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Systemic Thinking and System Dynamics for the Analysis of Public Policies: Fundamentals and Recommendations

Importante

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Abstract

This document presents a general vision of the systemic approach and one of its variants called system dynamics. It also explains the use of both frames for the analysis of public policies. The document begins by presenting some background on the systemic approach and the main principles of General Systems Theory as one of the most well-known variants. The conceptual foundations are then explained and specific definitions of key concepts are provided. The document also includes a brief description of some variants of this approach. The document then presents a brief review of the main elements of system dynamics as one of the variants of the systemic approach, giving special emphasis to the elements that are unique to this variant and those which complement common elements of the systemic approach as a whole. The next section discusses the utility of this approach for the analysis of public policies and describes the steps to follow using the systemic and system dynamics approaches as conceptual and methodological lenses. Finally, the document provides some advantages and limitations of this approach and it includes a series of final comments as a conclusion.

Resumen

Este documento presenta una visión general del enfoque sistémico y de una de sus variantes denominada dinámica de sistemas. También explica su uso para el análisis de políticas públicas. El documento comienza presentando algunos antecedentes del enfoque sistémico y los principales postulados de la Teoría General de Sistemas como una de sus expresiones más completas y conocidas. Los fundamentos conceptuales son después explicados dando definiciones puntuales de algunos conceptos clave y describiendo brevemente algunas de las principales variantes de este enfoque. Se desarrolla después una breve reseña de los principales elementos usados por dinámica de sistemas como una variante del enfoque sistémico, dando énfasis a aquellos que son propios de esta variante y complementan a los que son comunes para todo el enfoque sistémico. Después se menciona la utilidad de este enfoque en el análisis de políticas públicas y se describen los pasos a seguir desde la perspectiva sistémica y usando dinámica de sistemas como lente conceptual y metodológico. Finalmente, se proveen algunas ventajas y limitaciones de este enfoque y se incluye una serie de comentarios finales a manera de conclusión.

Introduction[*]

The term system is used to represent a set of interrelated components given a specific objective (Flood & Jackson, 2000; Sherwood, 2002; Van Gigch, 1997; Wasson, 2006). Systems are instruments that allow the global behavior of interrelated components, as well as their effects in real time, to be analyzed as a whole (Aracil, 1983; Kay, 2006). Due to its great flexibility, the systemic approach has been used in many different fields of study, such as organization theory (Clegg & Dunkerley, 1980), sociology (Jackson, 1991), biology (Flood & Jackson, 2000), systems engineering (Sherwood, 2002), software engineering (Presman, 1992), political science (Easton, 2001) and psychology (Hoos, 1983), among others. Some examples of systems include: a living organism, a society, a community, a public policy, a government, or a family.

The systemic approach has undergone significant development since the Second World War as a result of the need to resolve complex problems, changes in scientific thinking, and advances in fields such as cybernetics (Jackson, 1991; Mats-Olov & Gunnar, 2004; Pérez, 1999). In addition, the rise of computers as tools for making more efficient calculations, which were done manually at that time, positioned systems theory as a way to examine the world. The difference between reductionist thinking, which dominated at that time, and systemic thinking is that the latter holds a more holistic view of the world; in other words, it analyzes the elements of a system as parts of a whole instead of studying them as independent and isolated components (Jackson, 1991; Kay, 2006). In order to understand a system and predict its behavior, it needs to be studied as a whole; if a system is analyzed in pieces, the connections are destroyed, affecting the nature and behavior of the system itself (Sherwood, 2002).

The advance of systemic thinking led to the development of General Systems Theory (GST) whose purpose was to integrate physical and social sciences into a single science through the development of unifying principles (Hoos, 1983). GST proposed that there were higher-order laws that are general and applicable to living or inert systems regardless of their empirical nature (Bever, 1971). The objective of this proposal was to create a general theory that would allow the convergence of several disciplines through the concept of the system (Jackson, 1991; Marchal, 1975). The idea of creating a general theory was based on the fact that science had advanced less than was possible due to researchers working individually in their separate fields without an awareness of concepts that had been developed in other disciplines; this lack of communication is why general concepts tend to repeat themselves, which duplicates work between scientists (Bertalanffy, 1950).

[*] This document is an English translation of a working paper originally published in Spanish. Here is the full reference: Gil-García, J. Ramón. (2008). Pensamiento Sistémico y Dinámica de Sistemas para el Análisis de Políticas Públicas: Fundamentos y Recomendaciones. Centro de Investigación y Docencia Económicas, DAP, Documento de Trabajo No. 212 (Septiembre).

One variant of the systemic approach is called system dynamics (SD) which specializes in understanding the causes of the behavior that creates a problem (system), modeling it mathematically as a set of accumulations, activities, and feedback loops (Black, 2002; Jackson, 1991; Luis F. Luna-Reyes, 2008; George P. Richardson & Pugh, 1981). This variant is based on the use of models, simulation, and analysis over time to explain the behavior of the agents of a system in a complex reality (Jay W. Forrester, 1973; Kay, 2006; Morecroft, 2007; George P. Richardson & Pugh, 1981; Sherwood, 2002). Easton (1982) defines dynamic systems theory as that which allows us to deduce a present state given certain future results. This definition does not place limits on the types of entities that may be taken as elements of the system. The only implicit restriction is that both the elements and relationships can be clearly specified.

The advantage of modeling a system is that it allows a reality to be represented clearly and accurately. Unlike the mental models created by humans, who are unable to calculate all the possible relationships and consequences due to their limited rationality, models based on system dynamics can represent and analyze large numbers of variables, understand the relationships between them, and identify their possible effects over time through programming languages and new computing capacities (Jay W. Forrester, 1995; Luis F. Luna-Reyes, 2008; McGarvey & Hannon, 2004; Sherwood, 2002). Therefore, the systemic approach and system dynamics have significant advantages in the study of social systems.

There is no single way to represent a social problem; however, system dynamics proposes a methodology that allows problems to be simulated over time in order to capture the complexity of nonlinear relationships (Sherwood, 2002; Shimizu, Carvalho, & Laurindo, 2006). The models are built from explicit assumptions and the relationships are visible in the modeled system. System dynamics combines systemic thinking and its mental models with current advanced computing power (Jackson, 2000; L. F Luna-Reyes & Maxwell, 2003). It is performed by means of mathematical modeling and computational simulation after a problem is defined in terms of its behavior over time (a dynamic problem). Information about a social problem is obtained from historical evidence and expert knowledge on the social phenomenon studied (Luis F. Luna-Reyes, 2008).

The application of the systemic approach, in its variant form known as system dynamics, to the analysis of public policies allows us to understand social problems from a broader and more comprehensive perspective since problems generally arise from the structure of the system itself and not necessarily from external factors (Aracil, 1983). The systemic approach and simulation afford the necessary theoretical and methodological elements to represent public problems and their possible solutions (public policies) in a simple way, while preserving some of the existing complex relationships, so that the representation of the social context and behavior of the relevant variables is as close to reality as possible. Lastly, once the problem has been represented in systemic terms and programmed into a simulation model, this approach allows us to evaluate different public policy alternatives and provide estimates of the impacts of each alternative, enabling better decision-making without the costs associated with actual experiments or introducing different programs. This paper presents the basic fundamentals of the systemic approach and system dynamics, and demonstrates the usefulness of these approximations to the study and analysis of public policies.

This paper is organized into five sections including this introduction. Section two presents some background and theoretical basics of the systemic approach, specifically those related to General Systems Theory. Section three includes the important relationship between the general systemic approach and its variant called system dynamics. This section also includes some basic concepts and elements of system dynamics that are not common to other variants of the systemic approach. Section four briefly describes the steps to follow to analyze public policies using the systemic approach and system dynamics. Lastly, section five poses a series of conclusions and final comments.

Fundamentals of the systemic approach

The systemic approach is a holistic perspective because it integrates multiple processes and their interactions into a single analysis unit or phenomenon called a system. As stated earlier, the term system can have several meanings and appear in diverse contexts. As a result, system may hold a very different meaning according to the area of study. However, the common denominator of a system is an exchange between elements that are bounded by an external environment (Mats-Olov & Gunnar, 2004).

Background of the systemic approach

The systemic approach has a very diverse background that ranges from the natural philosophy of Leibniz to the medicine of Paracelsus, who used the term system in his studies (Bertalanffy, 1989). The systemic approach arose in contrast to the reductionist approach that studies the elements of a phenomenon in isolation from the remainder of its parts. Toward the end of the 19th Century, many scientists began to see the disadvantages of using the reductionist approach. Around 1920 biologists such as Walter B. Canon (who developed the concept of homeostasis[1]) and Bertalanffy began to use the systemic approach to explain the functions of living organisms through the interaction of their parts (Flood, 1999). This set of ideas, which arose mainly in the field of biology, gave rise to a new paradigm of study for social sciences called Systems Theory (Jackson, 2000).

One important characteristic of the systemic approach is that it studies the components of organizations and organisms as a set of elements that have complex interactions between them and outward with the environment (Budd, 1998). This way of analyzing units or elements and their interactions produces different results than a

[1] Homeostasis is the regulation mechanism of living organisms that allows them to maintain the balance of the system through feedback (Bertalanffy, 1950).

more isolated approach. Aristotle had stated that "the whole is greater than the sum of its parts," which means that systems do not function from the simple joining together of their elements, but from the complex relationships between them and with their environment, which are both equally important (Sherwood, 2002).

The systemic approach was consolidated in 1947 when Ludwig Von Bertalanffy proposed the General Systems Theory (GST) (Jackson, 2000). GST proposes a combination of concepts and principles applied to the study of complex systems of any type: physical, biological, or social (Jackson, 2000). It studies systems as a set of elements that may or may not interact with the environment through the defining of closed and open systems. The environment, communication, inputs, outputs, process, control, equifinality, homeostasis, and feedback are all essential concepts for analyzing a system (Jackson, 2000).

As mentioned earlier, the purpose of GST is to formulate principles that apply to systems in general, regardless of their disciplinary origin (Bertalanffy, 1989). GST is based on fundamentals of mathematics and uses precise language to understand and resolve a problem (Bertalanffy, 1972). Chisholm (1967) states that the main point of GST is to define the system to be studied—which may be an organism, a society, a public policy, a component of computer hardware or software—in order to then introduce the standards, laws, and rules that apply to the system.

"Similar concepts, models and laws arise time and time again in very diverse fields, independently and founded on completely different facts" (Bertalanffy, 1989, p. 33). For example, a public policy may be studied as a system to which concepts such as homeostasis or synergy may be applied. GST seeks to reuse concepts that have been developed in other research disciplines in order to avoid developing the same principles at different times and places, which delays progress in new fields of science (Jackson, 2000).

According to Bertalanffy (1989), the goals of GST can be summarized in the following way: (1) GST integrates various sciences, both natural and social, based on a set of analytical principles; (2) GST may facilitate the creation of universal concepts to help generate exact theories in nonphysical fields of science; (3) The development of unifying principles leads to the unity of science; and (4) The above may lead to the creation of concepts that help spur scientific development.

Before Bertalanffy consolidated GST into a unified theory, one of its practical application was known as Operations Research (Mats-Olov & Gunnar, 2004). Operations Research is a branch of mathematics that originated in order to optimize solutions to resource management and logistics problems during the Second World War (Jackson, 2000). Another form of systems theory that developed in parallel to GST was Cybernetics. Cybernetics is the study of the control and communication of complex systems that use mechanisms such as feedback (Edwards, 1996; Van Gigch, 1991).

The systemic approach is closely linked to engineering as it uses the mathematical elements, materials, ideas, and methodological conceptualizations of this field (Hoos, 1983; Jackson, 2000). These factors have been widely accepted by other disciplines, such as sociology, biology, philosophy, psychology, and economics because they all intrinsically use systems in their study (Hoos, 1983). Sociology uses the concept of society as a social system that has inputs and outputs. The sociologist Herbert Spencer (1910) compared society to a living organism that is comprised of individuals instead of cells. Information is exchanged through trade, which is similar to the circulatory system of an organism. There are also core systems that regulate the conduct of the individual, such as government, a function that the central nervous system fulfills in biological organisms (Hoos, 1983).

A comparison such as this one does not imply a living organism and society are identical nor is it about comparing their internal properties, but illustrates that both are systems with a set of interrelated components in a given context and that these interrelationships influence their behavior (Hoos, 1983). The theories or principles formulated from GST and used in different disciplines consider the differences between the systems studied. It is not about attempting to draw simple analogies or similarities between systems and applying the concepts directly. It is about applying general principles in a logical and limited way to specific systems that, due to their characteristics, can be replicated in other systems (Bertalanffy, 1989). What Bertalanffy attempts through GST is to propose a science based on principles that apply generally to the behavior of systems (Jackson, 2000), regardless of whether they are biological, social, or mechanical (Pascoe, 2006).

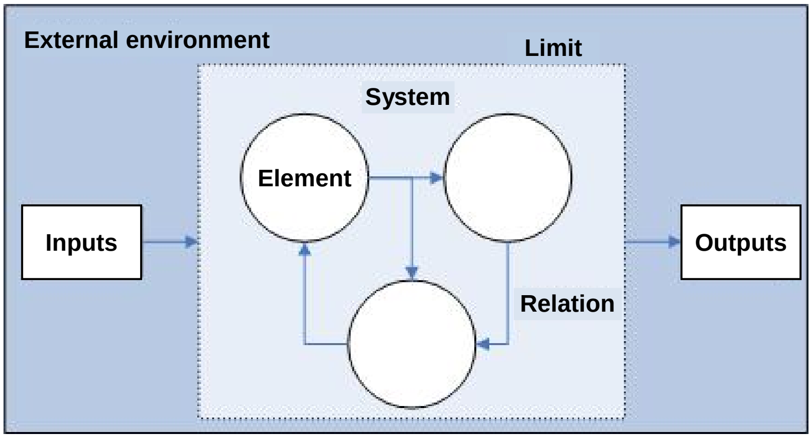
Basic concepts of the systemic approach

The systemic approach uses several important concepts to describe the phenomena studied. This section presents some of the key concepts and briefly describes different variants of the systemic approach.

System. A system can be defined as a collection or set of elements and parts that share a relationship within a determined space or boundary (Shearer & Murphy, 1967). A system can also be understood as a set of parts that work together to obtain a general benefit (Haines & Aller-Stead, 2005). Figure 1 shows a generic diagram that represents a system.

Similarly, a system can also be conceptualized as an integrated set of elements that can work together to produce results and achieve an established goal (Wasson, 2006). In this sense, some examples of systems in the field of social sciences include economic, political, environmental, social, and educational, among others.

FIGURE 1. GENERIC REPRESENTATION OF A SYSTEM



Source: Adapted from Mats-Olov and Gunnar (2004).

Inputs. Inputs are the raw materials of the system, and may be material resources, human resources, or information. Inputs are necessary for the system elements to start performing their functions and they constitute a powerful analytical element (Easton, 1989). More generally, an input can be any event that alters, modifies, or affects a system (Easton, 2001). For example, an input of a political system may be requests from the people to resolve a public problem.

According to Van Gigch (1997), the difference between inputs and resources is minimal, and depends only on point of view and circumstances. In the conversion process, inputs are generally the elements to which resources are applied. When identifying the inputs and resources of a system, it is important to specify whether or not they are under the control of the system designer. In addition, when assessing the effectiveness of a system in achieving its objectives, inputs and resources are generally considered as costs (Van Gigch, 1997).

Outputs. The outputs of a system are the results or end products that are obtained from processing inputs and are measured as results, successes, or benefits (Van Gigch, 1997). According to Easton (2001), outputs are the effects that propagate within or outside the limits of a system, which are the product of the interaction among system components. For example, in a political system, government decisions (e.g., public policies) are considered outputs.

Transformation or Process. The operation of a system can be seen through the transformation of inputs into outputs. A main characteristic of process is feedback from the system in which the behavior of one component modifies the behavior of another depending on the relationship between them (Flood & Jackson, 2000). Transformation or process is often represented as a black box where inputs are processed. In the case of a political system, they refer to all political and bureaucratic processes undertaken in order to transform a citizen need (input) into a public policy or governmental program (output).

Relationship. Relationships are the connections between system components or the exchanges between agents that enable communication (Mats-Olov & Gunnar, 2004; Sherwood, 2002). In the case of a political system, these relationships represent the influence of one variable on another; for example, in an international system, nation-states may be taken as components and their relationships include certain types of interactions between them, such as alliances, dependencies, protectorates, and labels of enemy status (Easton, 1982).

Limit. A limit is the divide between a system and its environments or other larger systems. The limits must be defined in order to determine the unit of analysis and problem in question, but achieving a consensus is not always easy (Allen, Consoli, David, Fava, & Warren, 1995). Defining the limits is also important because the components that allow for the analysis of a system's behavior must be left in the system, but at the same time, the system needs to be of a size that allows it to be understood and analyzed (Flood & Jackson, 1991). According to Aracil (1983), the limit must be defined in such a way that the behavior of the system can be explained from within and not based on external variables (Mats-Olov & Gunnar, 2004). However, despite the defined limits of a system, the analyst must take into consideration the system's interactions with the environment in order to achieve results that align with reality (Van Gigch, 1997).

Environment or context. This concept includes that which is out of the system's control (Vargas, 2004). The concept of environment is essential as it allows systems to be classified into two broad categories: closed systems and open systems (Fortune & Peters, 2005). A closed system is an isolated system that does not interact with the environment and obeys the second law of thermodynamics in which the system gradually reduces in energy and increases in entropy (Jackson, 2000; Van Gigch, 1991). An open system is a system that is constantly exchanging energy with the environment; in other words, the limit that separates the system from the environment is permeable (Flood & Jackson, 2000). An open system may be a human being, a bacteria, an animal, the Internet, society, or the State (Kramer, 2006). Generally, all living systems are open (Van Gigch, 1991).

Equifinality. This is the state or end position that a system can reach as it shifts from a different initial state (Van Gigch, 1991). In a closed system, equifinality is determined by the initial conditions, whereas in an open system, equifinality can be reached under different conditions than those of closed systems since the environment is constantly interacting and modifying the system (Bertalanffy, 1989).

Feedback. An essential component of system communication is feedback, which is the process through which system outputs or responses then provide information back into the system as a new input to modify the behavior of the system and respond to existing tensions (Easton, 1982). An example of feedback is certain electronic devices (e.g., thermostats) that receive information until they reach a specific state or objective (e.g., a certain temperature) (Bertalanffy, 1989). It can also be understood as the process through which the behavior of a system element can provide feedback to another, either directly or indirectly, until that first element arrives at the point where it can modify the behavior of the other element (Flood & Jackson, 2000). Feedback can be positive or negative (Kay, 2006) and allows the system to learn and self-regulate (Easton, 1990). Feedback is a fundamental part of a social system because the parts or elements respond positively (in a growth process) or negatively (in a stabilization process) according to the information they receive (J. W. Forrester, 1961).

According to Baumgartner and Jones (2002), the purpose of a negative feedback system is to act as a counterweight that allows the system to reach a balance. These types of systems are very common in political science and public policies as they are designed to achieve homeostasis of the system, such as actions for tackling inflation or policies to counteract poverty.

In contrast, positive feedback is an action that reinforces the direction of a process in a system, giving rise to self-catalytic processes. It is an operation that does not have a stabilizing effect on the system, instead it is considered unstable and explosive (Easton, 1982). An example of a positive feedback cycle can be seen in the location of certain industries, such as the software industry in Silicon Valley, California in the US. This place became popular for the production of technology and more companies, suppliers, and programmers converged on the location, which created economies of scale and other benefits that made it even more popular, and more companies kept arriving. In other words, a tendency or component of the system reinforces another and vice versa. For example, in a political system, we can see positive feedback cycles when an individual repeats the behavior or makes a similar decision to that of another, which in turn causes more individuals to make the same decision (Baumgartner & Jones, 2002).

Control. This happens when a system is able to maintain its identity and has stable processes over time within limits of viable balance (Flood & Jackson, 2000; Van Gigch, 1997).

Negative Entropy. Entropy is a measure of disorder (Van Gigch, 1997). It is also known as the wear that a system shows over time or due to its operation. In contrast, negative entropy represents the tendency of a system to move toward order (Bertalanffy, 1989).

Homeostasis. The concept of homeostasis refers to the capacity of a system to maintain its balance through exchanges with the environment (Flood & Jackson, 2000). It is also defined as the regulation mechanism of natural and social systems which, through feedback, allows the system to maintain its current balance or arrive at a new state of balance (Bertalanffy, 1950; Easton, 1982). The purpose of devices that function like homeostasis is to maintain the stability of the system (Baumgartner & Jones, 2002; Sherwood, 2002). It is an important mechanism for managing the tension that can arise from different events, such as war, revolution, and other social traumas. This tension also arises from the constant and day-to-day pressures of political life (Easton, 1982).

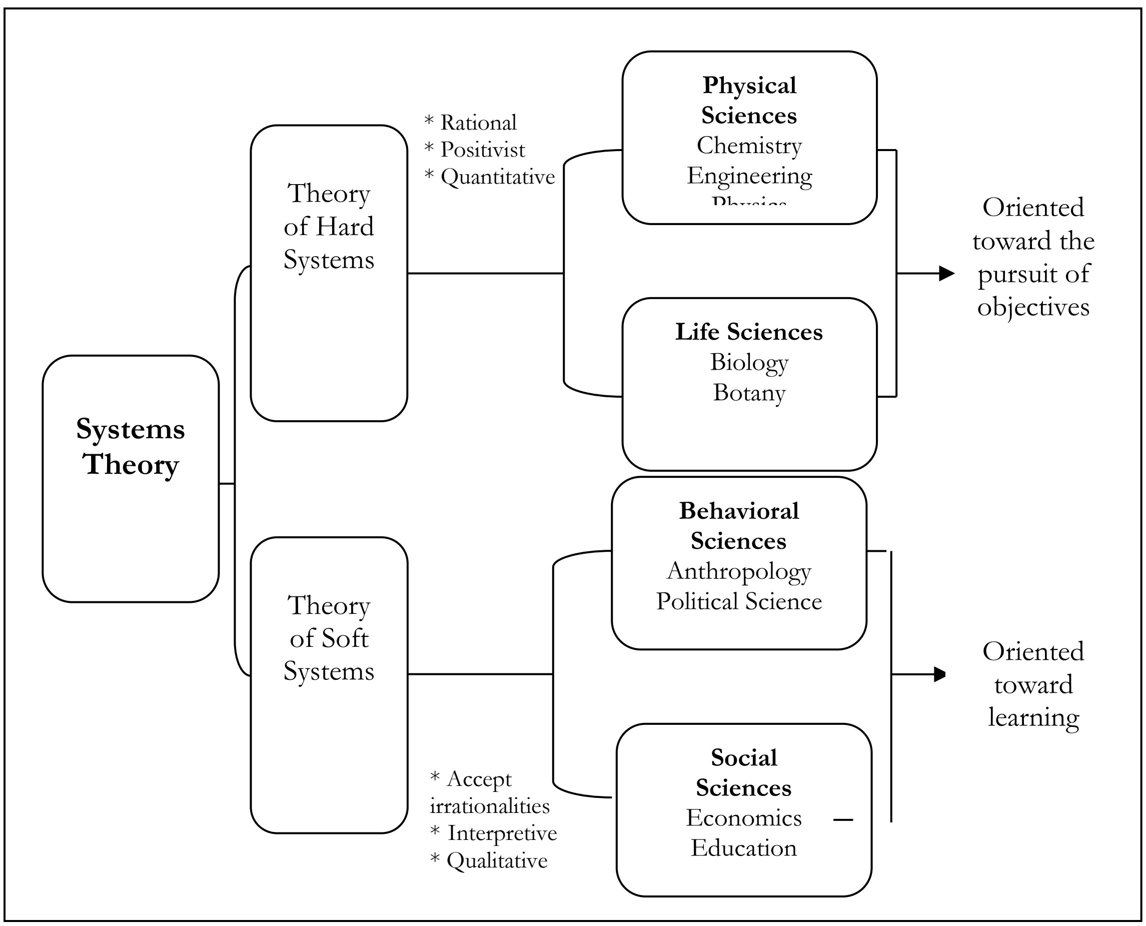
Hierarchy. The ranking of systems according to established values: structure, time, and complexity, among others (Van Gigch, 1991). Hierarchy can also be defined as the position of the components of a system in respect to the others (Vargas, 2004).

Synergy. The capacity of the components of a system to work as a whole (Flood & Jackson, 2000). It is when two or more components of a system complement each other to obtain a better result. This type of strategy is used frequently in areas of business to deliver better results (Gottschalk, 2006).

Variants of the systemic approach

Systems Theory can be divided into two broad categories: hard systems and soft systems. Soft systems are further divided into two branches: behavioral sciences and social sciences. Hard systems are also classified into two branches: physical sciences and life sciences (Van Gigch, 1991, p. 66).

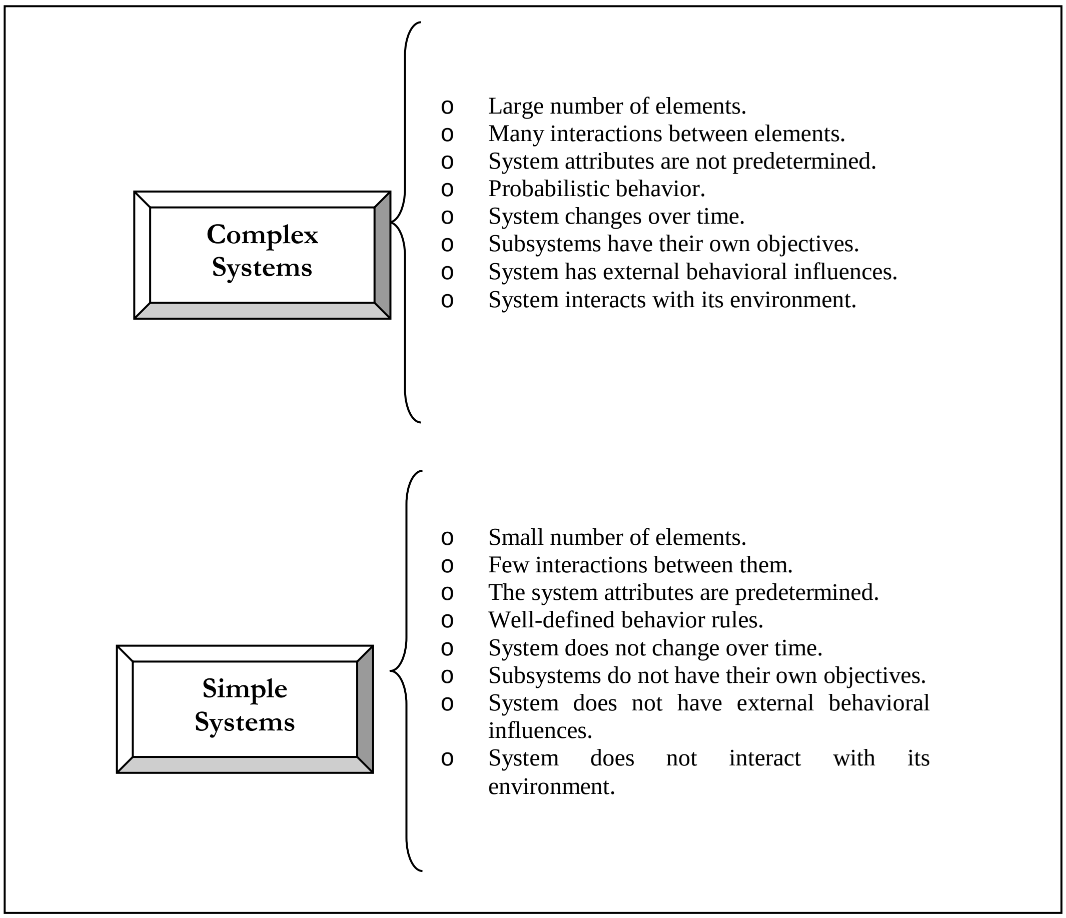
FIGURE 2. CLASSIFICATION OF SYSTEMS THEORY



Source: Based on Flood and Jackson (1991) and Van Gigch (1991).

According to Flood and Jackson (1991), the difference between hard and soft systems is that hard systems have a rational vision for resolving complex problems of optimization, much in the same way as operations research (OR) and critical thinking systems. One characteristic of this hard branch, which is strictly rational, is that it requires a precise definition of a problem in order to be able to arrive at an optimal solution (Jackson, 2000). In addition, it uses concepts from functionalist theory. In comparison, soft systems rely on an approach oriented toward learning and problem solving, using models that allow analysis of the different alternatives. The model is not considered to be the real world, but a simplified representation of it. This perspective, which is interpretative and qualitative in nature, is used in administration and social sciences.

FIGURE 3. CHARACTERISTIC NO. 1 - SYSTEM



Source: Flood and Jackson (2000).

Some of the different applications or methodologies that use the systemic approach for solving a problem are operations research, system analysis, system dynamics, contingency theory, design of social systems, and interactive planning, among others. According to Flood and Jackson (2000), two characteristics of the context of a problem must be taken into account when choosing the correct application: systems and participants (See figure 3 and table 1). The system's characteristics refer to the degree of complexity confronting the problem to be analyzed. The participant dimension is the level of agreement or conflict among actors in the system (Flood & Jackson, 2000).

TABLE 1. CHARACTERISTIC NO. 2 – PARTICIPANTS

Unitary	Pluralist	Coercive
Elements have the same common interest.	Elements have a basic interest that they share.	Elements have no common interest.
Values and beliefs are shared.	Values and beliefs are different to a certain extent.	Values and beliefs are in conflict.
They agree with the goal.	They do not necessarily agree with the goal, but are committed to the function.	They do not agree with the goal and have no commitment to the function.
Everyone participates in the decision making process.	Everyone participates in the decision making process.	There are coercion mechanisms for accepting decisions.
Act according to agreed objectives.	Act according to agreed objectives.	There is no agreement on objectives.

Source: Flood and Jackson (2000).

Simple problems can be analyzed as a simple system, and matters with greater internal and contextual complexity must be studied from a complex system perspective. For social problems it is important to consider the importance of the time variable and that the conduct of individuals is related with others, which is why it is not appropriate to classify a social or political system as simple.

Therefore, if the contextual problems known as unitary, pluralist, and coercive are combined with the dimension characteristics of the system, the resulting systems theory application matrix is as follows (see Table 2). Each of the squares represents a combination of dimensions and a methodology or an analytical approach.

TABLE 2. TYPES OF PROBLEMS AND CHARACTERISTICS

Simple		
Unitar	**Pluralist**	**Coercive**
▪ Operations research	▪ Design of social systems	▪ Critical heuristics systems
▪ System analysis	▪ Testing strategies	
▪ System engineering		
▪ System dynamics		

Complex		
Unitary	**Pluralist**	**Coercive**
▪ General systems theory	▪ Interactive planning	▪ There are no tools
▪ Socio-technical thinking type systems	▪ Soft system methodology	
▪ Contingency theory		

Source: Flood and Jackson (2000).

The Simple-Unitary table methodology is designed for problems where objectives can be clearly established (Flood & Jackson, 2000). The system can be represented by a quantitative or highly structured model in which various scenarios can be simulated by modifying different parameters or conditions. The Complex-Unitary model contains many relationships between its elements and assumes that there is a general agreement on the goals and objectives to be achieved and does not establish a procedure for debate of those issues (Flood & Jackson, 2000).

The Simple-Pluralist model is a construct which states that there is no agreement on system objectives (Flood & Jackson, 2000). Its methodology assumes that each actor has a specific vision for the organization. In this model it is important to analyze the actors and coalitions, know the composition of the group, and analyze the debate that arises from the conflict of interests. The organization can be viewed as a culture. The Complex-Pluralist model is identified as having a low level of agreement between its elements, but there may be certain commitments to solve a problem (Flood & Jackson, 2000). Once again, the organization can be compared to a culture.

The Simple-Coercive model is well-suited to political problems (Flood & Jackson, 2000). There are significant differences in values and meanings between the elements of the system and there are groups that want the power to make decisions. Debate is one of the solutions for ending the conflict. One peculiarity of this design is that the power of each actor is identifiable. Lastly, the Complex-Coercive model has no tools or methodologies for analysis due to its intrinsic complexity and the fact that other sources of power are not immediately evident (Flood & Jackson, 2000). Analyzing these types of situations requires an awareness of the organizational culture, the relationship between hierarchies, and the division of labor, among other important elements.

Systemic approach and system dynamics

System dynamics (SD) is a variant of the systemic approach that has been highly influenced by the development of technology, exact sciences, and the application of computer simulation methods to the analysis of complex social science and economic problems (Wolstenholme, 1999). Its purpose is to gain a better understanding of certain problems and behaviors in order to be able to design strategies and policies that improve the performance of the system over time (Kopainsky & Luna-Reyes, Forthcoming). SD is linked to a strong computational component for modeling and analyzing problems given that simulation is an indispensable tool for visualizing systems and relationships between elements.

In order to achieve a model that is more attached to reality, it is important to consider the client or user from the early model development stage (J. W. Forrester, 1961; Zagonel, 2002). SD has been used to represent the behavior of organizations and administration problems through the use of systemic models and feedback cycles (Grizzle, Pettijohn, & D, 2002). It helps to understand the dynamic behavior of a system that arises from the interaction of its elements over time. System dynamics is not limited to representing one reality at a given moment in time, but instead establishes a relationship between an initial and later time for that same reality (Easton, 1982; Flood & Jackson, 2000).

System dynamics was an idea that originated in the 1950's with professor Jay W. Forrester of the Massachusetts Institute of Technology (MIT) (Flood & Jackson, 2000). The author distinguished SD from other variants of the systemic approach by its intensive use of feedback cycles and greater emphasis on structure as the main cause of the behavior of a system (Jay W. Forrester, 1973). System dynamics uses models to represent certain phenomena. These models are abstractions or simplifications of mental models that cannot be expressed properly in writing and whose objective is to communicate and clarify a reality (Wolstenholme, 1982). A dynamic system can be defined as a set of elements within a determined context that starts with certain initial conditions and changes its behavior over time (Hoos, 1983).

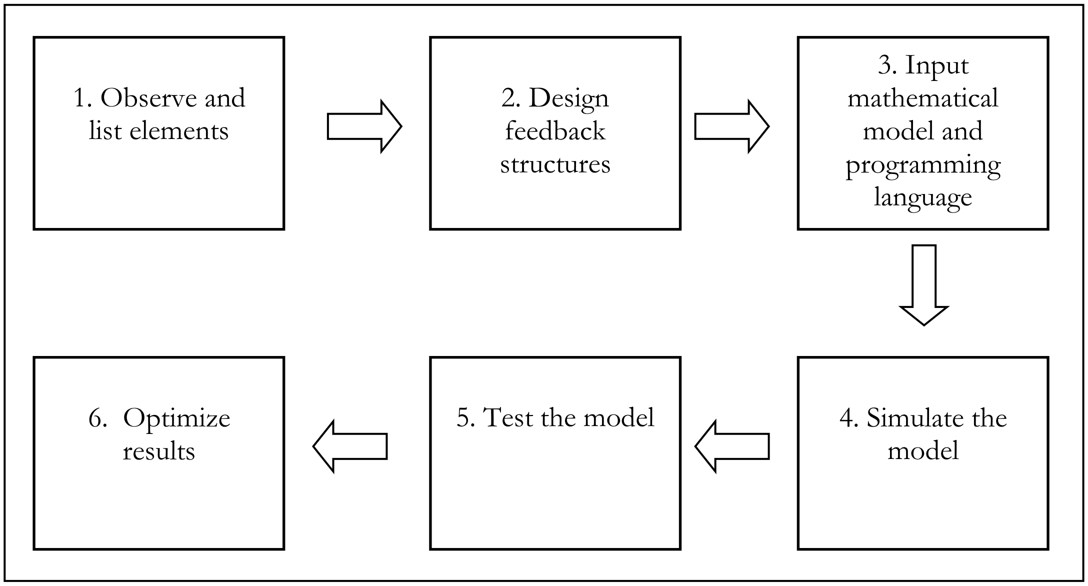
The purpose of SD is to create formal decision-making models in order to represent a concrete reality and resolve a given problem (Aracil, 1983; George P. Richardson & Pugh, 1981; Roberts, Andersen, Deal, Grant, & Shaffer, 1983; Sterman, 2000). SD does not claim to predict future situations, but to be a tool that can be used to analyze a public policy, understanding its possible consequences given a determined problem and context (De Geus, 2000; Sharp, 1972). This methodology uses computational tools to complement the human task of calculating the possible alternatives of a problem given our limited capacity. The models processed by a computer have the advantage of being able to represent the behavior of agents and analyze their relationships among components over time, something that would be difficult for an individual to calculate. The mental models created by human beings may conceive erroneous responses in complex situations, whereas a dynamic model programmed into a computational tool is able to calculate the possible consequences with greater reliability, and represent the different relationships and feedback of the system. The analysis conducted prior to creating the model and its mathematical representation, which is then programmed in computer language, forces analysts to explicitly and clearly express the relationships in the system (Jackson, 2000).

The models simplify the reality of the world and as a result intentionally omit some specifications and peculiarities of the reality studied. What the model claims to do is improve the understanding of a phenomenon and make its relationships with the rest of the system elements explicit. This simplification can be considered a weakness of system dynamics when it is difficult to represent relationships in highly complex problems that are difficult to quantify. However, it is a useful approximation that is used for analyzing nonlinear (social) problems and their development over time.

A dynamic model is best viewed as a support tool for understanding social problems and formulating possible public policy solutions. Technological change has made it possible to study social problems dynamically because of advances in hardware and software that allow the simulation of complex mathematical models. The models of system dynamics help us understand the complexity of the real world, giving the phenomenon a structured and complete shape, in addition to allowing the use of a large number of variables (Sherwood, 2002). A characteristic of these models is that they are (usually) closed systems with interrelated variables, but they also have the capacity to represent complex open systems (Van Gigch, 1997).

According to Aracil (1983), the system dynamics approach proceeds in six phases. The first phase is to observe the general conduct of the system in order to list and understand the elements that comprise it. The second phase is to design the feedback structures in order to reproduce the observed behavior. At the third stage, the analyst creates a mathematical behavior model of the system and programs it in computer language. The fourth phase consists of simulation of the model. In the fifth stage, the model is tested until the resulting behavior is as similar as it can be to that observed in the real world. Lastly, at the sixth phase, new variables are introduced to modify the behavior of the model in order to optimize the results (Aracil, 1983).

FIGURE 4. PHASES OF SYSTEM DYNAMICS



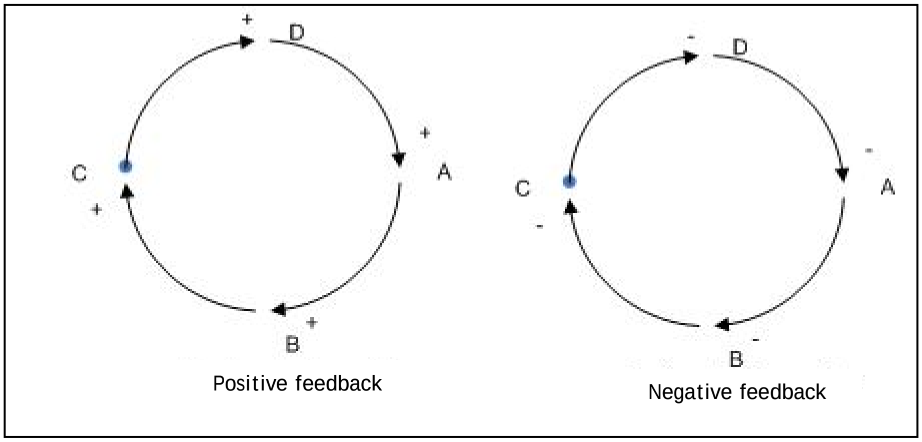
Source: Author based on Aracil (1983).

The information introduced into the dynamic system (such as relationships, variables, and the direction the data takes) is based on observation of the social problem and on the experience of people who participate in the analysis of this type of problem. In this sense, the system dynamic depends on the capacity and experience of those who design the model, as well as experts on the topic. A model on its own cannot give meaning to the relationships and behaviors if it is not supported by empirical data or theoretical precepts. Contrary to popular thinking, a dynamic model explicitly represents opinions and perspectives from the system and therefore it is appropriate to use these tools in social sciences since it exposes the suppositions and values on which they are based.

In order to study a social system through system dynamics, the relevant variables and their relationships must be identified and represented using feedback cycles and other elements inherent to the systemic approach and system dynamics. Below is a list of some of the important concepts of system dynamics that complement the concepts common to the overall systemic approach.

Feedback cycles. Interaction between the elements of the system produces changes in behavior over time. The analysis of these relationships (feedback direction) is of interest to system dynamics (Flood & Jackson, 1991). A cycle is a closed chain or flow of actions between elements that form the system. Cycles may be positive or negative. Positive flows refer to growth processes, while negative flows represent stabilizing processes.

FIGURE 5. POSITIVE AND NEGATIVE FEEDBACK CYCLES



Source: Aracil (1983).

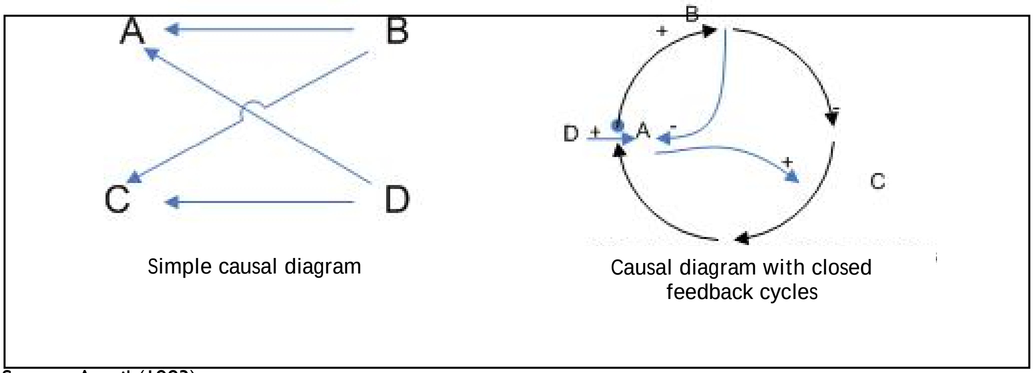
Parameter Sensitivity. Sensitivity is a measure of change of the social system that is brought about by modifying the parameters. It helps us to identify the effect that a change in parameters has on the system's behavior. Richardson and Pugh (1981) distinguish three types of parameter sensitivity: (1) numerical; (2) behavioral; and (3) policy. All are reactions to changes in the parameters. The first includes the same qualitative behaviors and only changes in the numbers or amounts, the second refers to changes in behavior patterns over time, and the last one refers to changes in conclusions and recommended policies—all according to changes in parameters (George P. Richardson & Pugh, 1981).

Conflicts between Objectives. This refers to problems that arise when a system is analyzed in the short- or long-term; the results are generally different when they are studied over time. The objectives and limits of a system are important in order for the different participants to judge or assess its usefulness (Van Gigch, 1997).

A dynamic system is represented through cause-effect diagrams (Jackson, 2000). It is first necessary to identify the elements of a system and relate them using arrows to indicate the nature of their relationship insofar as an increase in one component also increases the other A→B+ or reduces it A→B-. The relationship between the elements of a system can be represented as a complex causal structure (see Figure 6).

In summary, the application of SD to a social system is a useful alternative for analyzing a problem. It is an approximation that allows relationships to be modeled over time in order to measure their behavior and the effects they produce. The use of models has helped SD to simplify reality and give us a better understanding of the components that affect certain systems. The methodology does not claim to cover all social problems, but to provide the researcher or analyst with an additional tool to identify elements, relationships, and their behavior over time. The use of computation is an indispensible instrument for analysis because it facilitates the calculation of consequences and possible results in a relatively short amount of time (Spector & Davidsen, 2002).

FIGURE 6. SIMPLE AND COMPLEX CAUSAL STRUCTURES



Source: Aracil (1983).

Systemic analysis of public policies and decision-making

This section describes the use of the systemic approach and system dynamics for the analysis of public policies. A public policy is a deliberate course of action undertaken by different levels of government to achieve a specific objective (Allen *et al.*, 1995), which is not only limited to legislation and regulation, but to the different actions a legitimate authority or government power decides to take (or not take) (Meny & Thoenig, 1992; Theodoulou, 1995).

According to Theodoulou (1995) there are two approaches to the study of public policies. The first approach is mainly based on the actors, controls, and benefits of the policy. The analyst studies public policy through the group that dominates the political process, using group theory, elite theory, corporatism, and sub-governments, among other approaches (Theodoulou, 1995). The second approach focuses on analyzing the behavior of system elements through phases (or a cycle-process approach) through perspectives such as systems theory, structural functionalism, and political cycle theory (Theodoulou, 1995).

The application of systems theory to the social and political field can be seen through the work of David Easton (Theodoulou, 1995). Easton (2001) considers public policies as a political system in which petitions are made to resolve problems in a specific environment. The political system is a system to which the demands of citizens are introduced and processed to create a public policy that assures the stability of the system (Easton, 2001). Public policy, viewed as an output of the system, produces new demands in turn, which may be a new input into another system or feedback from the same one. The usefulness of viewing a public policy as a system rests in analyzing it as a set of elements that interact and exhibit certain behavior over time to achieve a goal.

Complementarily, the application of SD allows public policy scenarios and their implications to be analyzed over time according to the problem studied (Coyle, 1999).

According to Eugene Bardach (2004), the complexity of analyzing a public policy lies, among other things, in that many actors are involved: interest groups, public officials, popularly-elected public officials, citizens, and civil organizations, among others. In addition, institutional and legal frameworks govern all public policy, which includes laws, standards, regulations, and important cultural aspects. The interaction between multiple social actors and the context means that the analysis of public policy is considered more of an art than a science (Bardach, 2004). However, using a method can help us understand the complexity since it allows one to identify the elements or parts of a problem and analyze their exchanges. Bardach (2004) proposes eight steps for the systematic analysis of public policies: (1) define the problem; (2) obtain data and information; (3) prepare alternative solutions; (4) select criteria; (5) project the effects of results; (6) review costs and benefits; (7) choose a solution that addresses the specific problem; and (8) reveal the solution's history. Analogically, Sterman (2000) proposes five stages for the modeling process of dynamic systems: (1) state the problem; (2) create a hypothesis of the dynamic; (3) construct the model; (4) evaluate the model created; and lastly (5) formulate and evaluate the policy.

Taking into account the similarities and differences between these two processes, Table 3 gives a brief description of the steps to follow when analyzing a public policy using system dynamics specifically, and the systemic approach in general.

TABLE 3. STEPS FOR ANALYZING PUBLIC POLICIES AND SYSTEM DYNAMICS

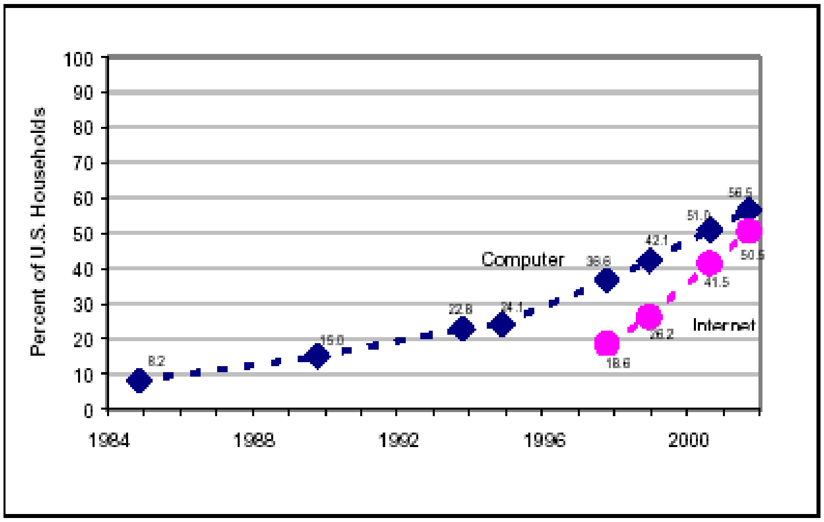
<table>
<tr><th>Public Policies
(Bardach, 2004)</th><th>System Dynamics
(Sterman, 2000)</th><th>Application of System Dynamics
To Public Policies</th></tr>
<tr><td>1. Define the problem</td><td>1. State the problem</td><td>1. Define a dynamic problem</td></tr>
<tr><td rowspan="3">2. Obtain data and information</td><td>2. Hypothesis of the dynamic</td><td rowspan="2">2. Develop a simulation model</td></tr>
<tr><td>3. Construct the model</td></tr>
<tr><td>4. Evaluate the model</td><td>3. Evaluate the model with real data</td></tr>
<tr><td>3. Prepare alternative solutions</td><td rowspan="6">5. Formulate and evaluate the policy</td><td rowspan="4">4. Explore public policy scenarios</td></tr>
<tr><td>4. Select criteria</td></tr>
<tr><td>5. Project effects or results</td></tr>
<tr><td>6. Review costs and benefits</td></tr>
<tr><td>7. Choose a solution that addresses the specific problem</td><td rowspan="2">5. Develop Policies or Strategies</td></tr>
<tr><td>8. Reveal its history</td></tr>
</table>

Source: Author.

Define a dynamic problem

The first step is to define a dynamic problem, which refers to defining a problem over time and not a one-time situation that does not consider the evolution or behavior of the variables (Kay, 2006). Defining the problem is one of the most critical steps of the entire process and depends in large part on the experience and knowledge of the researcher or analyst (Van Gigch, 1991). For example, a dynamic problem would be "that the number of families in extreme poverty has increased over the last few years", compared to the more traditional way of defining a social problem as "there are a large number of families in extreme poverty". This way of defining the problem to be studied is important since it attempts to understand the structural sources of the problem over time.

FIGURE 7. MARKET PENETRATION OF COMPUTERS AND THE INTERNET IN THE US



Source: U.S. Department of Commerce (2002).

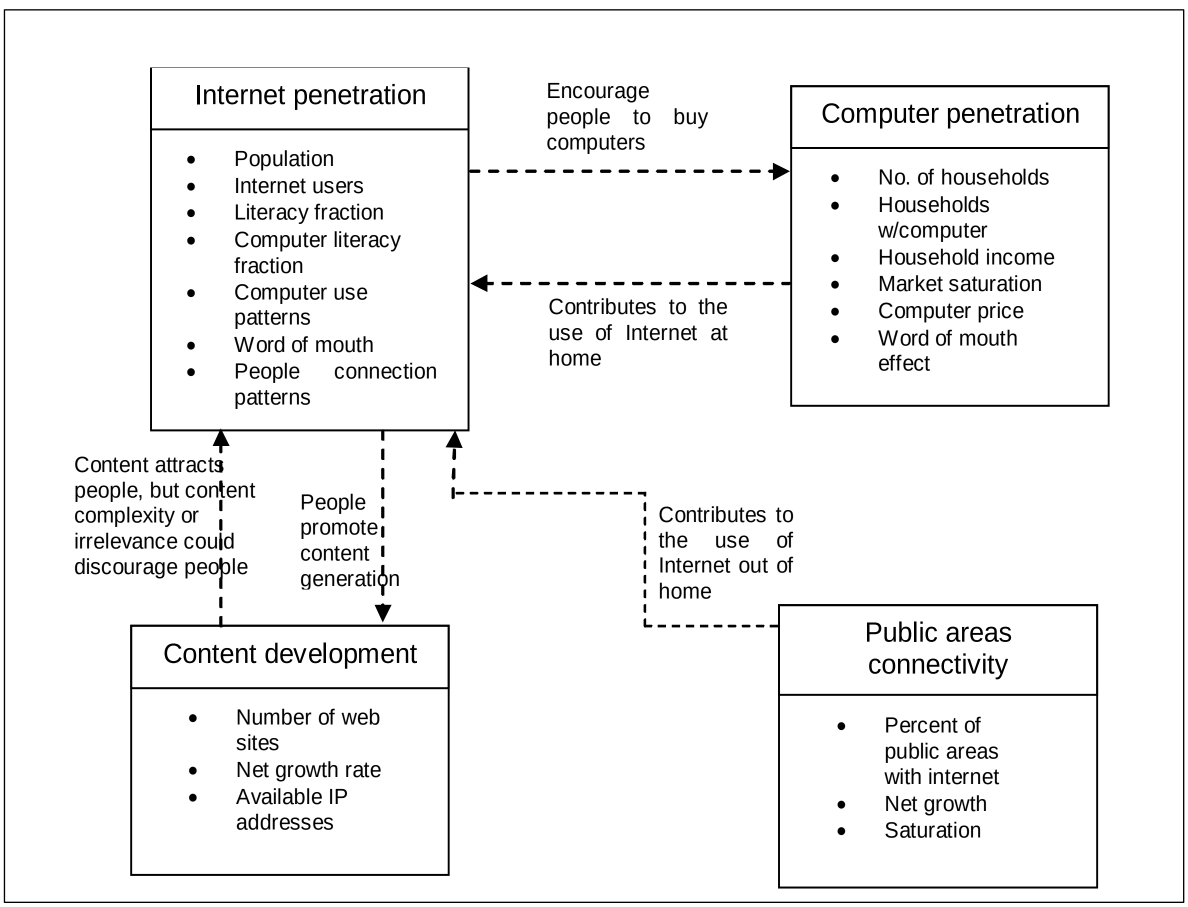
One way of representing a dynamic problem is through a graph, which shows the different levels of a target variable over time. Figure 7 gives an example of this type of representation, specifically, market penetration of the use of computers and the Internet in the United States. Moving forward, we will use this and a few other examples to illustrate the steps in the system dynamic approach.

Develop a simulation model

Once the dynamic problem has been defined, the next step is to identify the main variables that affect the problem and its exchanges, which are then represented in a simulation model according to the tenets of systemic thinking. This simulation model represents the target variable (public problem), its causes and its effects as an interconnected system. The relationships between variables, and particularly the feedback cycles represented in the model, produce certain dynamic behavior in the variables included in the system (tendencies over time). Despite being mathematical models, complex variables can also be included; in fact, qualitative data is recognized as the main source of information for developing a system dynamics model, but it is important to know when to use such data (J. W Forrester, 1992; Luis Felipe Luna-Reyes & Andersen, 2003).

One of the main objectives of a model such as this one is its ability to reproduce the dynamic behavior that a target variable has in reality. In other words, the result of the simulation of the relationships represented in the system should follow the same trend that was defined as the original dynamic problem—in this case, the reduction in the digital divide. Figure 8 givens an example of a model developed to understand the evolution of the digital divide.

FIGURE 8. SYSTEM OF VARIABLES THAT REPRESENTS THE DIGITAL DIVIDE



Source: Lunas-Reyes and Maxwell (2003).

Evaluate the model with real data

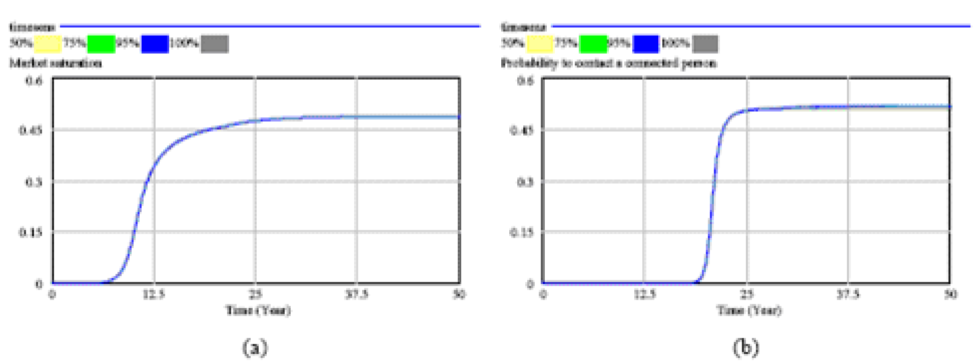
Once the simulation model representing the problem as a system of interconnected variables has been developed, it can be evaluated through the inclusion of real data or comparison against known tendencies (Sharp, 1972; Sterman, 2000). For example, once the model representing a reduction in the digital divide has been created, the analyst can evaluate other included variables and ensure that their behavior is consistent with existing data. In other words, if real data shows that the cost of computers has decreased and that average household income has increased, the results of the model must also coincide with these facts. That is, the purpose of this step is for the analyst to assure that the model is built from suppositions as close to reality as possible.

Other types of tests are conducted that also evaluate the plausibility of the model and its results. For example, the analyst must ensure that quantities that cannot be negative in reality are not negative in the model either, or that quantities that cannot exceed certain limits in reality do not do so in the model.

Explore public policy scenarios

Once the model has been calibrated and evaluated with real data and, insofar as is possible, the involvement of actors and experts on the topic, the next step is to incorporate different alternative public policy interventions. For example, in the case of the increase in the number of families in a situation of extreme poverty, different programs and policies that could be used to counteract the problem, such as the distribution of food assistance, the awarding of scholarships, and the inclusion of families in low cost insurance schemes, or combinations of these alternatives, can be incorporated into the model.

FIGURE 9. IMPACT OF CONSTRUCTION OF INFRASTRUCTURE IN PUBLIC PLACES

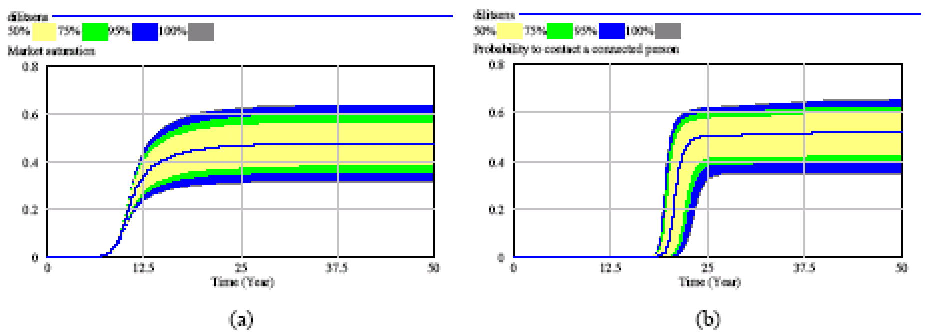


Sensitivity analysis for the amount of resources directed to build infrastructure in Public places.

Source: Lunas-Reyes and Maxwell (2003).

Each of these alternatives would have an effect on the different variables in the system and the simulation model will reveal their overall effect on the target variable (in this example, the number of families in extreme poverty). The systemic approach and simulation allow a large number of variables to be considered simultaneously and help us to understand their interrelationships and the feedback cycles that exist between the different processes.

FIGURE 10. IMPACT OF TRAINING IN TECHNOLOGY (DIGITAL LITERACY)



Sensitivity analysis for digital literate fraction

Source: Luna-Reyes and Maxwell (2003).

Figures 9 and 10 are examples of the application of system dynamics to the digital divide. The variables chosen as relevant results are market saturation and the probability of contacting a person using the Internet for the purpose of analyzing the digital divide in the United States. Market saturation represents the portion of households that have a computer in the home and the probability of contacting a person online represents the level of Internet penetration. The first graph shows the effort to provide Internet connectivity in public places; the model shows little change in behavior, which probably indicates that it is not an effective way to reduce the digital divide. The second graph shows us that attempts to increase digital literacy among individuals do have an impact on the target variables of the model.

Develop policies or strategies

Once the different public policy alternatives and their direct effects, cost, and possible secondary effects have been evaluated longitudinally, the analyst will have the necessary information to develop a public policy or long-term strategy. The majority of computer packages for system dynamics allow the effects of multiple alternatives to be compared directly, not just on the most relevant variable (in this case, the number of individuals that use the Internet), but also other variables that are considered strongly linked to it (Van Gigch, 1991). In other words, the analysis of public policies through the systemic approach and system dynamics allows for a more comprehensive view of a public problem and its possible solutions, as well as the identification of unplanned consequences (negative or positive) prior to making a decision and implementing a governmental program.

For example, in the case of Luna-Reyes and Maxwell (2003) we see that the public policy strategy with the greatest impact was to train the people in information technology and its uses (digital literacy), which indicates that this public policy would be more effective and recommended as a long-term strategy.

Some advantages and limitations

It has been shown throughout this paper that the systemic approach represents a very useful alternative for the analysis of complex problems, such as those that normally arise in the analysis of social problems and political policies (Sherwood, 2002). According to Herbert Simon (1949), it is very difficult for human beings to calculate all the possible consequences of their actions. Their decision-making capacity is based on the context surrounding them and the way they perceive it. However, "human beings strive to achieve rationality and although they are bound by the limits of their knowledge, they have developed certain work procedures to help them partially overcome this difficulty" (Simon, 1949, p. 79).

Consequently, the use of models to represent social problems is very useful since it allows us to understand a finite number of possible solutions, the relationships between variables, and the way they are immersed in a specific problem (Sherwood, 2002). The systemic approach is used in science to improve the hypotheses that have been developed, which, in the case of social problems, can help to achieve change in the *status quo* through the intervention of governmental authorities (Mats-Olov & Gunnar, 2004). A necessary condition for the systemic approach to be successful it that it is built through discussion and debate among all actors involved in the problem, since the proposed solution must be legitimate and clearly based on reality. If this occurs, then the approach generates spaces for communication between participants to satisfy a given situation, which is one of its most important contributions (Mats-Olov & Gunnar, 2004). To achieve this communication, model development sessions can be held with the individuals involved in tackling the problem, using their views to establish the variables and relationships between them, so as to arrive at a model that is closer to reality (Luis F. Luna-Reyes, 2008).

Some of the limitations of the systemic approach and system dynamics include the considerable impact of the way in which the problem is defined. Therefore, it is important to know whether the problem was identified objectively and visibly or whether the experience and knowledge of the researcher was the key factor used to define it (Van Gigch, 1991). This information helps to perform an appropriate evaluation of the model (Mats-Olov & Gunnar, 2004). Another potential problem is inadequately defining the limits of a system (Spector & Davidsen, 2002). Potential causes of this inadequate definition are theoretical directives, the researcher's capacity or field of study, time or factors related to financial resources, etc. Delimiting the object of study properly is very important in order to obtain reliable results.

On the other hand, one of the criticisms that system dynamics has received is the simplification required to deal with reality and represent complex systems through mathematical models. However, model a system through theory, which is why simplification is not only guided by the subjective experience of the researcher, but also by the theoretical teachings that underpin the design process (Aracil, 1983).

An important contribution of system dynamics is the growing use of diagrams to represent the endogenous behavior of complex systems through feedback cycles (G.P Richardson, 1999). System dynamics also has two important qualitative and quantitative strengths (Wolstenholme, 1999). First, there is the longitudinal simulation of the behavior of a system through mathematical models implemented with a computer, which provides researchers with greater analytical capacity and allows them to improve their chances of finding a solution to a problem. Second, computer simulation permits more rigorous analysis and allows systems to be represented more completely and comprehensively because it combines hard data with qualitative elements of the system, which are quite often intangible.

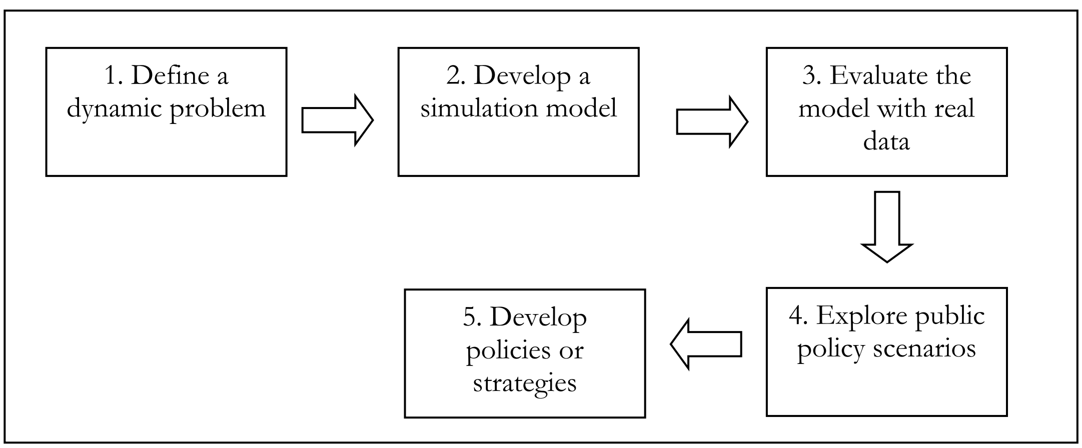
In contrast, Wolstenholme (1999) also presents some limitations related to the use of system dynamics: (1) data is required for all variables in order to conduct computer simulations, which may result, for some variables, in the inclusion of theoretical suppositions or opinions based only on the experience of the researcher; (2) by being able to use many variables and elements from a system, highly complex problems have to be designed clearly and accurately, which can often lead models to have such a high degree of detail that it is impossible to understand them; (3) it requires certain experience and skill to manage feedback diagrams and a knowledge of systemic thinking; and (4) system dynamics is a specialized variant for the management of information flows and many computer software packages have been developed by experts in the field, but there is no guide for which one to use in a specific situation, and sometimes these programs are not compatible with one another or with other general applications.

According to Flood and Jackson (1991), the use of system dynamics in the analysis of public policies has received three main criticisms. The first refers to the ideology. Designers that use system dynamics to analyze problems have become technical elites who decide how a policy is to be developed and use the technique to justify their decisions as neutral and objective. Furthermore, these elites do not always generate spaces for other actors to participate in the construction of the models, which is why the policy they develop is clearly biased toward the values of the designers themselves. This second point refers to usefulness. System dynamics must always be based on a rich source of empirical data or on known and accepted theories and principles, which is why it is necessary that analysts express the main sources that validate and legitimize the results of the system and its respective simulation. Lastly, the third criticism is related to methodology. According to its creator, system dynamics was developed to build models that accurately represent reality. However, the development of a model is strongly influenced by the data collection process that feeds it, which is not always explicitly described.

Conclusions

This paper explains the application of the systemic approach and system dynamics to the analysis of public policies. These approaches and their respective computer simulations allow us to model reality through mathematical models and feedback thinking and diagrams, which in turn help us to understand the possible consequences of a concrete dynamic problem. Although the use of system dynamics and computer simulation requires specialized knowledge and abilities, this approach is a valuable alternative for researchers and analysts of public policy. There are clear advantages in the use of the systemic approach and system dynamics in the analysis of public policies. Perhaps the most important is that it allows different public policy alternatives to be analyzed systematically and without the need for actual experiments or their full introduction into the reality being analyzed. In addition to explaining their theoretical and conceptual grounding, this paper proposes a series of steps for the application of system dynamics to the analysis of public policies (see Figure 11).

FIGURE 11. APPLICATION OF SYSTEM DYNAMICS TO THE ANALYSIS OF PUBLIC POLICY



Source: Author.

To end, here is a brief example of how these steps may be followed in the case of a public policy in Mexico. We will look at a case that requires the analysis of the problem of basic education and its possible alternatives in terms of public policy. First, the problem would need to be defined in dynamic terms; in other words, as changes in a variable over time. We could define the problem as a constant decrease in the quality of education in terms of Mexico's standardized exam scores when compared to different countries throughout the world that also participate in this exam. Second, a simulation model would be developed that includes all the variables considered relevant in an attempt to replicate the actual behavior of the target variable, in this case the decrease in the quality of education. Third, the model would be evaluated through systematic comparison with real data. In other words, if real data says that the number of children per classroom has increased over the last 10 years, the model must represent the same reality. This process must be followed for all variables for which there is real data. The fourth step would consist of exploring the different policy scenarios, which is done by changing the value of the variables that represent certain government interventions into the phenomenon studied, quality in education. For example, if it is thought that increased training among teachers or a reduction in the number of children per classroom would have an effect on the quality of education, the scenarios can be explored in the model by making these changes and evaluating their impact on the increase or decrease in the quality of education. Lastly, based on the exploratory results of the different public policy scenarios, recommendations can be made in terms of which variables or combination of variables should be included in a more effective public policy or strategy. Obviously the actual effectiveness of the policy cannot be fully guaranteed, but the systematic process through which recommendations were made increases the probabilities of actual improvement in the problem studied and, therefore, success of the new public policy

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