System Dynamics, Systems Thinking, and Soft OR

Jay W. Forrester
Germeshausen Professor Emeritus
and Senior Lecturer
Sloan School of Management
Massachusetts Institute of Technology
Cambridge, MA, 02139, USA
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Abstract: System dynamics, systems thinking, and soft operations research (soft OR) all aspire to understanding and improvement of systems. In all, the first step interprets the real world into a description used in following stages. In system dynamics, description leads to equations of a model, simulation to understand dynamic behavior, evaluation of alternative policies, education and choice of a better policy, and implementation. Case studies, systems thinking, and soft OR usually lack the discipline of explicit model creation and simulation and so rely on subjective use of unreliable intuition for evaluating the complex structures that emerge from the initial description of the real system. Nevertheless, systems thinking and soft OR, with emphasis on eliciting information from real-world participants, should contribute useful insights to system dynamics. Conversely, the model creation and simulation stages of system dynamics should contribute rigor and clarity to systems thinking and soft OR.

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This paper discusses “systems thinking” and “soft operations research” (soft OR) as related to system dynamics. The next section briefly presents a system dynamics context within which to consider systems thinking and soft OR.

System dynamics

System dynamics is growing at an impressive exponential rate. Interest in system dynamics is spreading as people appreciate its unique ability to represent the real world. It can accept the complexity, nonlinearity, and feedback loop structures that are inherent in social and physical systems.

On the other hand, several difficult steps in moving from problem to solution hamper system dynamics. First, and probably most elusive, little guidance exists for converting a real-life situation into a simulation model. At later stages, many system dynamics projects have fallen short of their potential because of failure to gain the understanding and support necessary for implementation. Systems thinking and soft operations research may help organize and guide group processes that must occur when system dynamics interfaces with people in the actual systems.

Figure 1 illustrates the system dynamics process. An investigation starts at Step 1, motivated by undesirable system behavior that is to be understood and corrected. Understanding comes first, but the goal is improvement. System dynamics appeals to activists. It is undertaken for a purpose. At the first step, on the left in the diagram, the relevant system must be described and a hypothesis (theory) generated for how the system is creating the troubling behavior.

Step 2 begins formulation of a simulation model. The system description is translated into the level and rate equations of a system dynamics model. Creating the simulation model requires that the rather general and incomplete description of Step 1 be made explicit. As with every step, active recycling occurs back to prior steps. In Step 2, writing equations reveals gaps and inconsistencies that must be remedied in the prior description.

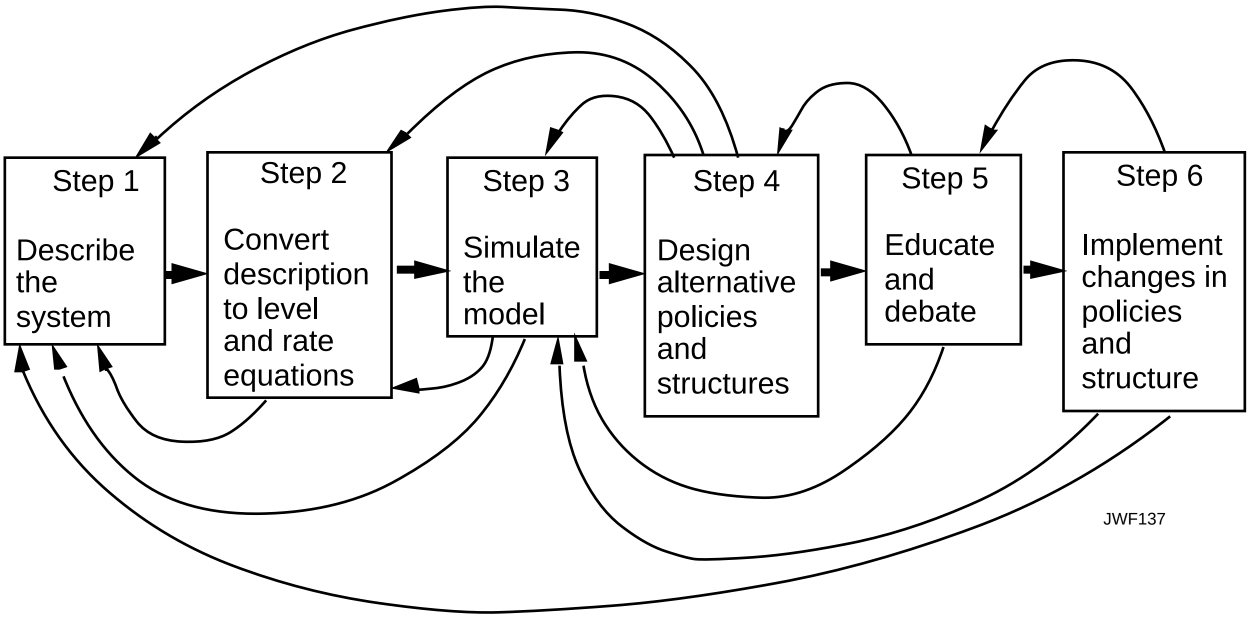

Figure 1. System dynamics steps from problem symptoms to improvement.

Step 3, simulation of the model, can start after the equations of Step 2 pass the logical criteria of an operable model, such as all variables being defined, none defined more than once, no simultaneous equations, and consistent units of measure. System dynamics software packages provide such logical checks. Simulation may at first exhibit unrealistic behavior. As a result, simulation leads back to the problem description and to refinement of the equations. Step 3 should conform to an important element of good system dynamics practice; the simulation should show how the difficulty under consideration is being generated in the real system. Unlike methodologies that focus only on an ideal future condition for a system, system dynamics should reveal the way we arrived at the present and then, in a later step, the path that leads to improvement. The first simulations at Step 3 will raise questions that cause repeated returns to Steps 1 and 2 until the model becomes adequate for the purpose under consideration. Note that “adequacy” does not mean proof of validity. There is no way to prove validity of a theory that purports to represent behavior in the real world.[1] One can achieve only a degree of confidence in a model that is a compromise between adequacy and the time and cost of further improvement. The proper basis of comparison lies between the simulation model and the model that would otherwise be used. That competitive model is almost always the mental model in the heads of the people operating in the real system. A system dynamics model creates so much more clarity and unity, compared to prior mental models, that the “adequacy” decision usually generates

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[1] There are no proofs for any of the laws of physics, only practical confidence that the laws are useful within a bounded region. (Forrester, 1961), Chapter 13, and (Forrester and Senge, 1980).

little controversy among real-world operators who are under time and budget pressures to achieve improved performance. However, being noncontroversial does not mean acceptance in Steps 5 and 6.

Step 4 identifies policy alternatives for testing. Simulation tests determine which policies show the greatest promise. The alternatives may come from intuitive insights generated during the first three stages, from experience of the analyst, from proposals advanced by people in the operating system, or by an exhaustive automatic testing of parameter changes. I expect that system dynamics will continue to rest on experience, art, and skill for imagining the most creative and powerful policy alternatives. Automatic parameter searching will be of limited usefulness. In the more complex systems, there will be many competing criteria for defining success; also, there will be many peaks in the multi-dimensional behavior map so that the most favorable performance may depend on several simultaneous changes in the model. In addition, the best alternative behaviors will often come from changing the system structure.

Step 5 works toward a consensus for implementation. Step 5 presents the greatest challenge to leadership and coordinating skills. No matter how many people have participated in Steps 1 through 4, many others will become involved in ultimate implementation. The model will show how the system is causing the troubles that are being encountered. Almost always, the reasons will lie in policies that people know they are following and which they believe will lead to solutions to the troubles. Implementation often involves reversing deeply embedded policies and strongly held emotional beliefs. It is not that people disagree with the goals, but rather how to achieve them. Even with widespread intellectual agreement with a system dynamics model and with the recommended improved policies, there may still be great discomfort with the prospect of changing from traditional actions.[2] To overcome both active and passive resistance requires sufficient duration and intensity of education and debate to reverse traditional practices. Questions will arise that require repeated recycling through Steps 1 through 5.

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[2] I participated in a major system dynamics project that arose because the company was losing market share and was experiencing high instability of production rate and employment. The model represented interactions among company internal functions and between the company and its customers and competitors. No one in the company differed with the assumptions in the model, or with the reason for falling market share and production instability as demonstrated by the model, or with the logic of the proposed alternative policies. However, a powerful deterrent stood in the way of implementation. The recommended policies were the reverse of those that three generations of top management had made public speeches about as the basis for their success (and the company had been successful). The three prior generations of management were all alive, in the community, stockholders, and on the board of directors. Such an environment inhibits unconventional action.

Step 6 implements the new policies. Difficulties at Step 6 will arise mostly from deficiencies in one of the prior steps. If the model is relevant and persuasive, and if education in Step 5 has been sufficient, then Step 6 can progress smoothly. Even so, implementation may take a very long time. Old policies must be rooted out. New policies will require creation of new information sources and training.

Evaluation of the policy changes comes after implementation. As with determining model adequacy, evaluation has no clear procedures, nor can one expect a conclusive outcome. While the new policies are being implemented and used, a process that can take several years, many other changes will have occurred in the system and its environment. Even when performance is unambiguously better, some people will claim that credit should go to changes, other than the new policies, that occurred during the system dynamics project. The evaluation may even rest on results other than those for which the project was undertaken. I recall a senior corporate officer who said, after a major system dynamics program had been operating in the company, “I can’t prove that it has made any difference on the profit and loss statement, but I know that we have a better understanding of what is happening and more confidence in what we are doing.” Evaluation will remain subjective. The weight of evidence will accumulate as system dynamics becomes the common thread through an accumulating sequence of successes.

Systems thinking and soft OR

Systems thinking and soft operations research (soft OR) fit, along with case studies and the conceptualization phase of system dynamics, into Step 1 of Figure 1 as expanded in Figure 2.

The first three in Figure 2—case studies, soft OR, and systems thinking—all tend to be soft approaches. The soft procedures, although they employ various organizational and presentation techniques, still depend on discussion and intuition. By definition, the soft methodologies operate without a rigorous quantitative foundation.

The conceptualization phase of system dynamics has much in common with the soft methodologies but system dynamics is disciplined by an organizing framework that leads to model formulation and simulation.

Step 1
Describe the system
Procedures:
Case studies
Soft operations research
Systems thinking
System dynamics,
conceptulization phase
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Figure 2. Approaches to identifying relevant elements of a system.

Case studies

Case studies have served for decades in analyzing business systems. The case-study approach has remained popular because it couples directly to the real world and addresses critical corporate issues. Case studies organize information from the tremendous mental database of participants.

Case studies depend on observation, discussion, and debate. In Figure 1, case studies, having no quantitative foundation, must jump from Step 1 to Step 4. Case studies lack a discipline for making the statements of Step 1 explicit as in the equation writing of Step 2. Case studies can not test the dynamic adequacy of the theory created in Step 1 because they lack the simulation of Step 3.

Case studies suffer from their dependence on intuitive judgment for policy analysis. A case-study description will usually imply a high-order, nonlinear feedback system. No one can reliably anticipate the behavior of such a system. The case-study approach may correctly identify structure and policies in the system under consideration, but then draw incorrect dynamic conclusions.

Many years ago, several hundred people attended a major anniversary celebration at the Harvard Business School. The program included a demonstration of the case-study method for which participants divided into classrooms of some 50 people each. The written description of the case had been distributed in advance. The group that I observed correctly identified the issues, structure, and relevant policies in the situation. The discussion progressed to recommendations for improvement. As it happened, the case was one for which we had done a system dynamics model and had tested alternative policies. The policy recommendations of the case-study group were wrong and entirely inconsistent with the system description as formulated at the beginning of the case discussion. Most misbehavior of corporate, social, and governmental systems arises from just this dependence on erroneous intuitive solutions to complex behavior.

Soft operations research

Before discussing soft OR in the context of system dynamics, the applications of soft OR should be divided between static and dynamic tasks. Some problems are intrinsically static. For example, making a choice between two routes for a proposed highway may involve only compromising between the proponents of the opposing views. In this discussion, I am not considering the possible static applications of soft OR. Instead, the comments here consider soft OR in the domain of dynamic situations.

Soft OR has evolved during the last several years as a reaction against the inability of classical or “hard” operations research to deal with the major issues of interest to managers and political leaders. Practitioners of soft OR attribute ineffectiveness of hard OR to various reasons. They feel that fundamental differences between physical and social systems prevent rigorous analysis, or that complexity of managerial and social systems excludes quantitative analysis, or that the human element precludes effective modeling, or that multiple criteria for desirable behavior prevent specifying objective measures of system performance.

On the contrary, I believe ineffectiveness of hard OR arose, not from differences between physical and social systems, but from two aspects of the operations research practice. First, hard OR drifted into the adoption of inappropriate mathematical methods—linear programming, queuing theory, regression analysis, scheduling algorithms, and Monte Carlo simulation. These mathematical procedures are all essentially static and linear in character and are not able to capture the dynamic nature of important processes in the real world. Second, hard OR became an academic discipline rather than a practical profession. In its academic setting, hard OR drifted toward continued refinement of the very theories that kept it from engaging the real world. There is a similar danger to system dynamics; academic research tends toward small technical challenges rather than engaging the major concerns of the larger society.

Having given up the mathematical modeling part of hard OR, soft OR concentrates on defining the situation, resolving conflicting viewpoints, and coming to a consensus about future action. As such, soft OR is fundamentally similar to the case-study method of analyzing business and social systems. The various practitioners of soft OR go beyond case studies by suggesting formal procedures for eliciting and organizing the system description in Step 1.

The soft OR literature does not reveal the counterpart of Steps 2 and 3 in Figure 1. There is no explicit language as at Step 2 for revealing incompleteness and contradictions in the description of Step 1. There is no generally accepted simulation process for testing the dynamic assertions that come out of group discussions. This means that soft OR is inherently vulnerable to the same fallacies that plague management and political practice in the real world.

I find a curious ambivalence in the soft OR literature about the nature of systems. In *Soft Systems Methodology in Action* (Checkland and Scholes, 1990), we find a denial that "systems" exist in real life, and an assertion that systems are only in the eye of the beholder, "Choosing to think about the world as if it were a system can be helpful. But this is a very different stance from arguing that the world *is* a system." (emphasis in the original, p. 22). Seeing "systems" as a construct for analysis but not as the nature of the real world probably arises from lack of a framework for analysis that is congruent with reality. In system dynamics, we have a set of principles (Forrester, 1968), incomplete as they may be, that I believe do represent the actual nature of physical and social reality.

Soft OR people resist being drawn into clear and unambiguous descriptions of problem situations as indicated in Jackson (1991):

> "…systems thinkers were using systems ideas in a much more applied fashion to develop methodologies for problem solving in real-world problem situations.… the work…gave birth…to hard systems thinking.… Checkland originally included in this category only systems engineering and systems analysis…we can add…operational research (insofar as it embraces systems ideas at all), decision science, and management cybernetics…All these share the basic orientation, identified by Checkland (1978), as 'the assumption that the problem task they tackle is to select an efficient means of achieving a known and defined end.'" (p. 73)
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> "…system dynamics…found a great range of applications, from the study of industrial to urban to world dynamics.…the world system was studied as depending on interactions among demographic, industrial, and agricultural subsystems…Using system dynamics models, decision makers can experiment with possible changes to variables to see what effect this has on overall system behavior. Forrester's modeling techniques have tended to be used in conjunction with essentially hard systems methodologies, and I shall not discuss them further." (p. 93)

In the above quote, Jackson fails to see the close relationship between system dynamics and soft OR in Steps 1, 4, 5, and 6 of Figure 1. System dynamics shares all the steps within soft OR practice, and in addition inserts Steps 2 and 3 that give an explicit and rigorous foundation that dispels much of the weakness inherent in the subjective aspects of soft OR.

In his excellent comparison of system dynamics and soft OR, Lane (1993) distinguishes hard and soft OR, “Hard OR assumes implicitly that it is practitioner-independent and that the problem is defined, the organisational objective clear and known, before technical analysis starts. In contrast, soft OR is consciously contingent, or requisite; involving models tailored for the individuals concerned in each specific project.” System dynamics fits the latter part of this description much better than the first part.

The writers in soft OR try to classify systems in such dimensions as physical vs. social, degree of complexity, susceptibility to control, area of application, causal vs. probabilistic, and degree of openness (Jackson and Keys, 1984). I find such classifications misleading compared to the system dynamics paradigm that recognizes all systems as having the same fundamental structure of levels and rates (accumulations and flows) structured into feedback loops that cause all changes through time.

Soft OR practitioners criticize hard OR for dependence on a single criterion for system evaluation. That need be true only when one uses optimizing mathematics that requires a utility function. In system dynamics modeling, criteria for accepting a proposed policy will usually depend on multiple measures of behavior. For example, in a business problem, one must balance the effect of a policy change on market share, profitability, inventory investment, stability of employment, available finances, and long-run vs. short-run results. In evaluating criteria one seldom encounters a zero-sum game. There is a free lunch. Most systems operate so badly that one can initially expect to find policies that improve some or most measures of performance without degrading others.[3]

Systems Thinking

“Systems thinking” has no clear definition or usage. The systems thinking terminology is applied to the field of soft OR as in *Systems Thinking, Systems Practice* (Checkland, 1981). Some use systems thinking to mean the same as system dynamics. In the United States systems thinking is coming to mean an activity that has gathered momentum on the periphery of system dynamics.[4] Here I discuss the form of systems thinking that is emerging in the United States.

“Systems thinking” is coming to mean little more than thinking about systems, talking about systems, and acknowledging that systems are important. In

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[3] See *Industrial Dynamics* (Forrester, 1961), Section 18.6 where new policies simultaneously reduce fluctuations of employment, inventories, and cash.

[4] In November 1993, some 900 people attended the “Systems Thinking in Action” conference in Boston sponsored by Pegasus Communications.

other words, systems thinking implies a rather general and superficial awareness of systems.

Systems thinking is in danger of becoming one more of those management fads that come and go. The term is being adopted by consultants in the organization and motivation fields who have no background in a rigorous systems discipline.

There are three possible consequences of systems thinking—two constructive, the third detrimental:

- Systems thinking can usefully provide a general public introduction to the existence and the importance of systems. An analogy is popular writing about medical diseases and treatments as found in the newspapers. Such articles alert people to possible illnesses and motivate them to seek advice from a medical doctor. However, the popularized medical articles should not be a basis for self diagnosis and treatment. Likewise, systems thinking can alert the public to systems as the cause of puzzling pathologies in business and social activities, but the wise person will not use such superficial knowledge as a basis for corrective action.

- Systems thinking can serve a constructive role as a door opener to system dynamics and to serious work toward understanding systems. If systems thinking leads to a deeper understanding through system dynamics, then the result will be positive.

- On the other hand, unquestioning and superficial enthusiasm for systems thinking may lead some people into trouble. Some people attain enough revealing insights from systems thinking that they feel the need for nothing else. Such people are in danger of finding that systems thinking does not help in solving their problems, or worse, that they take ill advised actions that make matters worse. Seeing no difference between systems thinking and system dynamics, they may then conclude that system dynamics is at fault. Where the consequence of systems thinking leads to a negative reaction against system dynamics, the result will be detrimental.

Much of systems thinking uses causal loops—diagrams that connect variables without distinguishing levels (integrations or stocks) from rates (flows or activity). Causal loops do not provide the discipline to thinking imposed by level and rate diagrams in system dynamics. Lacking the identification of level variables, causal loops fail to identify the system elements that produce dynamic behavior.

I do not use causal loops as the beginning point for model conceptualization. Instead, I start from identifying the system levels and later develop the flow rates that cause those levels to change. Sometimes I use causal loops for explanation after a model has been created and studied. For a brief over-all presentation to people who will not be trying to understand the real sources of dynamic behavior, causal loops can be a useful vehicle for creating a general overall impression of the subject.

One finds this after-the-fact use of causal loops in the very popular *The Fifth Discipline* (Senge, 1990). The book presents causal loops of various management situations. The reader may erroneously get the impression that one can look at real life, draw a causal loop diagram, and then carry through a penetrating description of dynamic behavior. Such a misleading assumption can occur if the reader fails to realize that the system archetypes and behavioral descriptions in the book are drawn, not from the causal loops, but from full system dynamics simulation models that had already been extensively explored by many different people.

System dynamics, conceptualization phase—theory creation

Step 1 in Figure 1, “Describe the system,” is the most important and the least straight forward of the stages in system improvement. Step 1 describes a model of the real system. A model is a theory of behavior. A model represents the way in which some part of the real system works. Model formulation belongs to the class of activities that include theory creation and invention. The process of taking various bits of information about the real world and turning them into a coherent and unifying theory can range in difficulty from trivial to most challenging.

The system dynamics literature offers multitudes of papers describing particular models (theories), but those papers reveal little about how the theories came into being. System dynamics is not alone in lacking objective processes for model conceptualization. There are no rules in soft OR that assure description of a successful model, only procedures for eliciting and displaying information that may be helpful in visualizing a model. There is no description showing how to create a theory that will win a Nobel Prize in physics. There are no rules that guarantee designing the best automobile. However, some people are better prepared than others. Inventing a theory (model) comes most easily to the prepared mind that is operating within a relevant framework.

A relevant structural framework disciplines thinking. Only if the modeling framework coincides with that of the real system can there be a natural flow of real-world information into the model. Herein lies the strength of system dynamics. I believe that the level-rate-feedback structure in system dynamics is indeed the fundamental and universal structure of real social and physical systems.

The system dynamics paradigm calls for causally-closed models (Richardson, 1991). The literature in the social sciences reveals different definitions of “open” and “closed” systems. In system dynamics, a causally-closed system is one in which the causes creating the behavior of interest lie within the system. A causally-closed system still is open in the sense that it can receive material, energy, random disturbances, and test inputs from outside the boundary. Requiring that the system boundary be drawn to include the causes of the relevant dynamic behavior means that one must seek the generating causes in conceptualizing a model of the system. Until one understands the dynamic cause of present undesirable conditions, one is not prepared to explore moving from present conditions to more desirable conditions.

The conceptualization phase in system dynamics has rested heavily on past modeling experience gained from working with “canned” models, from apprenticeship in working with experienced modelers, and from trial-and error learning. Some literature offers guidance to the conceptualizing process (Forrester, 1961; Randers, 1980; Forrester, 1980; Forrester, 1987; Vennix, et al., 1992; Hodgson, 1992; Saeed, 1992; Richardson, et al., 1992; Winch, 1993). Although there is a growing literature in system dynamics in model conceptualization, the process must still be baffling to those who are new to the subject. Provocative and potentially useful ideas exist in the soft OR field, but these need to be interpreted for possible contribution to the system dynamics sequence of Figure 1 wherein the conceptualization must be guided toward the equation writing and simulation in Steps 2 and 3. There is still much room for very constructive research on the process of converting information from the real world into system dynamics simulation models.

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