To Main Proceedings Document

System Dynamics Applied To Psychological and Social Problems

Ralph L. Levine
Department of Psychology and
Department of Resource Development
Michigan State University
East Lansing, MI 48824, USA
1-517-332-2317
leviner@pilot.msu.edu

ABSTRACT

Originally, system dynamics dealt with problems in manufacturing, management, resource use, and in urban problems. With notable exceptions, there are very few applications of system dynamics to psychological problems, per se, or the use of psychological variables in models which focus on management problems. Some psychologists have influenced the system dynamics, but their contribution has focused upon studying the process of systems thinking, cognitive maps, and the limitations of people dealing with feedback processes.

Unfortunately, one rarely finds psychologists who are interested in and are competent in system dynamics. This paper suggests ways to include the use of psychological and social variables in specifying the structure of one's model. It examines the underlying assumptions of system dynamics, such as the use of the bathtub metaphor. For modeling problems of attitudes, it is argued that the bathtub metaphor, which assumes potential conservation of material, may not be appropriate. On the other hand, emotional variables, such as anger, do display properties that are analogous to a draining process. I also suggest overt behavior (such as fighting) should be represented differently from inner psychological states. Thus, you can be angry without showing it. Also, I note the potential incompatibility between the trajectories of the SD model and the empirical time series, if the data (such as self-esteem level or level of depression) were measured on an interval scale. Finally, the paper will integrate personality and individual difference psychology into a system dynamics framework.

INTRODUCTON

Although system dynamics has been existence for a number of years, its influence on the social sciences has been somewhat spotty, i.e., it has strongly affected management and economics, but perhaps not sociology, political science, and psychology. The modeling aspects of system dynamics has not attracted psychologists to it fold. On the other hand, much of the work on systems thinking, cognitive maps, and mental models have attracted the attention of experimental psychologists and others, who are interested in studying these processes in a rigorous manner (Kleinmutz, 1993; Doyle, 1997; Doyle and Ford, 1998).

Unfortunately, there is little interest in utilizing the powerful computer modeling techniques which are one of the major characteristics and strong points of system dynamics. In addition, there is little appreciation of feedback concepts in academic psychological research. In the author's opinion, researchers in psychology and related fields are just beginning to inquire about feedback. Unfortunately, there are few people in the field who have a background and knowledge of feedback theory. Psychology graduate students, who generally do not have an extensive background in mathematics, have very few places to go to get this type of information.

There may be many reasons for this. First, psychologists frequently design studies which generate cross-section data rather than longitudinal, time series data. Second, although there is a long tradition of the application of rigorous experimental methodology to studying psychological processes, the vary use of this method can lead researchers to use open loop thinking (Richardson and Pugh, 1981) about psychological processes. The predominant strategy is to assume one-way causation, from stimulus to response. This viewpoint shows up in a number of places in the psychological literature, especially in terms of how data are handled. In the areas of social psychology and cognitive psychology, for example, it is very common to find the use of analysis of variance and multiple regression approaches to handling and interpreting data. Even at the next level of statistical sophistication, using path and structural equation models to represent psychological processes, the predominate approach is to represent causation in only one direction. One-way models are called "recursive models. Only on occasion will one find a nonrecursive model in the psychological literature, and even then, the model only has at most one or two loops in it (see Levine, 1992).

GOALS OF THE PAPER

The purpose of this paper is to (1) briefly discuss some of the reasons why academic psychologists have resisted the use system dynamics methods in their work, (2) describe some techniques which were found to be useful in modeling psychological and social processe, and (3) to discuss some technical problems with assessing the validity of system dynamic models when the original time series data are measured by traditional psychological scales.

Why Psychologists Have Resisted Learning System Dynamics: A Personal Note

To illustrate some of the difficulties system dynamicists might have working getting psychologists interested in SD, let me briefly describe two personal experiences the I had collaborating with my fellow colleagues over the years on modeling interesting processes. The first illustration was quite negative. Many years ago, the trend in engineer education was to emphasize the role of the engineering in the design of new technology. Engineers had always played an important role in orchestrating the manufacturing process, but this area of engineering had gone out of favor at that time. It had much less prestige than other engineering fields. This was a problem, and I began to work with my fellow psychologist, who was knowledgeable and interested in this area, on the dynamics of this problem.

I proposed to build a model of this problem as the first step in our joint work together. Before building the model, I presented him with a causal loop diagram of several key loops which were part of my dynamic hypotheses. To may surprise, my colleague was completely turned off and rebuffed by my diagram. He had a visceral reaction to it. For him, there were too many variables, too many arrows, and too many untested, "speculative" assumptions. It seems that his way of working was to very carefully state one or two one-way hypothetical statements about a set causal relationships and then empirically test those hypotheses by using statistical tools, such as hierarchical regression to see if there was a significant relationship between cause and effect. He was used to a time consuming, slow, methodical , and painful process of proving every causal statement from collected data. The thought to dealing with my four loops boggled his mind. It was definitely cognitive overload, and he, as a researcher would have none of it.

Perhaps this situation generalizes to many social sciences. There is a tendency to be very bound by data. Moreover, there is an over reliance on statistical procedures to establish reasonable and eventually falsifiable causal hypotheses based on experience, intuition, and the literature. Finally, because there is so much emphasis on unidirectional approaches to thinking about processes, psychologists are very unfamiliar with how to handle dynamics in general and feedback particularly.

In this case, my colleague and I parted company. However, here is a second example of a similar situation where a future collaboration effort is much more probable and hopefully less painful. In this case, I am working with a group of faculty members from several departments who are interested in some of the problems neighborhood associations have in retaining active members, who continue to participate in projects and neighborhood activities. This topic has been researched in the past (e.g., Chavis, 1991; Florin, et al, 1992), but there are few if any studies which actually modeled the dynamics of participation. We are seeking funds to do some outreach research with a number of neighborhood associations around the state, especially in inner city areas. I am proposing to model the problem of low participation rates. Other colleagues wants to research the question about relationship between participation and a sense of community. They feel that there may be a reciprocal relationship between the two variables and propose a panel study at two time points of test if participation affects one's sense of community and a sense of community affects participation rates. They further propose performing this test of reciprocity by "correlational analysis," which presumably implies using either a path analysis or a structural equation model to test reciprocity.

My reaction to this is quite favorable. As a system dynamicists, I see the presence of feedback all over the place. I have no problem seeing the possibility that an increase in participation leads eventually to actions which might make people have a greater sense of community. As a sense of community goes up, with time they will be motivated to participate even more in the neighborhood activities and projects.

My colleagues are almost there. They are open to the possibility of feedback in this situation. Again they want to put a lot of emphasis on testing this hypothesis using a statistical tool as the sole criterion of the validity of the dynamic hypothesis. However, the manner they propose to test reciprocity is fraught with danger. Recently I and my students have been interested in comparing system dynamic techniques with structural equation and pathanalytic models, which are frequently used by psychologists. We have found that these statistical techniques do not capture nonlinear processes very well. Unfortunately, they appear to validate incorrectly specified models and reject models which actually capture the true dynamics (Hovmand et al, 2000).

At this juncture, I am optimistic that I will be able to work with my potential collaborators, and more importantly, they with me. This time, instead to shoving the collective set of hypothesized loop processes into their faces, I am going to spend a lot of time building “social capital” by slowly discussing the topics of dynamics, feedback, and how to enter into the model validation process. My colleagues have a lot to offer, but we have to get to know and trust each other to be good collaborators.

Finally, a point should be made about this section of the paper. The problem of resistance to system dynamics by psychologists has evolved over time, and I would like to point out that thus far I have not model these dynamics. This would be more interesting and insightful. It reminds me of the eventual interest in modeling the growth (or lack of it) of the System Dynamics Society itself. Eventually we got around to modeling this process.

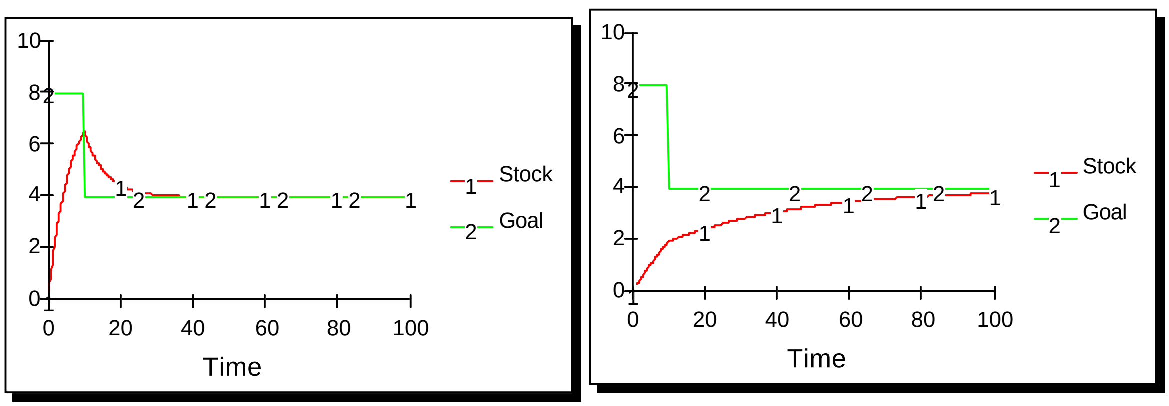
MODELING SOCIAL AND PSYCHOLOGICAL PROCESSES

Some psychologists, such as the author, have been interested in applying system dynamic modeling techniques to their work. There is much to do in this area. Several years ago, the author became interested in gathering and disseminating information about technical aspects of system dynamics particularly for psychologists and related fields (Levine, et al 1992a, 1992b, 1992c). The present paper will focus on some issues which deal with modeling psychological processes per se or combining those processes with more traditional management processes, such as marketing, manufacturing, or resource use. It should be noted that some of the points made about modeling are very general and known to people who have been in system dynamics for a long period of time. However, there are some aspects of modeling psychological variables which are perhaps somewhat different from modeling many other processes.

Keeping things on a level. One of the first problems one runs into in modeling psychological processes deals with whether one should define the psychological variable as a stock variable. For example, if a person fails to meet a target number of sales per month, works harder and then becomes discouraged and depressed, we know that one could designate the number of completed tasks as a level variable, but what about being discouraged or depressed. Should we define depression as a state variable or as an auxiliary? The obvious answer is whether one conceives of depression as something which cumulates over the time horizon of the study. If a variable accumulates, then most likely it should be considered as a state variable or stock. There are a lot of psychological variables which accumulate in some sense. Morale, interest, empowerment, social capital, trust, self-esteem, resentment, and long-term memory are just a few of the many psychological variables which cumulate over time, and thus can be modeled as levels in the system.

It is very important to differentiate conceptually between energy/material processes and information processes. Materials can be conserved, while information is not constrained. Thus, for example, a professor can give a lecture about system dynamics to a group of students without necessarily losing the information about SD. On the other hand, if the professor reached down into his pocket and gave a student a coin, the student would gain the coin and the professor would lose it. If the coin dropped out of the hand of the student, he or she would look for it on the floor. It has to go somewhere, because money is conserved.

Informational delays. When first learning system dynamics, the author was very impressed with the use of the basic negative loop process as a way to represent the way people take in information. The first principle is that it takes time to perceive one's world. Thus the basic negative loop represents this very important delay process. That is why one calls it a first order informational delay process. Also, as one translates the information from the outside, there is a tendency to smooth the input overtime, hence the name, "smooth" for this type of delay process. The amount of change observed in the smooth depends on the discrepancy between the "goal" and the present value of the informational stock. The goal is like a switch. If the value of the stock is below the goal, the change is in the positive direction. If, on the other hand, the value of the stock is above the goal, the change is in the negative direction.



A **B**

Figure 1. The response of a first order information delay when the goal changes direction. A – TimeConstant = 4, B – TimeConstant = 36

Even though the smooth is tracking the goal, it may or may not change direction when the goal itself changes direction. Again, the smooth can only change direction when the error (Goal – Information Stock) changes direction. This principle can be seen in Figure 1. The goal was changed midstream from a value of 8 units to 4 units at time 10. In panel 1-A, the time constant was set at 4 time units, relatively fast, so that the stock variable had already past 4 by the time it got to the tenth time unit. So, when the goal changed from 8 to 4, the error term was negative, and thus the stock changed directions. On the other hand, in panel 1-B, we set the time constant to 36 time units, which means the individual is taking much more time perceiving the goal. Under those conditions, the error term at time 10 continued to be positive, because the value of the informational stock is below 4.0. Thus, the stock continued to increase, although more slowly to its new asymptote

Material delays. Another type of delay process deals with the accumulation of material, people, and other entities, such as money, etc. A simple version of the first order material delay looks like this (see Figure 2).

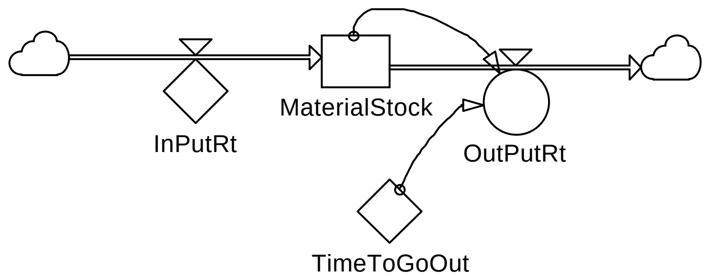


Figure 2. A stock and flow diagram of a first order material delay

In this situation, there are two separate and distinct rate variables, one for the input and one for the output from the stock. Presumably, the stock itself is filled with materials, like widgets, cars, empty bottle, water, etc. Again, we are now dealing with conserved processes. Note that the input rate variable is free of a self-loop, or compound process. In this version, the value of the input rate is constant. On the other hand, the output rate is a draining process, because the rate of change in the material stock is a function of itself.

The behavior of the first order material delay under most circumstances is the same as the behavior of the smooth. It looks logarithmic in both cases. However, under some conditions, they can generate different behavior. For example, suppose both the material and information delay are in equilibrium and then the time constant associated with the outrate for the material delay and the rate of change for the information delay are increased or decrease by x number of units. The material delay, having "stuff" in it, will adjust to the new conditions by moving either up or down to a new equilibrium. On the other hand, the smooth, when in equilibrium, has a zero error. Since the rate equation for the smooth is error/time, changing the time in the denominator of the ratio will not affect the rate, because one is dividing any number into zero, which always equals zero. Thus, once the smooth reaches equilibrium, a change in the time constant has no effect on the level.

Limitations of the smooth. The first order information delay is a very useful tool for modeling perception of outside stimuli. On the other hand, it lack the details which might be necessary for specifying the dynamics of a psychological process. For example, many behavioral levels and emotions take a lot of work to to change. There is a natural tendency to slip back over time. This implies that a draining process might represent that natural erosion of the value of a psychological process. Although one could use a draining process with the smooth, there may be some problems with that because of the steady state error one would get under those conditions. The author has come to use first order delays and similar structures a number of times for modeling psychological processes.

However, one has to be aware of some of the limitations due to the conservation aspects of material delays. Nevertheless, draining processes seem to be very necessary to modeling a lot of psychological processes. For example, the author modeled the dynamics of a family which was trying to deal with their child's diabetes. The mother was over-responsible in taking care of the child's routine and the father, denying the severity of the disease was under-responsible. The author built a model of these dynamics and included a variable called a "father's sense of responsibility" in the model. Treatment focused on increasing this variable through therapy. The author also knew that changes in a psychological variable like this one are hard to come by. It takes a lot of work to bring that up. Once it has reached a high level, it may erode over time if there are no intrinsic process constantly in place to sustain that level. Thus I included a draining process which slow had an effect on the father. After quantifying the model, we predicted that the father would gradually return to doing less and less for his son, and the mother would eventually perceive her husband's lack of responsibility. The model indicated qualitatively that sometime in the future the cycle of recrimination, burst of anger, and threat of divorce would start all over again without a second intervention by the therapists. Indeed, this was exactly what happened about six months after therapy was terminated. The family had to be brought back to deal with this crisis.

The Bathtub Metaphor

Once one begins to venture out of the territory of the first order information delay, the predominant analogy or metaphor used in system dynamics is the idea of filling a bathtub. Picture a bathtub. It gets filled by turning a faucet and gets emptied by opening a hole in the bottom of the tub. There is an input rate and an output rate. When they equal each other the water stays at the same level. One can manipulate both the input and the output independently. For example, you can open up the spigot and then open it up some more to make the water fill the bathtub faster. On the output end, theoretically one can change the size of the diameter of the hole on the bottom of the bathtub to speed up or to slow the draining process.

The level of water is the results of integrating both the input and output rates. All other things being equal, one can, let us say, increase the level of water by increasing the velocity of the water from the spigot or equivalently decreasing the diameter of the hole in the bottom of the tub. Both would work.

Problems with the metaphor. Usually, for material uses of the bathtub metaphor, one can conceptually separate operations which would enhance or impede the input and output rate. If you are manufacturing cars, one would know the difference between the operation of making cars to go into an inventory and selling cars which take them out of an inventory. The spigot and the hole in the bottom of the tub are very graphic and intuitively, the operations, such as turning the faucet, and pulling the plug are easy to grasp. On the other hand, for psychological, informational examples, it is hard to find conceptual handles to manipulate. For example, suppose one wants to model attitude change. It is not always clear, if an increase occurs, that the change was caused by increasing the input rate or by inhibiting the output rate. It becomes a real challenge to work with the bathtub metaphor for some social and psychological process.

The Bathtub Metaphor Revisited

It is suggested that one should not give up the bathtub metaphor altogether, because, with a little bit of reinterpreting, the benefits outweigh the costs of using it. There are many psychological constructs which are positive in nature. For example, one could model such things as empowerment, satisfaction, trust, reputation, and memory. These go in a positive direction. On the input end, one is trying to get higher values of empowerment, satisfaction, etc. On the output end, once empowerment is experienced or trust is built, then one would also like to find ways to maintain and sustain the lose of these entities. The operations and interventions used on the input and output end are clearly distinguishable. There is much similarity between the bathtub metaphor and distinguishing between enhancement of the input rate (turning the spigot clockwise) and retaining what one has by inhibiting loss (closing off the hole).

Thus, one can define one of these constructs as a level and then specify mechanisms for ways of enhancing the input rate and inhibiting the output rate.
For example, suppose a consultant wanted to build a model of the process of building trust the client and him or herself. Trust would most likely be one of the main stock variables this model. Perhaps the first thing one might include in specifying the loss of trust would be to include a draining process to account for the what might happen if client does not have the opportunity to work with the model or if the consultant waits too long between sessions with the company to keep interest in the modeling project going. Perhaps the client eventually would lose trust in the consultants work and in using the simulation model.

<u>Minor variation for pathology</u>. Many of the psychological processes in psychology which might be included in system dynamic models, deal with pathology and social problems. Thus, for example, we might find models including the following variables: Anger, resentment, delinquency, depression, compulsion, and conflict. On the input end, we would be anxious to inhibit getting angry, resentful, etc. That is the prevention side of things. On the output end, one focuses on lowering the existing level of anger, resentment, etc. That deals with doing something about the problem once it comes into existence. Although psychologists might have some problems applying the water metaphor to something like depression, it might be easy for them to know the difference between operations which prevent depression and operations, such as therapy or medical drugs to deal with a depressed person. This is the prevention and care metaphor.

<u>Summary of points of intervention</u>. In order to do well at modeling psychological processes, which are less concrete than money and widgets, it is suggested that one look at the operations and type of effort one could make in changing these constructs over time. .We would enhance the positive processes and inhibit the negative ones at the input end. On the other hand, we would inhibit the loss of positive processes and enhance or encourage the dissipation of things like anger, dishonesty, etc. Table 1 below focuses on the “good” determiners of input rates and on “good” determiners of output rates. These should be helpful in specifying rate equations.

Table 1. Concrete ways to differentiate between input and
Output rates with respect to what you can do with them.

	Positive Construct	Negative Construct
Input Rate	Enhancement Operations 1	Preventive Operation 2
Output Rate	Retention Operation 4	Care, Cure, And Enhancing Dissipation 3

Table 1 only shows ways to affect the rates which are to our advantage. Each of those cells could also contain operations which take the variable in a undesirable direction. For example, consider the construct of an organization's reputation in the business world. On the input side, the organization might make efforts to enhance their reputation through a variety of means, such as through marketing and service, etc. On the other hand, competitors would like to affect the output end of the reputation variable by perhaps putting out a negative campaign comparing their product with the company's product. Reputation is a positive construct in this context. The competition's operation is one of dissipating the company's reputation.

In attempting to stress operations on rates, it should be stressed that those operations may be embedded in one or more loop structures, especially in keeping with what was said earlier about some of the problems with open loop thinking.

The Role of Positive Loops in the Growth of Variables and The Limits To Growth

Let us get down to some concrete examples of modeling psychological processes. Suppose one were interested in anger, such as an anger of a group of people who feel that their government has slighted them in some way. We might start our model off by defining a stock as Group Anger. We know that anger grows and accumulates, so the next question is how do we specify the components of the growth rate of anger. Let's make the argument that anger feeds on itself, implying that the rate equation might include a compounding process which represents this positive self-loop mechanism.

The next thing one might want to think about is how anger might decrease over time, especially once the group gets angry. Let's focus on the output rates and put a draining process on our model to account for perhaps slow, spontaneous leakage of the intensity of the anger felt by the group.

On the input side, we have a compounding process and on the outside thus far we have drainage process. This certainly transforms our first order material delay into another molecule of structure, but by using the compounding process, we have captured the idea that anger feeds upon itself. Thus far our little model of group anger looks like this:

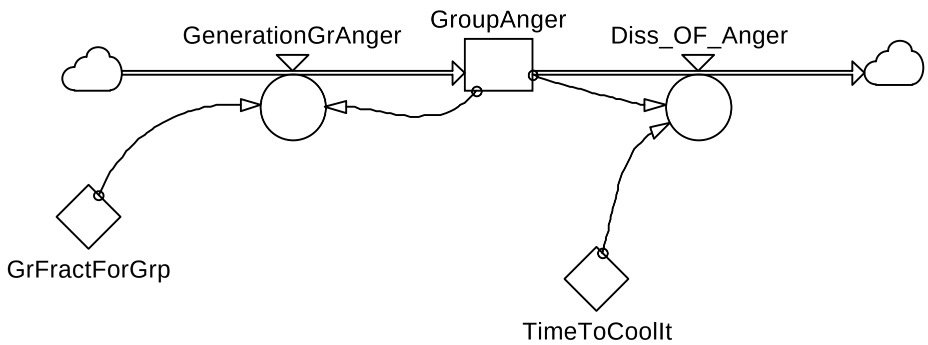


Figure 3. A simple model of the generation and dissipation of anger.

If the initial input rate, i.e. the rate variable GenerationGrAnger is faster than the output rate, i.e., Diss_Of_Anger, then the behavior of our little model of group anger will be dominated by the positive loop generated by the compounding process. It might look like this:

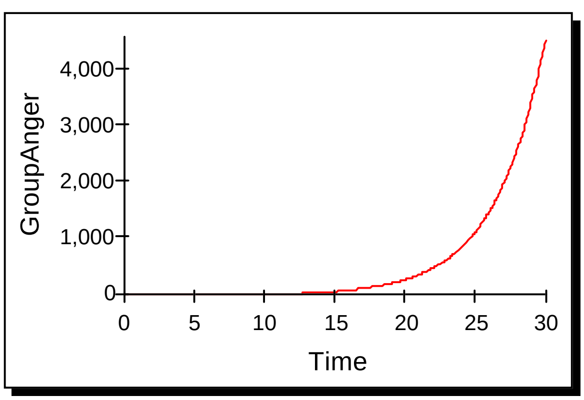


Figure 4. The output of a simple model of Generation and dissipation of group anger

As one can see, with these particular parameter values, the exponential growth pattern is explosive. Conceptually, anger can be very intense, but it does not go to infinity. If the intensity is high enough, then usually something happens. The person or group will do something, like leave the situation, strike out, start a war, etc. The point is that it seems reasonable to limit the top of the scale to some manageable value, and not have it potentially go to infinity. There are negative loop processes, which come into play, as anger and other variables like anger become intense. That is why, when psychologists measure traits, attitudes, etc.., they usually have the range of possible scores anchored on both ends.

The author likes to quantify psychological variables on a scale from a baseline of zero to a maximum value of 100. Quantifying a scale this way is convenient. It is like working with percentage points. For example, if one is working in the area of social capital, and modeling the role of trust in this situation, a value of 0.0 trust would mean no trust at all, and a value of 100 would imply unconditional trust.

Intense anger should lead to generate forces to limit upper ranges. The simplist thing to do is to define a table function which only comes into play at extreme values of anger. Figure 5 below shows one such table function.

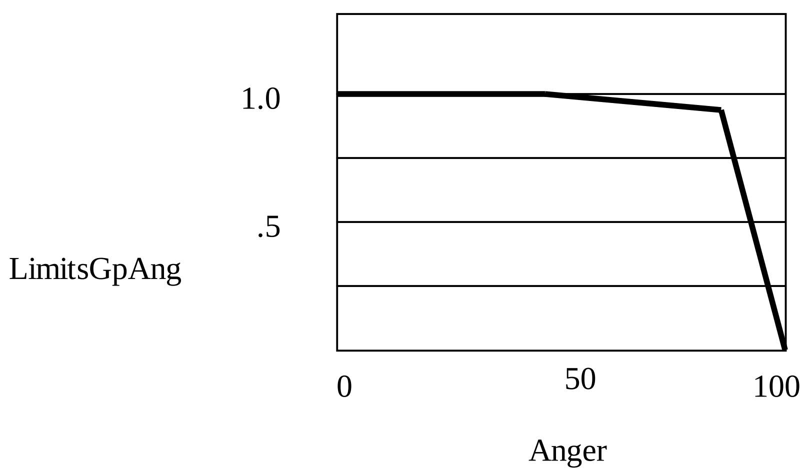


Figure 5. The multiplier used to limit the growth of anger

As one can see from this figure, the multiplier has very little influence across most of the range of anger, except for extremely high levels. Under most circumstances, one would not have to have such a device to "control" the upper bound of variable. Suitable parameterization might take care of this. However, the author believes that there are actual processes which dominate at extreme emotional values, so that this simple

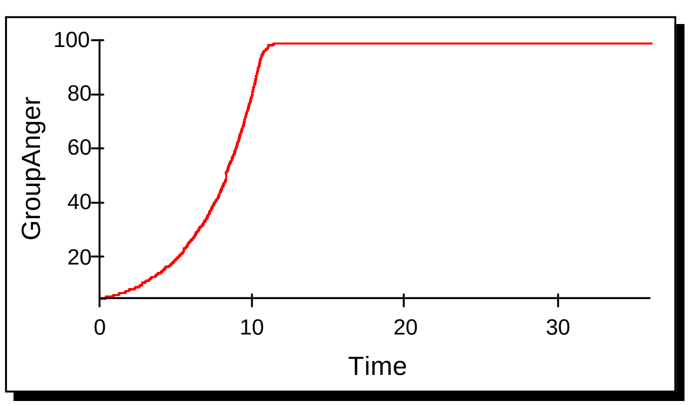


Figure 6. The output of a simple model of group anger when there are limits to growth

device has some substantive justification and me

External sources of anger. At this point, we have a s-shaped curve, where anger eventually saturates at extreme values. There are other internal mechanisms which can embellish this model and make it more realistic. For example, the drainage process really does not have much of a chance to decrease anger in this situation. It could take a very leading role if somehow the input end was shut off, but currently the model has no mechanism for this.

Given the scope of this paper, we shall consider this sector of the model is complete enough for illustrative purposes, so that we can move on to the influence of outside forces which are frequently important sources of anger. In this situation it is the persistent perceived negative treatment of this group by governmental institutions which is a source of anger for group members. The model assumes that the governmental agents, who have to deal with the group, react to the group's anger by persisting in harassing them. The more the group displays anger, the more they dislike them and do things to make the group more angry. So there is a positive loop between the two sectors, i.e. the governmental sector and the sector of the model associated with the group. The main level of the government sector is the government's dislike for the group.

Concerning the influence of the government on the generation of anger, since there is a compounding, self-loop included in the rate equation, one can still easily include this important source of anger in the form of a multiplier. Presumably, at low levels of the dislike for the group, the government does not spend much time harassing the group, but as the government agency begins to dislike the group, it will up its campaign against them. So, the model assumes that the multiplier starts out at a value of 1.0 and moves slow up to about 1.5, fifty percent higher as the intensity of their distaste for the group gets to be extreme.

The model also assumes a similar reaction of the agency to the anger expressed by the group. Extremely low levels of anger have little effect on generating dislike on the part of the governmental agency. However, we have assumed that the multiplier goes starts at 1.0 and goes up logarithmically to saturate at 1.5 when the group anger gets to be extreme. Under those conditions, the group has a profound effect on the governmental agency.

In addition, the model includes a drainage process on the agency's dislike variable. The notion of calling this variable the government's "dislike of the group" brings up a potential problem with some of the ways psychologists define their variables. The notion of "disliking" really is another form of having a negative attitude. In this model, disliking is quantified on a scale from 0 to 100. Actually, one could have used a scaled which could have gone from –100 to +100, zero being neutral, where the scale includes situations where the agency could like or dislike a given group. In SD, there is a general thought that levels should not have negative values. However, psychologist frequently work with attitudes as vectors, which have both magnitude and direction. Here is a case where negative values for levels make sense substantively. In any event, in this model we only worked with positive values. In other situations, it would be better to have one's stock variables included negative values.

The total model of simple group anger follows below:

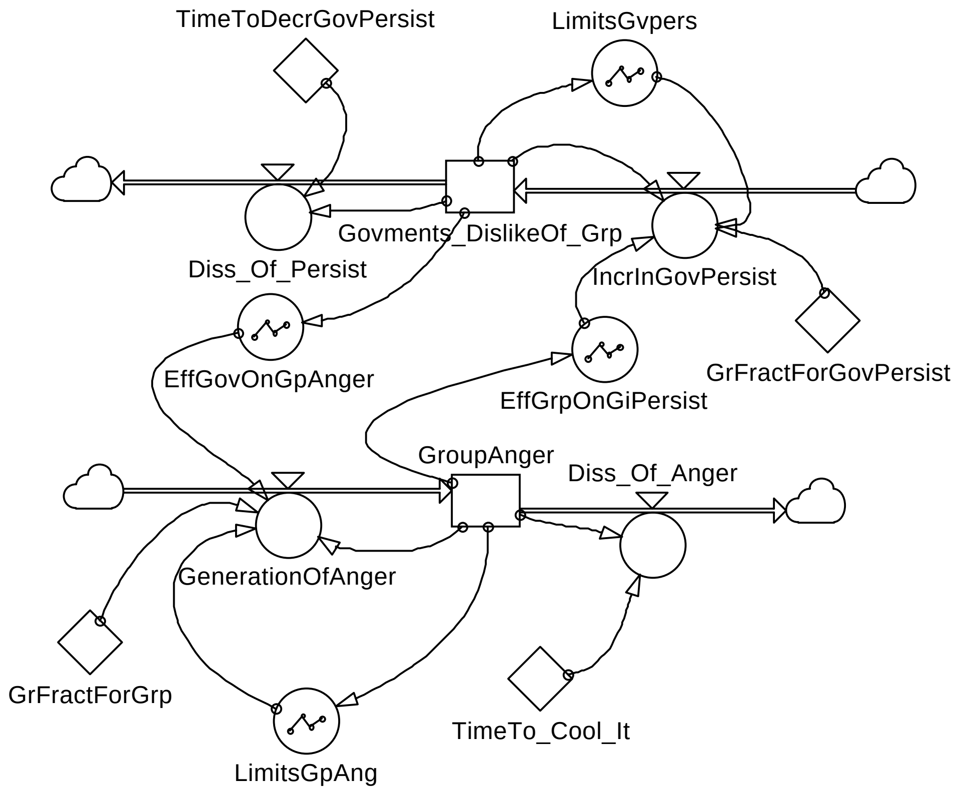


Figure 7. The completed simple model of group anger.

Figure 8 shows the behavior of the completed model. Again one observes s-shaped curves which reflects the combination of compounding process and a multiplier limiting the growth of anger at extreme values.

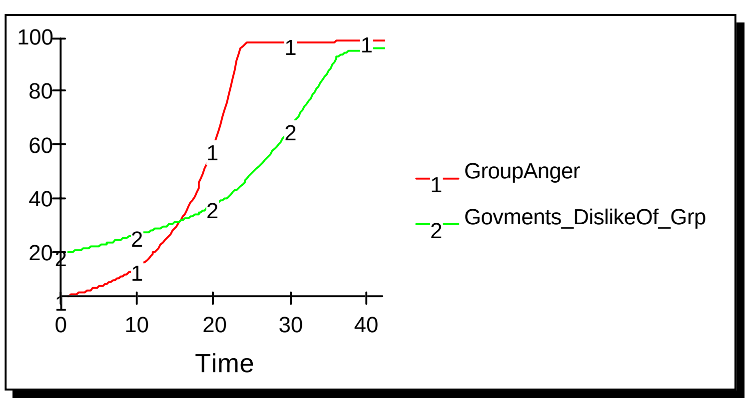


Figure 8. Behavior of the single anger model

The work of William Powers. The model, which we have used to illustrate some of the heuristic principles outlined in this paper, mainly stresses the use of positive loops, especially the loop which connects the two sector of the model. Actually, the reader may recognize the general characteristic of the dynamics of this situation, namely that it deals with an escalation process. The loop structure of the classical escalation archetype (see, e.g., Senge, 1990) is different in that it is composed of two negative loops, in which protagonists assess their relative position and act to outdo the other person or group when they fall behind. This approach is very consistent with that of William Powers (Powers, 1973a, 1978, 1990, 1992), an engineer and psychologist, who has had an effect on the thinking of researchers in cognitive psychology and those in industrial/organization psychology who are open to the notion of control theory and cybernetics. Powers work has also had an effect on psychotherapy (Glasser, 1981), and certainly has had a significant role in applying feedback concepts to psychology (Richardson, 1999).

One of Powers' major contribution is his emphasis on the hierarchical nature of cognitive and motor processes. His work is essentially also very compatible with system dynamic's internally oriented perspective on closed loop thinking. He goes one more step in specifying negative loops though, by stressing the difference between the outside input stream and the internal interpretation of the outside variable, which might be called in SD the "goal." From a practical point of view of modeling perception, Powers' work suggests paying more attention to how people may distort or control their reference signals, which are internal to the person. I am essentially in agreement on this matter.

Powers emphasizes almost exclusively the use of negative loop structures, especially within a person, because his work attempts to conform to the neurology of the brain as much as possible. He would have very little problem with using positive loops when modeling the relationship between people, but he would not stress using positive loops when modeling mechanisms within the person. Indeed he and the author might depart somewhat on the use of positive self-loops when modeling the dynamics of individual emotions. He might take a very different approach to accounting for the rise of anger in a person, for example. This paper suggests incorporating a positive self-loop if necessary to account for the escalation of anger or other volatile emotions.

SCALING CONCERNS

The last section of this paper has to do with issues of measurement in system dynamics. On occasion, this topic has been brought up for discussion. For example, Jacobsen and Bronson (1987), were concerned about how one operationalized variables and indicators to measure theoretical constructs used in system dynamic models. They discussed the idea of carefully going from theoretical constructs to valid measures of the key variables. Jacobsen and Bronson suggest that variables used in the softer side of system dynamics must meet the criteria of being realistic, reliable, and have face validity. Those criteria are sound for any type of dynamic modeling, not only in modeling social processes.

Perhaps the most detailed discussion of problem system dynamicists might have with using psychological scales has been presented by Nuthmann (1994). In general, he cautioned the reader to be aware of theoretical and practical differences among types of scales first described by Stevens (1951). Nuthmann's article introduced those scale types as nominal, ordinal, interval, and ratio scales. He makes an argument that frequently human cognition and judgment work at the lower end of the scale continuum. People frequently compare objects, cities, and alternatives in general on an ordinal scale. He indicated that human judgment, one of the main pillars of cognitive psychology, is quite difficult to model without being aware of differences in these types of scales. On the other hand, system dynamicists frequently rely on the use of multipliers in their models. Nuthmann is somewhat critical of the set of assumptions modelers might use about human judgment. But, when one looks at psychological concepts as psychologists use them, conceptually a number of everyday social and psychological variables, especially motivational and emotional variables act like ratio scales. For example, one can literally have no interest in jumping off a building under most circumstances. If one has no interest, then nothing happens. This implies that the variable interest combines multiplicatively with other variables.

Measurement and quantification. Quantification of variables in one's model is not the same as empirical measurement. One could, for example, quantify a variable to have a meaningful absolute zero point and have the property that ratios of the scale are meaningful. For example, we might define the scale so that a score of 50 is twice as much as a score of 25. On the other hand, empirically, one could actually go into the field to obtain measure of the variable in which 50 was not really twice as intense as a score of 25. For example, 50 degrees centigrade is not twice as hot as 25 degrees centigrade. The author feels that system dynamicists are actually correct in using multipliers in their models. Many of these constructs, such as "quality of the workplace" or "attractiveness index" are <u>products</u> of other factors. Theoretically, the assumption is that one is using a set of ratio scaled variables so that multiplication, as a way of combining variables is supported.

If many psychological variables, such as depression, guilt, shame, self-esteem, co-dependence, etc. have natural zero points, then psychological variables would fit very nicely into system dynamics models, if substantively appropriate. There is a problem, however. During the last sixty years of so, psychologists have developed rather sophisticated methods for measuring almost any psychological construct imaginable. They generate a set of items which hopefully taps off the same construct, and then through such techniques as confirmatory factor analysis, develop internally consistent scales of the original theoretical variable. Those scale scores, however, are measured at best as interval scales. Ratios of those scales are not very meaningful.

The problem then is this. If a model assumes that all variables have properties of ratio scales, then empirically one should consistently measure those variables as ratio scales. Unfortunately this is not done in most psychological research. Although there established techniques for generating ratio scaled variables (Stevens, 1957; Woefel et al, 1980; Lodge, 1981), all of the bread and butter techniques used to obtain measures of psychological variables are at best interval in nature. Psychologists use these non-ratio methods because first there did not seem to be any theoretical argument against using interval scales and secondly, the technology for generating scales has been refined and learned over the years.

The author began to look into the potential consequences of defining variables substantively at the ratio scale level, but measuring them at the interval level. This was reported previously (see Levine et al, 1992d), so we will not go into details here. It was discovered that, under some circumstances, if it is assumed in the model that the variables are quantified as in terms of ratio scales, yet the empirical data were measured only at the interval level, the qualitative patterns of the model's output might be different from the qualitative patterns of empirical data. Thus, even though the model might validly capture the dynamics of the problem, the researcher, assessing the fit of the model on an empirical data set, might reject the model on the basis of a poor fit. So the a perfectly good model is rejected because of poor data.

Theoretically there has been some research on the relationship between ratio and interval scales measuring the same set of characteristics, just as there is a mathematical relationship between temperature measured on a Celsius scale and a Fahrenheit scale
From Baird et al (1978), the relationship between the two types of scales can be summarized by the following equation:

$$X_{int} = m\log(L_{ratio}) + k,$$

where
X_{int} is a measurement of the psychological trait understudy,
L_{ratio} is the value of the construct or theoretical trait which has ratio properties, and
m and k are constants to be determined empirically.

To illustrate how measuring these constructs on the wrong scale could lead to confusion and a rejection of a perfectly good model, one can think of a social psychologist, who after reading about a system dynamics model which modeled a problem dealing with changing morale, decided to empirically validate the model by fitting the model to some of his data on company morale, which he happened to have handy. The empirical morale scale ranged from 0 to 7 or an eight point interval scale. The scale itself was composed of a number of items, each one of which was measured on a Likert scale, and then averaged to get the mean score per person. A zero on the scale only means a very "low" degree of company moral. It was not intended to indicate that there was no morale at all.

Suppose further that the psychologist had been hired as a consultant to the company three years ago, and came in and started working with both management and labor to change things around. Each month the psychologist would have people fill out a short morale questionnaire to assess how they were doing at that moment. He has three years of time series data. For a psychologist this is phenomenal, for it is quite rare to have so much data. He is ready now to take a look at the system dynamics model seriously.

Suppose the model assumed that it is very difficult to increase extreme levels of morale on both ends of the continuum. It was assumed that actually intermediate levels of morale are easiest to change, so the modeler introduced an inverted u-shaped table function to reflect this non-linear relationship. The SD model therefore qualitatively predicted a S-shaped trajectory over time. Even before attempting to fit the model to the time series data, the psychologist might play around with rough estimates of the parameters, run some preliminary simulations and perhaps even do a sensitivity analysis of the model. In this particular situation he would always find that model generates an S-shaped curve. Figure 9 might be what he found when plotting the output of the model and comparing it to the his actual data, which should be remembered is interval scaled data.

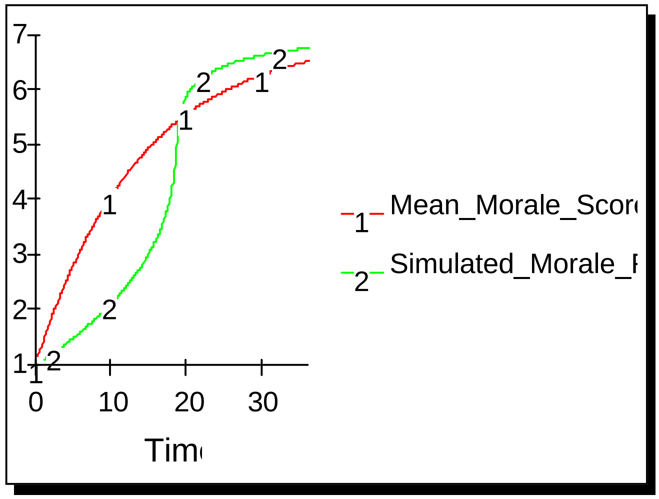


Figure 9. Comparison of the patterns of the output of a model assuming ratio scales and data which is measured by interval scales.

One can see immediately, that there is a qualitative difference between the two curves. The trend in the data set is logarithmic in pattern, while the model generates typical exponential growth, followed by a shift in dominance to generate an S-shaped curve. This would be enough for the psychologist to reject the model outright, even before fitting the model precisely. The point the author wants to make is that in this case the model is valid, but the data are measured in a way which would translate an S-shape curve into a curve which has a logarithmic pattern. Unfortunately, the psychologist may not be aware of the impact of using interval scales in the study. He would be rejecting a correct model outright out of ignorance. The author has made some suggestions about how to live with interval data and still assess the quantitative fit of the model (Levine et al, 1992d).

BRIEF SUMMARY

In this paper, the author has attempted to lay the groundwork for further discussion about how to use system dynamics to either model psychological processes and problems or to integrate psychological processes into solving problems in other domains. We discussed the nature of the bathtub metaphor and suggested a way of separating conceptually operations which would affect either the input rates or the output rates of a given stock. Then a few heuristics of modeling emotions like anger were introduced to show how to apply the bathtub metaphor in this psychological domain. There are limit to growth in any emotion and those were put into the model as well. In addition the author discussed the use of both positive loops when sensing the importance of self-reinforcement and negative loops when describing either perceptual processes or generally behavioral mechanisms in response to environmental pressure. Finally, the paper concluded with a discussion of the measurement issues, especially with respect to the fact that most psychological scales do not have ratio properties, and therefore may interfere with the quantitative validation process without suitable data transformation.

REFERENCES

Baird, J. C, & Noma, E. (1978). *Fundementals of scaling and psychophysics.* John Wiley, New York.

Chavis, D. (1991). Sense of community in the urban environment: A catalyst for participation and community development. *Am. J. Community Psychology* 18, 55-81.

Doyle, J. K. (1997). The cognitive psychology of systems thinking. *System Dynamics Review* 13, 253-265.

Doyle, J. K. & Ford, D. (1999). Mental model concepts for system dynamics research. *System Dynamics Review* 14, 31-29.

Florin, P., Chavis, D., Wandersman, A., and Rich, R. (1992). A systems approach to understanding and enhancing grassroots organizations: The Block Booster Project. In Levine, R. L., and Fitzgerald, H. (eds). *Analysis Of Psychological Systems (vol 2): Methods and Applications,* Plenum Press, New York, pp. 215-243.

Hovmand, P., and Levine, R. L. Analyzing dynamic systems: A comparison of system dynamics and structural equation modeling. *Proceedings of the Eighteenth International Conference of the System Dynamics Society***,** Bergen, Norway, August, 2000.

Jacobsen, C., & Bronson, R. (1987). Defining sociological concepts as variables for system dynamics modeling. *System Dynamics Review,* 3,1-7.

Kleinmutz, D. N. (1993). Information processing and misperceptions of the implications of feedback in dynamic decision making. *System Dynamics Review* 5, 223-237

Levine, R. L. . (1992a). Introduction to qualitative dynamics. In Levine, R. L. and Fitzgerald, H. (eds), *Analysis Of Dynamic Psychological Systems: (Vol 1): Basic Approaches To General Systems, Dynamic Systems, and Cybernetics.* Plenum Press, New York, pp.276-330.

Levine, R. L., Van Sell, M., & Rubin, B. (1992a). System dynamics and the analysis of feedback processes in social and behavioral systems. In Levine, R. L. and Fitzgerald, H. (eds), *Analysis Of Dynamic Psychological Systems: (Vol 1): Basic Approaches To General Systems, Dynamic Systems, and Cybernetics.* Plenum Press, New York, pp.145-266.

Levine, R. L., & Lodwick, W. (1992b). Sensitivity of parameters and loop structures. In

Levine, R. L., and Fitzgerald, H. (eds). *Analysis Of Psychological Systems (vol 2): Methods and Applications,* Plenum Press, New York, pp. 43-86.

Levine, R. L., & Lodwick, W. (1992c). Parameter estimation and assessing the fit of dynamic models. In Levine, R. L., and Fitzgerald, H. (eds). *Analysis Of Psychological Systems (vol 2): Methods and Applications,* Plenum Press, New York, 119-150.

Levine, R. L., & Lodwick, W. (1992d). Psychological scaling and filtering of errors in empirical systems. In Levine, R. L., and Fitzgerald, H. (eds). *Analysis Of*

Psychological Systems (vol 2): Methods and Applications, Plenum Press, New York, 87-117.

Lodge, M (1981). *Magnitude Scaling: Quantitative Measurements of opinions.* Sage Publications, Beverly Hills, CA.

Nuthmann, C. (1994). Using human judgement in system dynamics models of social systems. *System Dynamics Review* 10(1), 1-27.

Powers, W. T. (1973a).*Behavior: The Control of Perception.* Aldine/deGruyter, Hawthorne, New York.

Powers, W. T. (1978). Quantitative analysis of purposive systems: Some spadework at the foundations of scientific psychology. *Psychol. Rev. 85(5), 417-435.*

Powers, W. T. (1990). Control theory: A model of organisms. *System Dynamics Review 6(1), 1-20.*

Powers, W. T. (1992). A cognitive control system. In Levine, R. L., and Fitzgerald, H. (eds). *Analysis Of Psychological Systems (vol 2): Methods and Applications,* Plenum Press, New York, 327-340.

Richardson, G. P. (1999). *Feedback Thought in Social Science and Systems Theory.* Pegasus Communications, Waltham, MA.

Richardson, G. P., & Pugh, A. (1981). *Introduction to systems dynamics modeling with DYNAMO.* The MIT Press, Cambridge, MA.

Senge, P. M. (1990). *The fifth discipline: The Art & Practice of The Learning Organization.* Doubleday Currency, New York.

Stevens, S. S. (1951). Mathematiics, measurement theory, and psychophysics. In *Handbook of Experimental Psychology,* Wiley, New York.

Stevens, S. S. (1957). On the psychophysical law. *Psychological Rev* 64, 151-181.

Woefel, J. & Fink, E. L. (1980). *The Measurement of Communication Processes: Galileo Theory and Method.* Academic Press, New York.