

- The structure that is inferred from reverse analysis may not remain constant as a community evolves from its current state over time; the context may change. A fair amount of reflection-in-action (Section 6.4) and awareness is necessary to update the structure and its components over time.
- Reverse analysis requires close collaboration between all community stakeholders. It must be kept in mind that insiders know best what is going on in their own communities and are more able to explain behavior patterns and ongoing community issues than outsiders.
- The participatory action research (PAR) tools used in the appraisal and causal analysis stages of project management discussed in Chapter 6 are critical in carrying out the reverse analysis. These tools are part of a methodology and road map necessary to guide the reverse analysis.
- At times, only a limited number of behavior patterns and ongoing community issues can be analyzed. Others may be too difficult to handle and analyze, are deemed to be of lesser importance, or simply cannot be addressed due to time or funding limitations.

7.3 Community Structure Formulation

From Global to Community Models

By conducting the reverse analysis mentioned above, development practitioners gain a better understanding of the structural components that are responsible for the current state of the community, its forms of behavior, and issues it might be facing in its current context. Practical questions arise as to (i) what systems, subsystems, modules, components, and linkages must be selected to model the structure of a community in its current state using system dynamics tools and (ii) how can this be done without losing touch with reality and falling into paralysis analysis? The following discussion assumes that all recommendations on system dynamics modeling outlined in Section 4.5 have been taken into consideration. This includes a clear identification of a reference mode of behavior and a proper selection of spatial and temporal boundaries.

Developing a conceptual model of a community in order to simulate and evaluate its current state, propose changes to that state, and predict its long-term performance can follow an approach similar to that used in the global change models discussed in Section 1.3. A caveat is that the approach needs to be simplified since community models do not need to be as comprehensive and broad as the global change models that simulate the dynamic at the country, regional, and global scales. Conceptual models of communities involve multiple components that act at smaller albeit nonnegligible scales. The interaction between these components can sometimes mimic that observed at larger scales and vice versa.

Similar to global change models, conceptual modeling of communities can start, in an abstractive manner, by selecting broad topics (e.g., social, economy, environment, etc.) and subtopics deemed important to the community of interest. Paraphrasing Rotmans and deVries (1997) about the abstractive nature of global change models such as TARGETS, it must be kept in mind that (i) it is not possible to model everything even though this might be tempting; (ii) modeling provides an "organizing framework" for improving the discussion about change and development; (iii) modeling helps understand the dynamics of many systems and subsystems at play at different physical and temporal scales; (iv) many useful models are possible; and (v) the simpler (but not more simplistic) and more integrated models are, the better and more useful they become for simulation, predication, and decision making. To that list, I would add that all involved in conceptual modeling must conduct, on a regular basis, multiple instances of reality check through reflection-in-action. Short of that, modeling could lead to models that are disconnected with the reality they are supposed to represent.

System dynamics models of communities can consist of many components (systems, subsystems, modules, state and control variables, and links between variables) representing real entities and issues going on in the communities or some of their parts. For comparison sake, Table 7.1 summarizes the different broad topics at the system and

Table 7.1. Modules and submodels included in various development frameworks: World3-03 (Meadows, 2004); International Futures (IFs) (Hughes, 1999); TARGETS (Rotmans and deVries, 1997); and Viability Loops (Hjorth and Bagheri, 2006).

Global Change Frameworks	Modules or Submodels
World 3-03	Population dynamics Industry Employment Services Agriculture Soil fertility Food production Environmental pollution Nonrenewable resources
International Futures (IFs)	Population Economy Agriculture Infrastructure Environmental resources & quality Education Health Sociopolitical International political Technology
Tool to Assess Regional and Global Environmental and health Targets for Sustainability (TARGETS)	Population & health Energy Water Land & food Biochemical
Viability Loops	Human needs Economy Environment Life services

subsystem levels that are included in the existing global change frameworks discussed in Section 1.3 and which could be integrated into community conceptual models. The linkages between these topics (referred to as modules or submodels) can be found in the description of each global model: World 3-03 (Meadows et al., 1972, 2004; Bossel, 2007c) and TARGETS (Rotmans and deVries, 1997). The linkages in the IFs framework (Hughes, 1999; Hughes and Hillebrand, 2006) are shown in Figure 1.1. In Table 7.1, I have also added the basic viability loops suggested by Hjorth and Bagheri (2006) and discussed in Section 2.4.

Community Dynamics Representation

Recall Figure 3.1 which shows the interaction of five major groups of systems that are likely to be at play in communities. These are human, infrastructure, natural, capital, and economic systems. From the results of the community appraisal, community insiders and outsiders can decide (using group dynamics exercises at different stages in the project framework of Figure 6.3) which systems of Figure 3.1 are important in explaining the behavior patterns observed at the community level or in some parts of it such as a neighborhood or a group of individuals. For each system, further inquiry by the stakeholders may help in deciding which subsystems are more critical than others and their potential *intraconnections*. The subsystems can in turn be broken down into modules containing parameters and variables where intraconnections are also operating. Finally, the *interconnections* across the various systems of Figure 3.1 (and across their subsystems) need to be included as well. These different steps of analysis help create multiple dynamic hypotheses at different levels in the aforementioned system hierarchy.

It should be noted that the idea of decomposing complex adaptive systems into multiple "conceptual tiers" in a hierarchical manner is not new and has been suggested by several authors (Holland, 1992; Simon, 2000; Ostrom, 2007). As remarked by Ostrom, "how far down or up a conceptual hierarchy a researcher needs to proceed [in a nested system] depends on the specific empirical or policy question under investigation." In that decomposition, however, one needs to stay mindful of the intra- and interconnections at play within and across each tier level of analysis.

As one might expect, the graphical representation of the inter- and intraconnections of the systems, subsystems, and modules at play in a community can quickly become complex. The challenge in developing a comprehensive community system dynamics model is not to complicate that representation but rather to keep it simple, yet comprehensive enough in order to explain the observed patterns of behavior and enable possible future scenario predictions. Furthermore, the graphical representation must be flexible enough to be able to describe the dynamic of the entire community, some parts of it, or that of a specific issue such as water, sanitation, energy, or food. Finally, it must also be flexible enough to accommodate change over time and the possible cycles of iteration expected in the modeling process shown in Figure 4.6.

It is clear that a single graphical representation—such as one using only system dynamics models—cannot meet all the requirements mentioned above. Instead, it is recommended that several graphical methods be combined to capture the dynamics between the different systems, subsystems, and modules. Possible methods include the stock-and-flow and causal loop diagrams of system dynamics, social network analysis, mind maps, double entry causality tables, and agent-based modeling described in Section 4.8. Other appropriate methods can be included as needed, a comprehensive list of which can be found in Glen (2014).

The possible systems, subsystems, and modules that enter into the conceptual modeling of communities, even small-scale ones, are too many to list. Table 7.2 gives a *nonexhaustive* list of these endogenous building blocks for the five major groups of systems shown in Figure 3.1. They are also represented in Figure 7.3 in a hierarchical way using layers. Each layer is associated with one of the groups of systems of Figure 3.1. In each layer, a network analysis can be conducted to decide what intralinkages exist among the different systems based on their importance and level of *horizontal connectivity*. Each system contains multiple subsystems which could be represented as a series of layers (not shown) with additional connectivity. The process could be repeated further down into the model hierarchy at the module level operating in each subsystem. This was illustrated in Figure 1.3 in regard to the various types of infrastructure systems involved in a specific flood event. In addition to the horizontal connectivity, a *vertical connectivity* exists between the systems of Figure 7.3 and the subsystems in each system.

Table 7.2. Nonexhaustive list of possible systems, subsystems, and modules that could be included in a conceptual model of a community.

Systems Groups	Possible Systems	Possible Subsystems, Modules, and Parameters
Human Systems	Populations Communities Institutions	• Demography: birth, death, life-expectancy, literacy and employment (by age group and gender), migration • Education: by level, age group, and gender • Health (by age group and gender): HIV/AIDS, diseases (communicable and noncommunicable), hygiene, fertility, causes of death and disability, child mortality • Employment: by level, age group, and gender • Human needs: physiological, safety, love & belonging, self-actualization (Maslow, 1943) • Community state: cohesion and stability, equity, security, castes, support systems, participation, social networks, vulnerable groups, services, gender equity • Governance: legislation, regulations, administration, governance (local, regional, country), stability • Rule of law: conflict, corruption, legal frameworks, accountability, access to justice
Natural Systems	Water Land Air Biota	• Quality and quantity: soil fertility, deforestation, water usage, water availability, seasonal variations • Carrying capacity of natural systems • Pollution level and damage (reversible, irreversible) • Climate change effects on natural systems
Infrastructure Systems	Water Waste (liquid, solid) Sanitation Food/Agriculture Health Telecom, ICT Shelter/housing Energy Transportation	For each type or combination: • Primary sources: nonrenewable and renewable • Types of use and disposal • Reserves • Level of functioning: interruption, delivery, backup • Technical capacity: operations and maintenance (preventative, corrective, crisis); adaptation and upgrading; supply chain • Critical infrastructure and lifelines
Capital Systems	Human Natural Industrial	• Human resources: professional, skilled labor, unskilled labor, literacy issues, jobs • Assets, debts

Systems Groups	Possible Systems	Possible Subsystems, Modules, and Parameters
	Financial Others (institutional, social, knowledge)	• Access to loans and investment • Private, public, and service sectors • Manufacturing sector • Agricultural sector
Economic Systems	Production Distribution & Trade Consumption	For different economic sectors (i.e., agriculture, public, manufacturing, industry, energy, information, and telecomm) • Goods • Products • Services

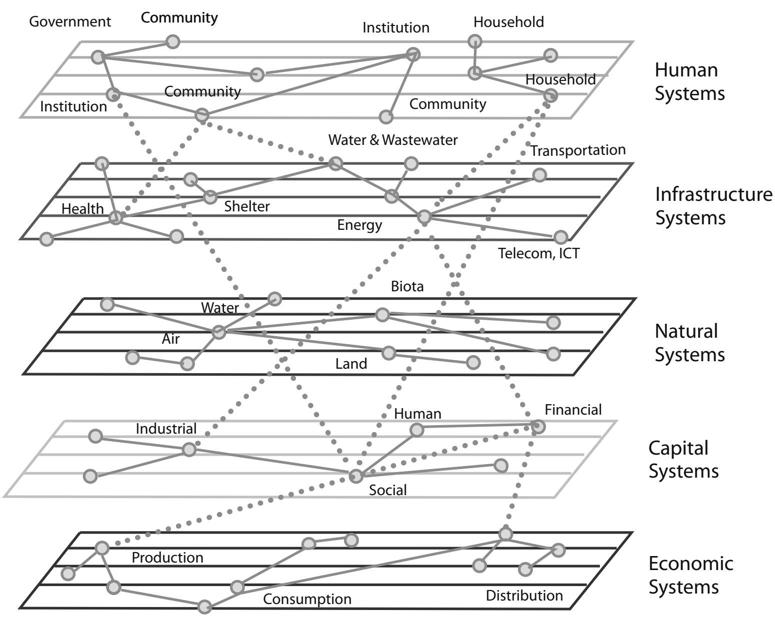

Figure 7.3. Multilayered diagram showing the different groups of systems at play in a conceptual model of a community.

Note: Intraconnections are represented by solid lines connecting the nodes in each layer. Interconnections are represented by dotted lines across layers. Only a limited number of possible linkages are shown.

The dynamic of each system, subsystem, and modules nested in each subsystem can be analyzed using causal loop and stock-and-flow diagrams such as those discussed in Chapter 5 or other examples available in the literature (Richmond, 2004a, b; Hannon and Ruth, 2001a, b; Fisher, 2011; Bossel, 2007a, b, c; and Pruyt, 2013). The diagrams may include one dominant state variable (stock) in order to address, for instance, a specific issue. In that case, the other intra- and interlinked state variables (stocks) can be modeled as exerting an exogenous influence on the issue being analyzed. For a given issue, a stock-and-flow diagram can also be created to account for the different types of capacity and vulnerability that are deemed responsible for that issue's existence. The radial diagram shown in Figure 6.5 is a great place to start for mapping the different forms of capacity or vulnerability and their components. This will help in creating more comprehensive causal loop and stock-and-flow diagrams.

In other instances, multiple intra- and interlinked state variables (multiple stocks) may need to be included in the causal loop and stock-and-flow diagrams in order to model either one issue at a broader scale or multiple interacting issues that form a nexus such as water, energy, food/agriculture, and health. The combinations are endless and are dictated by the project hypotheses discussed in Section 6.7 and their underlying structure. The ultimate system dynamics model, if it were possible, would include all the systems of Figure 3.1 and incorporate all constraints (economic, cultural, security, ethical, environmental, political, etc.) as endogenous or exogenous issues. This is easier said than done.

As an example of a multiple issue model, Figure 7.4 shows a stock-and-flow diagram originally proposed by Hjorth and Bagheri (2006). The original diagram was modified to include additional components and has been redrawn using the iThink software. Figure 7.4 consists of four balancing mechanisms called *viability loops* by Hjorth and Bagheri. The *first loop* involves the interrelationship between human needs and economic capital. An increase in human needs creates an economic demand and spending of economic capital. This in turn, creates a feedback mechanism leading to a reduction in the needs per person and human needs overall. The *second loop* involves the dynamic between economic capital and the use of renewable and nonrenewable resources. A decrease in economic capital creates a demand for resources which are utilized and contribute to economic growth and creating capital. The *third loop* deals with the environmental consequences of resource exploitation. As resources are used for economic growth, waste is

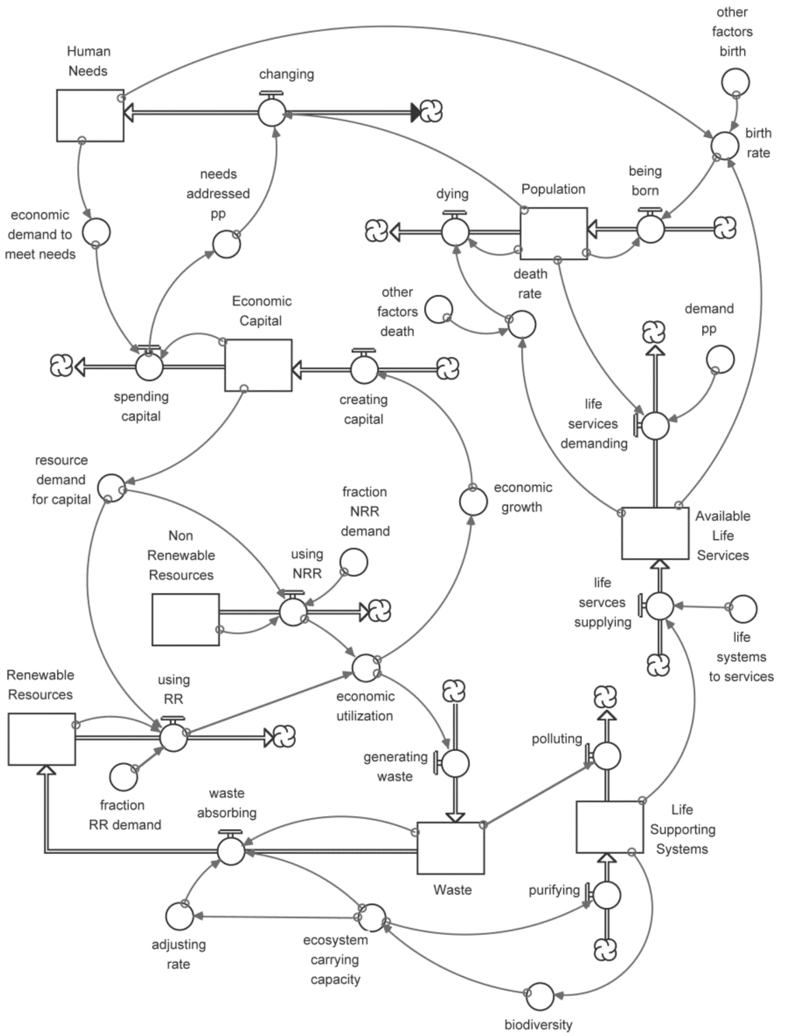

Figure 7.4. Stock-and-flow diagram showing four interacting viability loops: human needs and economic capital; economic capital and resources; resource exploitation and environmental consequences; and services provided by life support systems. This diagram was adapted from that originally proposed by Hjorth and Bagheri (2006) and redrawn using the iThink software.

generated. Some of it, but not all, can be absorbed by natural systems at a certain adjusting rate which depends on the gap between the waste amount and the ecosystem's carrying capacity to handle the waste. The absorbed waste is returned to the pool of renewable resources. The rest of the waste contributes to pollution and a reduction in the life supporting systems, the ecological biodiversity, and the ecosystem carrying capacity. Finally, the *fourth loop* shows the dynamic between the available services provided by the life supporting systems and the population growth. Also included in the stock-and-flow diagram are other factors that may affect the birth and death rates.

According to Hjorth and Bagheri (2006), the viability loops shown in Figure 7.4 should be seen as being critical in maintaining the balance between humans and their environment if sustainability is to be achieved. More loops could be added to Figure 7.4 to explore further the internal dynamic of each viability loop if necessary.

Additional Remarks

A multilayered model similar to the one shown in Figure 7.3 could also be developed using the five domains suggested by Ben-Eli (2011, 2012). In that case, each layer is associated with one of the five domains shown in Figure 2.3, i.e., the material, social, life, economic, and spiritual/value domains. The topics listed under each domain in Figure 2.3 become intrarelated subsystems in the model hierarchy, each one having modules and components similar to those mentioned above.

Whether one starts with the five groups of systems of Figure 3.1 or the five domains suggested by Ben-Eli, an additional understanding of the community's dynamic could be gained by using additional double entry causality tables such as Table 4.5. They would help understand linkages and feedback mechanisms that exist between building blocks, issues, and parameters at different levels of the hierarchy of Figure 7.3. For instance, a 5 × 5 table could be created to explore the various cross-correlations and cross-impact that exist between each system group of Figure 3.1 and the other four. The same methodology could be used among the systems of a given group, the subsystems in a system, the modules nested in a subsystem, and the various parameters within a module.

Finally, once a system model for one community has been successfully tested, a similar (but even more complex) methodology may be developed to explore the dynamics between multiple communities at the regional level, and eventually at the country level. The challenge in scaling up the model, however, becomes one of modeling the processes that are context- and scale-dependent.

7.4 Defining the Sustainable State

The methodology presented above is complex and consists of many building blocks acting at different levels in the conceptual model hierarchy. Even if all the building blocks of the model could be identified, and the state of the community indicators determined, the next formidable challenge would be to assign values to all the parameters and variables that make these building blocks at the module, subsystem, and system levels. This is clearly impossible as many of the building blocks are nonquantifiable. In other words, the current state of a community (S in Figure 7.1) can never be fully defined in a purely objective way as there will always be both objective and subjective components at play. The same can be said about the desirable state (DS in Figure 7.1) which is left to be decided by community insiders in participation with other stakeholders such as government representatives and outsiders.

An additional challenge is that both (S) and (DS) are not static and change with time, thus requiring continuous monitoring and evaluation. In summary, today we do not yet have a clear understanding of the measures and indicators that define the state of a community, except perhaps purely subjectively as discussed in Section 2.3. It is noteworthy that it is probably easier to define what a desirable community state is *not* than what it actually is.

The same conclusion could be made about the sustainable state (SS) of Figure 7.1, except that a great deal of effort has been put into trying to define what sustainability means in a practical way, especially in engineering where metrics are being developed to define sustainability at the project scale. Two project sustainability frameworks have been developed and are both worth mentioning: the *Project Sustainability Management framework* (FIDIC, 2013) and the *Envision framework* (ISI, 2012). I will briefly describe the Envision framework and suggest how it could be modified to quantify the level of sustainability achievement of development projects or define a community state of sustainability.

The Envision framework has been developed in the United States through a collaboration between the Zofnass program for Sustainable Infrastructure at Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure (ISI) which is a not-for-profit association of several professional engineering societies. The idea behind the Envision framework, once complete, is to be able to evaluate and rate infrastructure projects over their entire life cycle so that they can have a more beneficial impact on humans and the environment. The current version of the framework (ISI, 2012) focuses on evaluating projects in their planning and design phases only. It targets certain types of Western world infrastructure such as "roads, pipelines, bridges, railways, airports, dams, levees, landfills, water treatment systems, and other civil infrastructure that make up the built environment."

Table 7.3 shows the overall Envision rating system in a tabular form. It is assumed that an infrastructure project can attain one of five possible levels or states of sustainability achievement: improved, enhanced, superior, conserving, or restorative. Five categories of project-related issues that cut across the people, planet, and profit dimensions of sustainability are expected to contribute to the levels of sustainability. They include the quality of life (QL), leadership (LD), resource allocation (RA), the natural world (NW), and climate and risk (CR). As indicated in Table 7.3, each category is further divided into two or three subcategories with each subcategory consisting of several credits that are assigned some point values. According to the Envision framework manual (ISI, 2012):

> . . . A credit comprises a sustainability indicator on an aspect of environmental, social, or economic concern. In the Envision Guidance Manual, each credit section presents a description and evaluation criteria for how to earn points associated with the credit. A point value is assigned for each level of achievement within the credit. The point value has been determined according to the importance of the credit subject for infrastructure sustainability.

A total of sixty credits are possible, but only credits that apply to a given project are considered in each category. Furthermore, not all five project achievement levels are possible for each credit.

Table 7.3 The Envision rating system and framework.

			IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
QUALITY OF LIFE	PURPOSE	QL1.1 Improve community quality of life	2	5	10	20	25
		QL1.2 Stimulate sustainable growth and development	1	2	5	13	16
		QL1.3 Develop local skills and capabilities	1	2	5	12	15
	WELLBEING	QL2.1 Enhance public health and safety	2	~~~	~~~	16	
		QL2.2 Minimize noise and vibration	1	~~~	~~~	8	11
		QL2.3 Minimize light pollution	1	2	4	8	11
		QL2.4 Improve community mobility and access	1	4	7	14	
		QL2.5 Encourage alternative modes of transportation	1	3	6	12	15
		QL2.6 Improve site accessibility, safety and wayfinding	~~~	3	6	12	15
	COMMUNITY	QL3.1 Preserve historic and cultural resources	1	~~~	7	13	16
		QL3.2 Preserve views and local character	1	3	6	11	14
		QL3.3 Enhance public space	1	3	6	11	13
					Maximum QL Points:	181*	

			IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
LEADERSHIP	COLLABORATION	LD1.1 Provide effective leadership and commitment	2	4	9	17	
		LD1.2 Establish a sustainability management system	1	4	7	14	
		LD1.3 Foster collaboration and teamwork	1	4	8	15	
		LD1.4 Provide for stakeholder involvement	1	5	9	14	
	MANAGEMENT	LD2.1 Pursue by-product synergy opportunities	1	3	6	12	15
		LD2.2 Improve infrastructure integration	1	3	7	13	16
	PLANNING	LD3.1 Plan for long-term monitoring and maintenance	1	3	----	10	
		LD3.2 Address conflicting regulations and policies	1	2	4	8	
		LD3.3 Extend useful life	1	3	6	12	
					Maximum LD Points:	121*	
RESOURCE ALLOCATION	MATERIALS	RA1.1 Reduce net embodied energy	2	6	12	18	
		RA1.2 Support sustainable procurement practices	2	3	6	9	
		RA1.3 Use recycled materials	2	5	11	14	
		RA1.4 Use regional materials	3	6	9	10	
		RA1.5 Divert waste from landfills	3	6	8	11	

			IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
		RA1.6 Reduce excavated materials taken off site	2	4	5	6	
	ENERGY	RA1.7 Provide for deconstruction and recycling	1	4	8	12	
		RA2.1 Reduce energy consumption	3	7	12	18	
		RA2.2 Use renewable energy	4	6	13	16	20
		RA2.3 Commission and monitor energy systems	----	3	----	11	
	WATER	RA3.1 Protect fresh water availability	2	4	9	17	21
		RA3.2 Reduce potable water consumption	4	9	13	17	21
		RA3.3 Monitor water systems	1	3	6	11	
					Maximum RA Points:	182*	
NATURAL WORLD	SITING	NW1.1 Preserve prime habitat	----	----	9	14	18
		NW1.2 Protect wetlands and surface water	1	4	9	14	18
		NW1.3 Preserve prime farmland	----	----	6	12	15
		NW1.4 Avoid adverse geology	1	2	3	5	
		NW1.5 Preserve floodplain functions	2	5	8	14	
		NW1.6 Avoid unsuitable development on steep slopes	1	----	4	6	

			IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
		NW1.7 Preserve greenfields	3	6	10	15	23
	LAND & WATER	NW2.1 Manage stormwater	—	4	9	17	21
		NW2.2 Reduce pesticide and fertilizer impacts	1	2	5	9	
		NW2.3 Prevent surface and groundwater contamination	1	4	9	14	18
	BIODIVERSITY	NW3.1 Preserve species biodiversity	2	—	—	13	16
		NW3.2 Control invasive species	—	—	5	9	11
		NW3.3 Restore disturbed soils	—	—	—	8	10
		NW3.4 Maintain wetland and surface water functions	3	6	9	15	19
					Maximum NW Points:	203*	
CLIMATE & RISK	EMISSIONS	CR1.1 Reduce greenhouse gas emissions	4	7	13	18	25
		CR1.2 Reduce air pollutant emissions	2	6	—	12	15
	RESILIENCE	CR2.1 Assess climate threat	—	—	—	15	
		CR2.2 Avoid traps and vulnerabilities	2	6	12	16	20
		CR2.3 Prepare for long-term adaptability	—	—	—	16	20
		CR2.4 Prepare for short-term hazards	3	—	10	17	21

			IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
		CR2.5 Manage heat islands effects	1	2	4	6	
					Maximum CR Points:	122*	
					Maximum TOTAL Points:	809*	

* Not every credit has a restorative level. Therefore totals include the maximum possible points for each credit whether conserving or restorative.

Note: This table presents the most recent credit point values which differ slightly from those published by ISI in 2012.

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Taken directly from the ISI (2012) report, the five categories can be described as follows:

- *Quality of life* relates to a "project's impact on surrounding communities, from the health and well-being of individuals to the well-being of the larger social fabric as a whole. These impacts may be physical, economic, or social. Quality of life particularly focuses on assessing whether infrastructure projects are in line with community goals, incorporated into existing community networks, and will benefit the community long-term. For that purpose, community involvement should be sought by infrastructure owners. Community members (both users and nonusers) affected by the project should be considered important stakeholders in the decision-making process (during design as well as during operations)." The maximum credit value for the quality of life rating is 181.
- *Leadership* relates to how project teams "communicate and collaborate early on, involve a wide variety of people in creating ideas for the project, and understand the long-term, holistic view of the project and its life cycle" and how "collaborative leadership produces a truly sustainable project that contributes positively to the world around it." The maximum credit value for the project leadership rating is 121.
- *Resource allocation* refers to "the quantity, source, and characteristics of these resources and their impacts on the overall sustainability of the project. Resources addressed in this rating system include physical materials, both those that are consumed and that leave the project, energy for construction, operation, and maintenance, and water use. Each of these materials is finite in its source and should be treated as an asset to use respectfully." The maximum credit value for the resource allocation rating is 182.
- *Natural world* is about how to "understand and minimize negative impacts while considering ways in which the infrastructure can interact with natural systems in a

synergistic, positive way." The maximum credit value for the natural world rating is 203.

- *Climate and risks* is about how to "minimize emissions that may contribute to increased short- and long-term risks and to ensure infrastructure projects are resilient to short-term hazards or alter long-term future conditions." The maximum credit value for the climate and risk rating is 122.

The sustainability achievement level of a project is that with the highest overall rating which cannot exceed 809 credit points. The ISI (2102) report contains more detailed information about (i) the meaning of each level of sustainability achievement; (ii) recommendations on how to advance from one level to a higher level of achievement; (iii) the criteria used to evaluate each credit value and the expected supporting documentation; (iv) the international standards and resources used to determine the credits; and (iv) the sustainability issues and practices associated with each credit. The Envision framework uses a multicriteria decision analysis method similar to the one discussed in Section 6.7. Its main limitation, however, is that it does not account explicitly for possible linkages that may exist between the various categories and their subcategories. However, the links between a given credit and the other credits are identified.

With *substantial* modifications, the Envision framework represents a possible approach to defining the sustainability level of achievement of community development projects. A more ambitious goal would be to develop a similar framework that would be able to determine the sustainability level of achievement of the entire community: that is, its emerging state or level of development. The rationale is that the Envision framework is already designed to account for the interaction between people and their environment. It also emphasizes the integration of various seemingly independent disciplines and client participation in the decision process along with the project designer. Finally, team dynamic is also assumed to be an important factor in the rating system.

In my opinion, a comprehensive framework to determine the sustainability level of achievement of community development projects or the state of sustainability of a community would consist of several possible yet well-defined levels of achievement at the project or community level. The levels could be named "sustainability impossible," "sustainability possible," and "sustainability likely" as suggested, for instance, by Schweitzer and Mihelcic (2012) for rural water projects. Credits or sustainability indicators would be introduced for the five groups of systems shown in Figure 3.1 and listed in Table 7.2 (or the five domains and their subdomains of sustainability suggested by Ben-Eli, 2011). Additional domains such as leadership and climate and risk could be introduced as well if deemed important. The points assigned to each credit for each level of achievement would be based on whether specified criteria and/or agreed-upon international or national standards are met. Such standards already exist in the areas of water, shelter, food, energy for development and crisis situations (WHO, 2006a, b; Sphere Project, 2011). The level of achievement with the maximum number of points would define the sustainability level of a project or of the community. Finally, recommendations could be proposed to move from one project or community sustainability level to the next.

An additional level of complexity in developing the proposed framework would be to account for the intra- and interconnections that exist between the systems and subsystems at play in the community and illustrated in Figure 7.3. One way of capturing that connectivity and accounting for it in the framework is to use double entry causality tables at the system and subsystem levels of the framework as discussed in the previous section. Imagine, for instance, a 5 × 5 table that shows the double causality existing between the five main systems of Table 7.2. In addition, each diagonal term of that table would itself be a subtable that analyses the double causality that exists among the subsystems in each system. Analysis of the double entry causality tables could help create new credits and sustainability indicators that would enter into some of the categories and subcategories of the framework.

Accounting for all these intricacies and levels of complexity in defining the sustainability level of achievement of community development projects or the state of sustainability of a community would be a formidable (but not impossible) task that is worth pursuing and could be the topic of another book . . .

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CHAPTER 8

Conclusions

"The significant problems we face today cannot be solved at the same level of thinking we were at when we created them" (Albert Einstein).

8.1 Development and Systems

This book makes the case for a systems approach to projects in small-scale developing communities. It recognizes that, by definition, communities are complex adaptive systems consisting of multiple systems and subsystems interacting on a daily basis. That dynamic changes over time and can be different at scales ranging from individuals, households, neighborhoods, interest groups, all the way up to the entire community. The community itself also interacts with other communities at the regional and national levels. This book recognizes these characteristics and the complex and uncertain context in which communities evolve over time. It does not pretend to assume that such characteristics do not exist or that the systems at play are either simple (i.e., we know the known parameters and definite solutions to community issues are always possible) or complicated (i.e., we know the unknown parameters at play in the community and experts can solve the problems). Instead, the book emphasizes the complex, uncertain, and adaptive characteristics of communities and proposes ways of dealing with such characteristics. It also acknowledges, however, that some parts of these systems can be treated as simple or complicated and should be approached as such.

A common theme that permeates this book is that within the context of community development, complexity and uncertainty should be welcomed, embraced, and acknowledged with all the advantages and limitations it entails. Failure to do so is equivalent to using the wrong tools to solve a problem. It would lead to the same mistakes that have been made in the past and have led to so many questionable deliverables in development projects. These mistakes can be seen as the emerging consequences of a dominant reductionist and rigid mindset that is based on simplifying complex problems, breaking the problems into pieces, finding experts to solve each piece, and putting the solutions side by side without due consideration of initial links between the problems and linkages between the proposed solutions. Systems thinking recognizes that many issues are at play in a community and cannot be separated. Each of them can be looked at individually but at the same time must be understood in concert with other interrelated issues.

This book emphasizes and shows how to include systems thinking and various systems tools in the different phases of small-scale community project management. It is about integrating a system- and complexity-aware approach to project initiating, planning, executing, monitoring and controlling, and closing. This requires a system- and complexity-aware approach to community appraisal (data collection and analysis), problem identification and ranking, design of solutions, planning, execution, closing, and long-term performance while monitoring and evaluating all project phases. A systems approach to development emphasizes the importance of reflection-in-action and adaptation in all stages of project management. This implies using not only continuous monitoring but also very frequent evaluation to capture rapid project changes. As suggested by Barder (2012), this form of project management embraces "experimentation, adaptation, and learning" as projects unfold.

The combination of traditional project management tools and systems thinking was presented, somewhat ambitiously, in this book as development 5.0. It builds on the previous steps of development 4.0 (i.e., capacity development), 3.0 (i.e., technical cooperation), 2.0 (i.e., technical assistance), and 1.0 (i.e., economic aid) that have evolved over the past 50 to 60 years. Development 5.0 is about building on existing development project frameworks and integrating multiple systems tools to account for the complexity and uncertainty inherent to those projects.

Incorporating systems thinking in community development projects does not come without its share of challenges. One of them is that using a systems approach to complex problems does not lead to unique solutions to well-defined problems. The problems are ill-defined to start with and solving them requires accepting that there are no perfect solutions but rather a multitude of good enough solutions, some better than others. Development 5.0 is about *satisficing* rather than *optimizing*. It is about adaptation and recognizing that, under certain complex and uncertain conditions, one must follow an interactive and reflective approach in project decision making. At other times when the project conditions are better defined, a directive or blue print approach is more appropriate.

A second challenge, related to the previous one, has to do with the decision process that must be in place to deal with an adaptive and reflective practice. Questions arise as to: How are decisions made and agreed upon between all project stakeholders as a project unfolds? How are conflicting opinions resolved? What is the role of observation, monitoring, and evaluation in an ever-changing project environment? What are the appropriate group dynamics between project insiders and outsiders in that complex environment?

Finally, the third challenge is the training of all project stakeholders in using a systems approach. The importance of having complexity- or system-aware practitioners was discussed in this book as part of a recommended core practice and body of knowledge expected of individuals and of teams/groups involved in development projects. Answers to all the aforementioned questions require field work and working on case studies to gain a better understanding of the advantages and challenges associated with introducing the new system mindset into an already well-established and conservative decision-making process that is dominant in development agencies. A systems approach to development projects should not be seen as excluding the role of experts. These experts are necessary but not sufficient to guarantee meaningful projects.

8.2 Community Structure and Behavior

A systems approach to community development projects requires using a combination of (i) observational tools through direct interaction with communities; (ii) empirical tools relying on the opinion of experts; and

(iii) simulation or modeling tools. Development practitioners have to be versed in these three groups of tools and be cognizant of which tools to use in different contexts. The book introduced simulation or modeling tools such as the system dynamics software iThink/STELLA. When combined with other tools such as social network analysis, double entry causality tables, agent-based modeling, and many others, system dynamics models can be integrated into all project management phases. A challenge is that not all modeled issues are quantitative as many issues are subjective in nature. Qualitative and quantitative system dynamics models expressed in the form of causal loop diagrams and stock-and-flow-diagrams show trend, logic, connections, and help run "what if" scenarios.

Several simple stock-and-flow diagrams were shown in Chapter 5 to describe common issues that are more likely to be found in small-scale communities. They only represent a small sample of what is possible. Many system dynamics models are available in the literature and have been tested with software packages such as iThink/STELLA, Vensim, or Powersim. The challenges in using such models in community development projects are (i) to find those models that meet specific community needs and (ii) to integrate them into a systems logic that best predicts existing patterns of community behavior.

In building system dynamics models of communities or parts thereof, development practitioners need to be fully aware of the interplay between system structure and behavior since both are interrelated. They also need to be mindful of the system's interaction with its environment. In communities, development practitioners are exposed to patterns of behavior first. From that exposure, they must infer the structure and components that are responsible for the behavior which may express itself at different scales (e.g., individual, household, interest group, entire community, etc.) As discussed in Chapter 7, this reverse analysis does not have a unique solution.

Communities are complex and adaptive open systems with all the characteristics that it entails (e.g., nonlinearity, feedbacks, interconnectedness, path dependency, sensitivity to initial conditions, synergy, etc.). Furthermore, unexpected behavior patterns can emerge from interacting system components in a given context. Hence, a given pattern of behavior can be explained by many possible structures. As the patterns change over time so does the underlying structure and vice-versa. As a result, reverse analysis of community patterns of behavior and associated community issues is likely to be done in an iterative and trial-and-error manner using various feedback mechanisms. It also requires making assumptions and laying out multiple preconditions, which, if not fulfilled, could make the inferred structure far from reality.

However, this does not mean that systems tools cannot guarantee some *satisficing* (i.e., good enough) levels of success in addressing and resolving community issues. A systems approach to community development is not about finding the one and only structure that represents the field reality; this would be impossible. As discussed in Chapter 7, once an *adequate* structure and a model have been developed and are deemed "good enough" by all stakeholders to reproduce existing observed behavior patterns and explain the issues, it can be tested further by conducting parametric studies and sensitivity analysis. At that point, existing leverage points can be identified, the future of the community can be predicted, and recommendations can be proposed regarding what structural or policy innovations are necessary for the community to solve its ongoing issues and to reach a more desirable state, even a state of sustainability.

8.3 Community Development States

Chapter 7 emphasized the dynamic existing between the current development state of a community and any possible desirable state. It is likely that multiple opinions will arise when various stakeholders are asked about defining these states. Questions arise such as: What constitutes a level or state of development? What are the corresponding indicators? Who defines these indicators and how are they monitored and evaluated? What criteria define a development "finish" line, that is, whether a certain desirable state has been achieved? Answering these questions is still a work in progress.

The same questions could be asked about the sustainability state of a community which seems to be the "holy grail" in the development literature as testified by the new round of forthcoming sustainable development goals to be launched by the United Nations in fall 2015. The problem with that approach is that sustainability is seen as a tangible thing to be won by checking off items on a laundry list of goals, subgoals, and targets that need to be met separately of each other. In my opinion, sustainability is instead a *state* like a state of health or wealth: that is, a state that can be seen as *emerging* from multiple interacting functional socioeconomic and environmental systems and their subsystems. Seeing a community as an organism, the state of sustainability of a community can be seen as being equivalent to the state of health of a human being. It depends on the proper functioning of its parts and of the linkages between these parts. The organism needs to be in harmony with other surrounding organisms with which it shares inputs and outputs. This harmony results from various positive and negative feedback mechanisms that keep the organism in check with its environment under certain constraints and rules of behavior.

System dynamics tools are extremely valuable in exploring and understanding how the interaction between different parts of a community creates an emerging state. In Chapter 7, I mentioned the *Envision* framework which has been proposed in the engineering literature to quantify the level of sustainability achievement of infrastructure projects. My question to the reader is what would it take for the development research community to create something similar to the Envision framework in order to quantify the level of sustainability achievement of community development projects or the sustainability state of a community.

I believe that, around us, there are many successful examples of social and natural systems (or parts thereof) that operate in a healthy state, which we could call a sustainability state. We are unable to identify them since we still don't know what a sustainability state looks like in all its many possible expressions. There is a lot to learn from these success stories. As an example, nature has been a great experiment in sustainability for billions of years and represents a unique learning platform. Likewise, many great civilizations have operated on our planet at times more successfully than others. What valuable lessons can we learn from them? In my opinion, it is our obligation to open our eyes in whatever we are challenged with and to be willing to change our belief system or mindset so that we can perceive what we do not yet perceive. In the field of human psychology, it is accepted that perception supports belief systems and vice versa.

Echoing a remark from Ramalingam (2014), it might be time to acknowledge that, in human development and in our daily lives in general, "the real voyage of discovery consists not in seeking new landscapes but in having new eyes." To that recommendation, which uses a quote from Marcel Proust, I would like to add that we need the courage to endorse change and walk the talk so that *all* people on this planet can live in dignity, peace, and prosperity. This calls for authentic leadership at the individual level and in all of our institutions.

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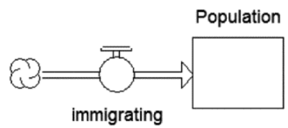
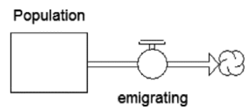
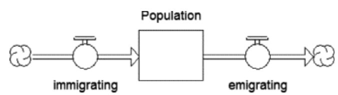
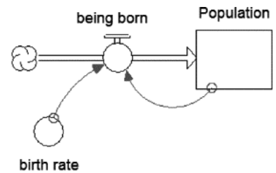
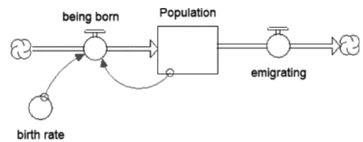
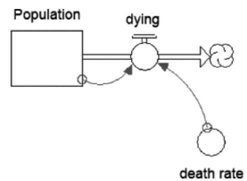
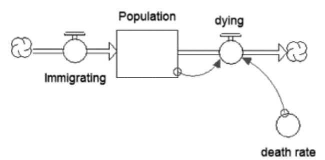
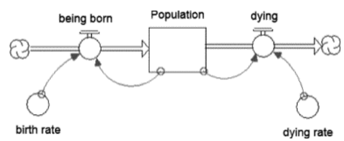
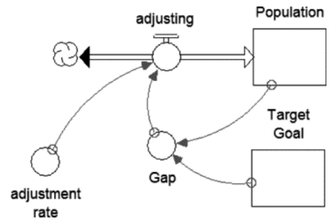
APPENDIX

Table A.1 Single-function (flow) stock-and-flow diagrams.

Generic Structures	Input (Flow)	Stock-and-Flow Diagrams	F(t)	Output (Flow)
Constant growth rate	Constant dF/dt = a	 Immigrating = people/time	$F(t) = at + F_o$	
Constant decay rate		 Emigrating = people/time	$F(t) = -bt + F_o$	Constant dF/dt = −b
Growth and decay	Constant dF/dt = a	 Immigrating = people/time Emigrating = people/time	$F(t) = (a - b)t + F_o$ Linear increase $(a > b)$; decrease $(a < b)$; or equilibrium $(a = b)$	Constant dF/dt = −b

Generic Structures	Input (Flow)	Stock-and-Flow Diagrams	F(t)	Output (Flow)
Exponential growth Compounding process	Proportional to current value, F $dF/dt = aF$		$F(t) = F_o e^{at}$ a is growth rate or fraction $c = 1/a$ is a growth time constant	
Compounding process + constant decay rate	Proportional to current value, F $dF/dt = aF$		$F(t) = b/a +$ $(F_o - b/a)e^{at}$ Increase ($F_o > b/a$); decrease ($F_o < b/a$); or equilibrium ($F_o = b/a$)	Constant b $dF/dt = -b$
Exponential decay Draining process			$F(t)=F_o e^{-bt}$ b is decay rate or fraction $c = 1/b$ is a decay time constant	Proportional to current value, F $dF/dt= -bF$

Generic Structures	Input (Flow)	Stock-and-Flow Diagrams	F(t)	Output (Flow)
Draining process + constant growth rate	Constant dF/dt = a		$F(t) = a/b +$ $(F_o - a/b)e^{-bt}$ Increase ($F_o < a/b$); decrease ($F_o > a/b$); or equilibrium ($F_o = a/b$)	Proportional to current value, F dF/dt= −bF
Compounding process + draining process	Proportional to current value, F dF/dt = aF		$F(t) = F_o e^{(a-b)t}$ Increase ($a > b$); decrease ($b > a$): or equilibrium ($a = b$)	Proportional to current value, F dF/dt= −bF
Stock adjustment process Goal seeking	Proportional to difference between target value K and current value F dF/dt = a(K − F) a is the adjustment rate or fraction c =1/a is an adjustment time constant		$F(t) = K +$ $(F_o - K)e^{-at}$ Exponential growth ($F_o < K$) or decay ($F_o > K$) becomes asymptotic to target value K F(t) is constant if $F_o = K$	Note the bi-flow nature of the model

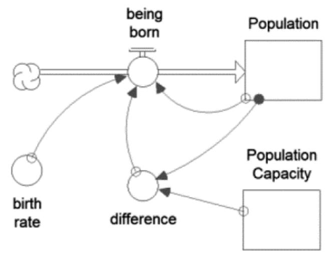
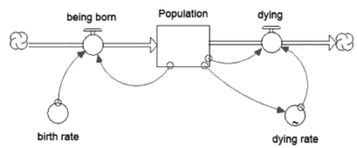
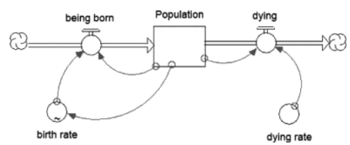
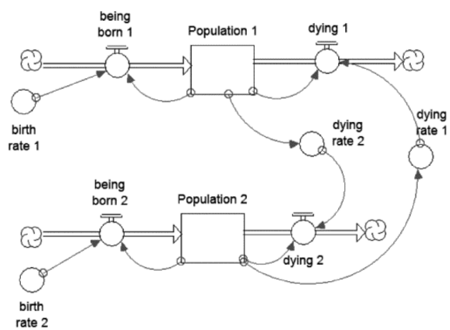
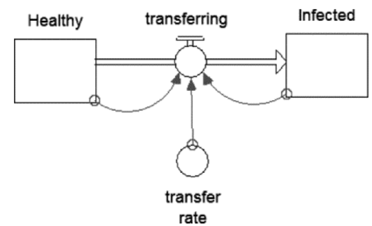
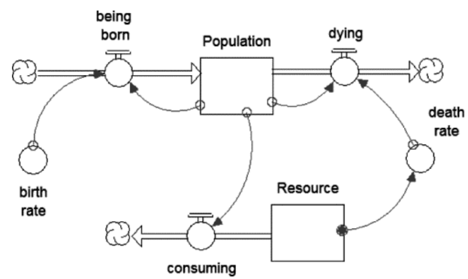
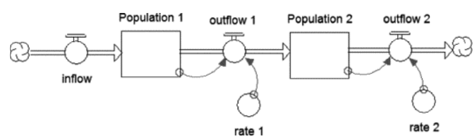
Generic Structures	Input (Flow)	Stock-and-Flow Diagrams	F(t)	Output (Flow)
Logistic S-shaped model Carrying capacity	Proportional to the product of (i) the difference between carrying capacity value C and current value F, and (ii) current value $dF/dt = aF(C - F)/C$		$F(t) = C/\left(1 + [C/F_o - 1]e^{-at}\right)$ S-shaped curve Exponential growth or decay becomes less dominant as F(t) reaches asymptotically its capacity C	
Compounding process and draining process with variable rate	$dF/dt = aF$		Nonlinear equation F(t)	$dF/dt = -b(F)F$
Draining process and compounding process with variable rate	$dF/dt = a(F)F$		Nonlinear equation F(t)	$dF/dt = -bF$

Table A.2 Double-function (flow) stock-and-flow diagrams.

Generic Structures	Input (Flow)	Stock-and-Flow Diagrams	Functions (t)	Output (Flow)
Two interacting populations F and G (Could also be used as oscillation model)	dF/dt = aF dG/dt = cG		Nonlinear equations F(t) and G(t)	dF/dt = −b(G)F dG/dt = −d(F)G
Transmission model F is healthy G is infected T is transfer	dT/dt = aFG a is transfer rate		Nonlinear equations F(t) and G(t)	

Generic Structures	Input (Flow)	Stock-and-Flow Diagrams	Functions (t)	Output (Flow)
Overshoot and collapse F is population G is resource	dF/dt = aF		Nonlinear equations F(t) and G(t)	dF/dt= −b(G)F dG/dt = g(F)
Main chains Conservative chains F is pop. 1 G is pop. 2	dF/dt = a dG/dt = bF a is constant inflow		Nonlinear equations F(t) and G(t) b and c are decay rates 1 and 2, respectively	dF/dt= −bF dG/dt = −cG

Index

A Systems Approach to Modeling Community Development Projects

Bernard Amadei

This book makes the case for a systems approach to small-scale community development projects. It specifically looks at the application of one branch of systems science, called system dynamics, to develop conceptual models of small-scale communities and address specific issues they might be facing at different scales. A systems approach recognizes that, by definition, communities are complex adaptive systems consisting of multiple subsystems and parts (e.g., individuals, institutions, and infrastructure) that are interconnected, driven by some purpose, follow certain rules, and interact with each other and with their surrounding environment. In order to address community issues and problems, complexity and uncertainty must be embraced and dealt with.

The author demonstrates how to include a system- and complexity-aware approach in the different phases of small-scale community project management. Adopting this approach comes with unique challenges such as dealing with ill-defined problems, considering uncertainty, recognizing that no unique and best solutions to complex problems exist, and accepting satisficing solutions. The text details the need for community development practitioners to integrate in all stages of their projects: participation, systems thinking, continuous reflection-in-action, and a combination of critical and creative tools.

Dr. Amadei is professor of civil engineering at the University of Colorado at Boulder. He holds the Mortenson Endowed Chair in Global Engineering and serves as a faculty co-director of the Mortenson Center in Engineering for Developing Communities. He is also the founding president of Engineers Without Borders - USA and the co-founder of the Engineers Without Borders-International network. Dr. Amadei is an elected member of the U.S. National Academy of Engineering and a Senior Ashoka Fellow.

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