System Dynamics/Systems Thinking: Let's Just Get On With It

by
Barry Richmond

Delivered at the 1994 International Systems Dynamics Conference
in Sterling, Scotland

Author Biography: Barry Richmond is Managing Director of High Performance Systems, Inc., where he's responsible for charting the overall strategic direction of the Company as well as for stewarding product and service development.

Abstract: The world has many problems. Many of these problems are approaching crisis proportions. The System Dynamics community has something very powerful to contribute to addressing these problems - whether we call that something Systems Thinking or System Dynamics. We have not been very effective in sharing what we have to offer because we have failed to truly appreciate the essence of System Dynamics. As a result, we have both consciously and unwittingly diluted this essence, and in the process made more difficult the task of disseminating what we have to offer. We need to better understand and appreciate the essence of our field, and then focus our energies on the real task at hand: Figuring out why this essence seems to be so difficult for people to grasp, and then fixing that.

The Big Picture: The world's problems haven't lessened much, if any, since 1961 when Jay Forrester penned Industrial Dynamics (Forrester, 1961). In fact, you could make a pretty convincing argument that things are going to hell in a hand-basket pretty quickly! We, in the System Dynamics community, have something very powerful to offer to our increasingly troubled world. We can offer a way of thinking, doing, and being that can help the planet's citizenry to achieve a much saner day-to-day existence, as well as a more promising longer-term future.

So, if we have this much to offer, why isn't the world beating a path to our doorstep? It is my contention that we ourselves are thwarting the realization of our potential for making the world a better place. We are doing so by not fully appreciating the essence of what we have to offer. Lacking this appreciation, we have not focused our attention on meeting the very real and very formidable challenges associated with disseminating this essence. Instead, sensing the challenges, we have both consciously and unwittingly diluted this essence in an effort to make it more palatable. But the solution is not dilution! We must instead work to develop a shared appreciation for what really is the essence of what we can bring to the party. We must then focus our energies on figuring out how to best disseminate this essence. The purpose of this paper is to contribute to the achievement of both ends.

I'll begin by providing an operational definition of Systems Thinking. Then, I'll relate that definition to what I understand System Dynamics to be. From here, I'll focus on what I perceive to be the challenges we must confront if we are to achieve more widespread assimilation of what we have to offer. I'll conclude by first examining some new and promising approaches to meeting these challenges, and then identifying one of the important challenges that remains.

What is Systems Thinking, and how does it relate to System Dynamics? Let me begin by briefly saying what Systems Thinking is not. Systems Thinking is not General Systems Theory, nor is it "Soft Systems" or Systems Analysis - though it shares elements in common with all of these. Furthermore, Systems Thinking is not the same thing as Chaos Theory, Dissipative Structures, Operations Research, Decision Analysis, or what control theorists mean when they say System Dynamics - though, again, there are similarities both in subject matter and aspects of the associated methodologies. Nor is Systems Thinking hexagrams, personal mastery, dialogue, or total quality.

Understanding what Systems Thinking "is not" will help us to more fully appreciate what its essence is. I have taken, and will continue to take, the non-politically-correct position that "reaching out" to these other disciplines and approaches is not where we should be focusing our energies. This is not to say that these disciplines and approaches do not themselves have much to contribute! Nor is it to say that we should not celebrate the synergies, or avail ourselves of cross-fertilization opportunities, where these occur. What I do want to say is that we have something in what I will define as Systems Thinking that is quite unique, quite powerful, and quite broadly useful as a way of thinking and learning. It's also capable of being quite transparent - seamlessly leveraging the way we learn biology, manage our businesses, or run our personal lives. We need to concentrate on realizing the substantial untapped potential which has been sitting right there in front of us for so many years, before we devote much explicit attention to "reaching out."

Allow me two more "nots." First, Systems Thinking is not quite the same thing as System Dynamics. However, the overlap is very substantial, and the differences are more in orientation and emphasis than in essence. Second, my definition of Systems Thinking is not the same as Jay Forrester's. I believe Jay's definition, represented in Venn Diagram terms, would look like Figure 1.

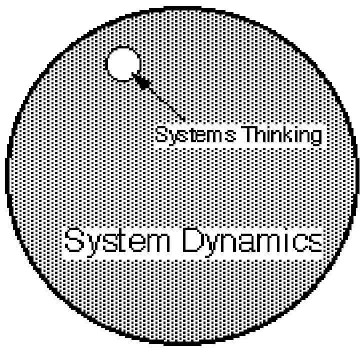


Figure 1. A Venn Diagram Representation of Forrester's View of the Relationship between System Dynamics and Systems Thinking

As the Diagram suggests, Forrester sees Systems Thinking as a small subset of System Dynamics, viewed in terms of what the latter package has to offer vis a vis understanding and improving the way the world works. I have inferred Jay's view from comments that he has made in various forums. Recently his sentiments were reflected in an interview which appeared in the McKinsey Quarterly. In that interview, he stated that Systems Thinking will get you " less than 5 percent of the way towards a genuine understanding of systems. The other 95 percent lies in the rigorous System Dynamics-driven structuring of models and in the simulations based on these models" (McKinsey, 1992). Jay considers rigorous-structuring and simulation activities to fall outside his definition of what constitutes Systems Thinking. By contrast, both are subsumed within my definition. My Venn Diagram-like picture of the relationship between Systems Thinking and System Dynamics appears in Figure 2.

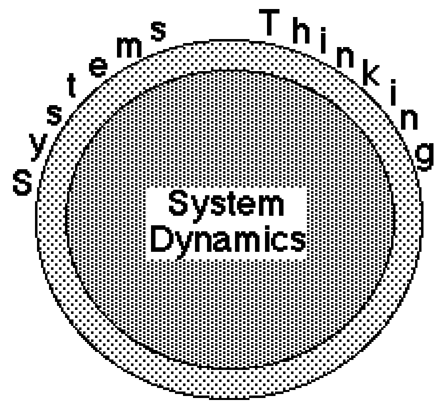


Figure 2. A Venn Diagram Representation of Richmond's View of the Relationship between System Dynamics and Systems Thinking

The picture contrasts quite sharply with the one I perceive Jay to hold. However, as you'll see, I am in violent agreement with Jay with respect to what the thrust of his picture implies. The differences in our pictures arise from differences in assumptions about which items are included under the rubric of Systems Thinking versus System Dynamics. As Figure 2 is intended to suggest, my view of Systems Thinking is that it encompasses all that Jay thinks of as System Dynamics, "plus some." A parallel, non-Venn Diagram, way to interpret Figure 2 is that Systems Thinking is "System Dynamics with an aura" (you Californians will like thinking about it this way!). Let's examine both what's in the core and what's in the aura, as well as why I feel an aura is needed (and justified)

I first developed a discomfort with the name "System Dynamics" when I began teaching at Dartmouth in 1979. The name did not seem encompassing enough to students for what they felt they were getting out of the courses I was teaching. Students felt that first and foremost they were emerging with a "new way of thinking." They averred that this "new way" pervaded their lives, changing the way they saw things, interpreted events, and made meaning out of situations. The name "System Dynamics" seemed to them (and to me) to apply more to "the system" - as in referring to the system's dynamics (which is, I believe, why many people continue to misspell the name of our field as Systems Dynamics). When people asked them what the name of this new way of thinking they had embraced was, they wanted to be able to provide a name that had something to do with a worldview. The name "System Dynamics" was very unsatisfying in this regard.

I sat with a mounting frustration with the name "System Dynamics" for several years. Then, in 1985 when HPS was ready to release our first version of what became the STELLA® software, I was pressed to come up with a name for the product. After much thought, and only a little reverse engineering, I came up with the acronym: STELLA (Richmond, 1985). The acronym stood for "Structural Thinking, Experiential Learning Laboratory with Animation." Now that was a mouthful! At the time, the name "Structural Thinking" seemed to be a more accurate description of what we were about than System Dynamics. I still kind of like the name Structural Thinking because it points directly to what I consider to be the essence of System Dynamics (and, therefore, Systems Thinking). Unfortunately, the term also is a pretty good characterization of what a civil engineer does when planning an apartment building or a dam. Structural Thinking simply didn't capture enough of the story.

One year later, when preparing our first real User's Guide for the STELLA software, I began using the name "Systems Thinking" to describe what it was that "stood behind" the software (Richmond, et al., 1987). I was unaware of other uses of this name, and I liked where it put the emphasis - i.e., on the thinking! Yes, you did rigorous structuring. And yes, you did simulations. But both activities were guided by a paradigm, a way of viewing the world. The purpose was not the structuring or the simulating. The purpose was to think more productively about how to improve the way a system worked. So, we had both key elements: System and thinking. The name felt more accurate.

The need for a more accurate description of the nature of our undertaking was not the only motivation behind my shift away from using the term System Dynamics. The second important reason was that I felt the historical emphasis in the practice of System Dynamics had been incorrect. I wanted to radically shift this emphasis, and felt that doing so (under the rubric of what people had known to be System Dynamics) would be too difficult to pull off. The emphasis in System Dynamics practice circa 1976 (which is when I arrived at MIT to begin my study) could be characterized as: "We have the way to get the wisdom; we will get that wisdom for you (just name the context); then we will transmit that wisdom to you." The message writ large across Industrial Dynamics (Forrester, 1961), Urban Dynamics (Forrester 1969), World Dynamics (Forrester, 1971) and The Limits to Growth (Meadows, et al, 1972), which constituted the majority of the seminal works in the field at that time, was: "We've seen more deeply, we'll tell you how it works." The prevailing dogma was that it took 4 - 5 years of study in a PhD program (at a place like MIT) just to get a basic grip on this thing called System Dynamics. To become competent, took another ten years or so of practice. System Dynamics was definitely for the privileged and the few! The emphasis was on product, not on transferring the process. Here's a model of the city, the corporation, the world, the National economy. Look, this is how these things really work.

My intention here is not to cast aspersions on any of the seminal work in the field. The work is of very high quality, and represents the product of excellent thinking (and writing!) by some of the greatest minds of our time. However, it is nonetheless the product of the privileged and the few. The implicit strategy is: Help the world by showing them the way. My bias (coming of age in the 60's) always has been toward a very different strategy: Give the power to the people; let them figure out how to save themselves! The distinction is the same as that captured in the popular aphorism (abbreviated here): "Give a fish, eat for a day; teach to fish, eat for a lifetime (unless you happen to be over-harvesting your fishing grounds, of course!). My bias isn't just the result of 60's ideology. People who generate insights for themselves learn much more than those who are fed them. It's freeze-dried versus fresh and crunchy, just-picked. The more people who have the capacity for generating systemic insight, the more likely the planet will be to arrive at some desirable steady-state.

This shift in practice orientation is primarily what I have intended the "aura" in Figure 2 to represent. The spirit of what I think of as Systems Thinking is different than what I came to know as System Dynamics. It was this new "transfer the process" spirit that we were seeking to capture in the STELLA software - and which we have continued to seek in our subsequent software offerings. The feeling was: anyone can do this, and everyone should try. No few and privileged here!

I've now talked a lot about how the term Systems Thinking came into being for me, but I've yet to say much about what it is. I'll now do that. And, as I do, what I am saying (by my definition) also applies to System Dynamics. This is important! It's important because though I prefer the name Systems Thinking to System Dynamics for the two reasons cited, the fact remains that whatever we opt to call it, Jay Forrester deserves a lot of credit for inventing the crux of it! I now have been active in this field for nearly 20 years, and yet I continue to be amazed at how powerful the underlying framework which Professor Forrester has provided really is. As we move forward, we must never lose sight of, nor fail to adequately acknowledge, the tremendous contribution of the Founder of our field.

The definition of Systems Thinking at which I have arrived is: Systems Thinking is the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure. The art and science is composed of the pieces which are summarized in Figure 3.

Systems Thinking is a...

Paradigm

- *Vantage Point*
- *Set of Thinking Skills*

Learning Method

- *Process*
- *Language*
- *Technology*

Figure 3. The Components of Systems Thinking

As the Figure indicates, to me, Systems Thinking is a Paradigm and a Learning Method. The first conditions the second. The second supports the first. The two parts form a synergistic whole.

Briefly, the Paradigm consists of two pieces: Vantage Point and Thinking Skills. The vantage point determines where you position yourself relative to the fray. The thinking skills you employ determine both what you perceive within the fray (i.e., what aspects you attend to, and which you ignore), as well as the meaning you make out of what you perceive. The Systems Thinking vantage point is best characterized by the term "bi-focal." That is, people embracing Systems Thinking position themselves such that they can see both the forest and the trees (one eye on each). The positioning has both structural and behavioral implications. Structurally, Systems Thinkers see both the generic and the specific - not just the latter! Behaviorally, they see both the pattern and the event - not just the latter!

Once positioned with respect to the fray, those embracing Systems Thinking filter what they see using three thinking skills: System as Cause Thinking, Closed-loop Thinking and Operational Thinking. The first two have been recognized as part of the System Dynamics paradigm for a long time. The third, in my view, has remained very under-appreciated in the field. I began using the term "operational thinking" in 1987 (Richmond, et al., 1987), and to my knowledge, there was not another term to describe this thinking skill at that time. The reason why I believe we have failed to adequately distinguish this third thinking skill is because it is so much a natural part of the way Jay Forrester sees the world that he doesn't (or didn't) recognize it as anything "separable!" Instead, it simply became rolled into the essence of System Dynamics - so obviously true that it didn't require any particular distinguishing.

But I will argue that it is precisely the failure to appreciate the critical importance of this third thinking skill (operational thinking) that is causing many in the field to unwittingly dilute the essence of what we have to offer. In so doing, they are reducing the magnitude of their potential contribution, increasing the difficulty that we will experience in seeking to build Systems Thinking capability in the broader population at large, and potentially undermining the long-term credibility of the the field.

Before turning to operational thinking, I will provide a few words on the first two thinking skills.
System as Cause Thinking - what George Richardson refers to as "the endogenous viewpoint" (Richardson, 1991) - is the notion that it's useful to view the structure of a system as the cause of the problem behaviors it is experiencing, as opposed to seeing these behaviors as being "foist upon" the system by outside agents. Closed-loop Thinking then becomes the next step in the thinking progression. If structure is "the cause" of behavior, what does structure look like, how is it arrayed? The answer: in closed-loops. Causal relationships do not run one-way. They're reciprocal. Operational Thinking completes the progression. If structure is composed of closed-loops, of what are closed-loops composed? The answer: stocks and flows (and connectors). Put together, the three thinking skills constitute a way of making meaning out of the fray: (1) Look at system structure, (2) structure is composed of stocks and flows, (3) stocks and flows are arranged so as to form feedback loops.

It is the third thinking skill, operational thinking, that I feel represents the unique essence of System Dynamics, and hence by my definition, the unique essence of Systems Thinking. It is also this skill which poses the greatest challenges to disseminating Systems Thinking. Before moving to a discussion of these challenges, let's take a moment to become clearer about what operational thinking really is. Many years ago, Mark Paich and I started referring to this type of thinking as "getting down to 'the physics'." I also pretty freely use terms like "plumbing" and "infrastructure" to characterize that with which operational thinking deals. You're doing operational thinking when you get at the core stock/flow infrastructure that lies at the heart of a system or issue. Figure 4 presents three examples, taken from diverse contexts. Each was uncovered in the course of a conversation with a client. Each is dirt simple. Yet each shed a tremendous amount of light on what had been, up to that point, a very murky discussion.

In the first example, we were working on the issue of alcohol addiction with some doctors from the Mary Hitchcock Medical Center (associated with Dartmouth College). It had been noted several times in the discussion that one of the distinguishing characteristics of alcohol addicts is their chronically low levels of self-esteem. The discussion was seeking to understand why various treatment interventions seemed to be so ineffective in lifting these levels. Each appeared to raise self-esteem in the short-term, only to see it plummet once again in the not very distant future. All of a sudden, it occurred to me to draw the simple stock/flow diagram which appears in part "a" of Figure 4. The phrase "There are two ways to fill a bathtub!" flowed out as I was sketching. The second way is of course to stem the outflow. By doing so, any self-esteem which is deposited in the stock would remain there for a longer period of time. The result is a higher, steady-state level of self-esteem. Until that point, all of the interventions which had been considered were focused on the inflow! We were ignoring a whole set of potentially highly effective policy initiatives.

The second example arose in a discussion with a group of educators who were interested in understanding how to accelerate and enrich learning. Most of the discussion was spent in "dumping" everything that each member of the group suspected was related to learning. The laundry list (and subsequent causal loop diagram) grew to completely outrageous proportions! Motivation, IQ, teacher quality, physical and emotional well-being of the child, difficulty of the subject matter, quality of the textbook, and so on, all were included. The potential list is endless, and what's more, each item on the list leads to an infinite regress both inward (e.g., the components of physical well-being; the components of the components) and outward (e.g., the relationships which govern emotional well-being; the relationships which govern those relationships).

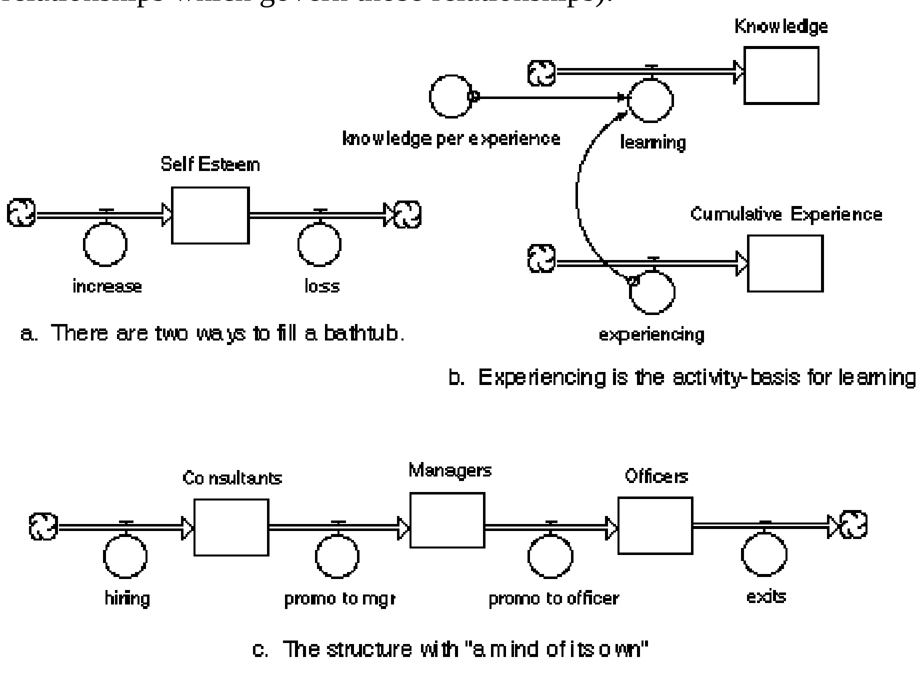


Figure 4. Three examples of Operational Thinking

In order to cut through the very thick tangle of spaghetti that was impeding progress, I asked people to shift out of the brainstorming mode (a more picturesque way to characterize this mode is "mental avalanching;" a lot of stuff tumbles down, usually very rapidly, and the result is not very useful). I asked them to think instead about how they learn. I specifically asked them not to allow their minds to drift into the "What are all the factors that influence learning?" mode. Instead, I suggested they think operationally: How does learning occur? An even more specific question is: What is the activity-basis for learning? As "b" in Figure 4 indicates, an answer that all members of the group seemed to embrace was "through experience." The activity-basis for learning is experience. Once we had painted this simple, operational picture of the learning process, the discussion was able to proceed much more fruitfully.

The final example arose in the context of some work we did for a strategic management consulting company. The issue commanding the firm's attention at that point in time was the inexplicable increase in the attrition rates of their highest quality consultants, and the concomitant increase in the difficulty of recruiting the best and the brightest B school grads. The discussion, as is often the case, focused more on "fixing the problem" (with incentive systems and recruiting packages) than on understanding what was causing it. After a few hours of wandering, people were unable to agree on any real solution - I suspect because they sensed that the solutions being proposed lacked any sort of foundation in the underlying operating reality. In response, we shifted gears, following my suggestion that we begin by "getting down to the physics of their business." A key element of those physics was the Company's promotion-chain infrastructure (depicted in part "c" of Figure 4). Once we had laid out this infrastructure, we quickly outfitted it with a set of parameters that reflected the Company's operating goals with respect to growth rates, promotion times and attrition fractions. When we simulated, we discovered "Urban Dynamics"! That is, just as did Forrester's chain of housing and business structures, this infrastructure had a "mind of its own" with respect to how it will seek to distribute the material resident within it. Specifically, the infrastructure, as parameterized, dictated a very top-heavy personnel pyramid. This was a real eye-opener to the senior management team!

In all three examples, and hundreds more like them collected over the years, a simple stock/flow infrastructure produced a major insight - and perhaps more importantly, produced a quantum increase in the clarity of the understanding. This is operational thinking! It doesn't necessarily involve closed loops. It's also doesn't necessarily involve computer-based simulation - though this often is useful. We've discovered that many of the simple infrastructures can be reliably simulated via "mental walk through."

So, if operational thinking is not closed-loops, and does not necessarily even involve computer simulation (though, again, often it is needed, and always it is useful!), then what is it? It's primarily just seeing key arrangements of stocks and flows, with an occasional wire thrown in to make a connection.

Stocks and flows are very profound building blocks! They precede feedback loops! They form the infrastructure of a system. They provide the substrate for feedback loops to exist - just as the spinal cord and skeleton provide the framework which houses the muscles and organs that give rise to, and are stimulated by, feedback signals coursing throughout the nerves. Without the infrastructure, there can be no feedback system!

It is for this reason that I submit that it is poor practice to use causal loop diagrams before having laid out, and understood, the underlying stock/flow infrastructure of a system. Such practice celebrates the nerves, without regard for the spinal cord, skeleton, or organs. It gives you the wires without the things that house the wires, or which give rise to the impulses that course through the wires. Drawing causal loop diagrams, at the outset of a discussion or analysis, encourages Laundry List (or "Factors") Thinking (Richmond, et al., 1987). In fact, it's likely to make that thinking even more difficult to understand because rather than a set of causal factors and a resulting "effect," the causes themselves become effects when you close the loops. Causal Loop Diagrams, when used in advance of laying out a stock/flow diagram, are in service to closed-loop Laundry List Thinking, not Systems Thinking. They represent the antithesis of operational thinking!

To make matters worse, once the causal loop diagramming language is internalized, it actively impedes assimilation of the stock/flow language - and hence operational thinking. It does so by making the task of assimilating Systems Thinking both appear considerably more difficult, and actually be considerably more difficult (because of the "un-learning" that is required). I first discovered the barriers that causal loop diagram-based thinking creates for the assimilation of stock/flow thinking in teaching Dartmouth undergrads. I have subsequently re-discovered these barriers numerous times over the last seven years in working with people in a variety of contexts.

The appropriate role for causal loop diagrams is "after the fact." Once a system's structure has been grasped, and the associated dynamic implications of that structure have been well-understood, causal loop diagrams can be of value in helping to communicate how structure creates behavior. However, causal loop diagrams are not vehicles for making reliable inferences about behavior! This is true because there is no way to "refute" a causal loop diagram - you can't simulate one to show that it can be rejected as a hypothesis! Using causal loop diagrams to make inferences about behavior is a treacherous business. Continued use of the practice poses serious risks to discrediting the field.

The second practice we need to exercise great care in executing is the purveyance of "Systems Archetypes" (Senge, 1990). The care required becomes multiplied several-fold when these archetypes are packaged for consumption via causal loop diagrams. Again, to me, one of the major "problems" with System Dynamics was the "we have a way to get the wisdom, we'll get it, then we'll share it with you" orientation. I feel that Systems Thinking should be about helping to build people's capacity for generating wisdom for themselves. Though I believe that Senge offered the archetypes in this latter spirit, too many people are taking them as "revealed truth," looking for instances of that truth in their organizations (i.e., engaging in what amounts to a "matching exercise"), and calling this activity Systems Thinking. It isn't. I have encountered many situations in which the result of pursuing this approach has left people feeling quite disenchanted with what they perceive Systems Thinking to be. This is not a "cheap shot" at Peter. His book has raised the awareness with respect to Systems Thinking for many people around the globe. However, we all need to exercise great caution in the purveyance of Systems Archetypes - in particular when that purveyance makes use of causal loop diagrams.

This discussion leads us to Part 2 of the progression: What are the challenges to disseminating Systems Thinking?

The challenges to disseminating System Thinking: Because my definitions of both System Dynamics and Systems Thinking rely so heavily on operational thinking, the challenges I feel we must confront center around understanding the impediments to internalizing the language of stocks and flows. Given space constraints, I will focus on three of the largest impediments. The first is the abyss between the mind's eye view and the associated stock/flow representation of the mental model. The second is visual complexity. The third has to do with an ambiguity in our diagramming language.

The abyss: One of the fundamental problems inherent in our modeling approach is that although you are seeking to use our nice, operational language to represent "a system" at some level of aggregation, you must begin by putting down a single stock! That is, people's mental models consist of some complex, multi-dimensional amalgam of images and recollected experiences. It is these mental models which serve as the basis for the subsequent stock/flow-based rendering. The problem is that at the outset of the rendering process, the distance between what the mental model looks like, and what a first stock on a naked screen looks like, is a vast abyss! In fact, I believe that when seasoned System Dynamicists engage in the model-construction process, although they are indeed beginning by putting down a single stock, they've already formed a much larger stock/flow image in their minds. What outwardly manifests as the deposition of a single stock really is more akin to writing the first word in a paragraph. Yes, you begin by writing the first word. But, as you do, you already have an image in your mind of an entire set of sentences (the image of the authors of the US constitution scribing "We hmm? the umm? people" just doesn't ring true!). And so it is with seasoned System Dynamicists. They begin by putting down a single stock. Yet they already have at least an entire sub-system in mind.

Images of systems (webs of relationships) populate the mindscape. It is a natural form for mental models to assume. Beginning with one stock therefore is unnatural! It's a single tree in a very large forest. Yet this is what we ask the novice to do! Is it any wonder that the hill looks so steep at the outset?! We need a way to ease the transition from the systemic images which constitute people's mental models to the stock/flow rendering of these images. The gap between the mental model and that first, rifle-shot stock is an abyss. Until we can figure out a way to effectively span this abyss, our priesthood will remain a very exclusive club. I will present one promising approach in the next section.

Visual complexity: The second major impediment to internalizing operational thinking lies at the other end of the model-construction continuum. It's not a "first stock" issue. It's a spaghetti of stocks (and flows, and converters, and connectors) issue! The stock/flow representations of what experienced System Dynamicists know to be very simple systems, can appear completely intimidating to the uninitiated. In part, this is due to the fact that experienced System Dynamicists automatically filter the visual complexity associated with stock/flow diagrams. They know how to cut through the spaghetti to focus on what's most important - the stock flow infrastructure, then the associated feedback loops. To the novice, everything they see is relevant. And, there's usually way too much there to meaningfully imbibe. The result: cognitive overload. The conclusion: I can't do this!

We must find ways of parsing out the stock/flow display into more bite-sized chunks, so that people can remain in control of what they're seeing. While "management flight simulator" interfaces can make some contribution in this regard, they are not stocks and flows! And, they are subject to falling prey to the video-game syndrome - push the buttons, but never really understand what the engine that's propelling the flight really looks like. In the next section, I will present one approach which HPS is currently employing for addressing the visual complexity issue.

Language ambiguity: The third barrier to the assimilation of operational thinking is an ambiguity in our diagramming language. The ambiguity has been there from the "get go." It's right at the heart of what I feel confuses many people who try to learn the stock/flow language. I'll begin by relating an approach to learning the stock/flow language with which we've been having great success. Then, I'll focus on the fly in the ointment.

HPS has been enjoying great success with people "getting" the concept of stocks, flows and connectors (and even converters), by doing a simple water-pouring exercise. We begin with two transparent glasses, one filled to near brim with colored water, the other empty. First we begin pouring water from the first into the second. We stop pouring abruptly and draw people's attention to the fact that the flow has ceased, yet the stock persists. Voilà, a fundamental difference. You also can make a number of other more subtle points about the differences between stocks and flows using the pouring exercise (such as decreasing the rate at which water is flowing, yet noting that the stock continues increasing). This little demo really cements the concepts of stocks and flows incredibly well, and takes no more than 5 - 10 minutes to execute.

Next, we draw a ring around the empty cup, select someone from the audience, and tell them their assignment is to pour until you "hit the mark." They think, "No problem" (I must be inherently good at this Systems stuff). Just before they begin, we drop the other shoe by telling them that they must close their eyes while pouring (it's a really good idea to have them position the mouth of the cup with the water directly above the empty cup before letting them begin pouring!). They pour, and of course miss the mark. We then ask the group, why. The responses can be translated into the phrase: "because there was no feedback." We then whip out a keyboard cord, a power cord, a piece if string, or any other wire-like appliance we happen to have handy, and run it from the water level to the eye - making the point that feedback of the "condition" of the water (i.e., its level), relative to the established goal for the condition (i.e., the line around the cup), is processed into a decision stream which controls the pouring activity. Stock/connector/converter/flow, you've got the basic components-of-a-feedback-loop configuration depicted in Figure 5.

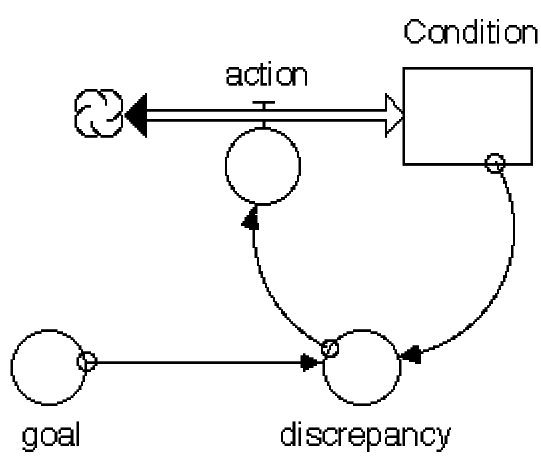


Figure 5. The Basic Components of a Feedback Loop

This second piece of the demo is similarly 5 - 10 minutes. It is incredibly effective at driving home the basic idea of a feedback loop, and the important distinction between a connector and a flow (i.e., the latter "transports," and hence is an instrument of conservation; the former "transmits," and hence leaves no impact on that from which it is transmitting). All of this is great! But now arises the glitch The wires which run from "Condition" to "discrepancy," and from "discrepancy" to "action" in Figure 5 are easy to explain as "information conduits" (they're kind of like telephone wires). They carry information about the state of the system to a decision-maker whose actions control the rate of change of the state. No problem. But, in Figure 6, what about the wire that runs from "Labor" to "production"?

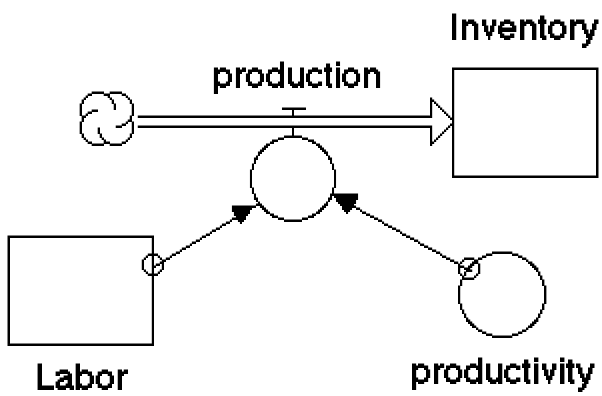


Figure 6. "Strange" Wires

You can't say that it's carrying "information about" Labor that is being "transmitted to" production. And, what about the wire running from "productivity" to "production"?! Is it "information about" productivity that enables production to occur? [NB: The fact that "productivity" stands alone (i.e., is disembodied from Labor, of which it is an attribute) is, itself, a big conceptual disconnect for many people! Great topic for next year's conference.]

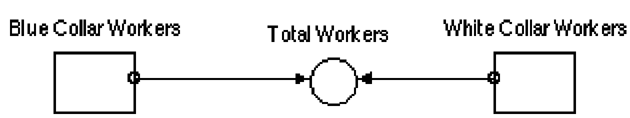


Figure 7. Wires used as Flow-Charting Vehicles to show Inputs to an Algebraic Expression

The problem here is two-fold. First, wires are being used as flow-charting vehicles, not just flow-diagramming vehicles. That is, our language makes use of wires both to represent "information about" and also to show "inputs to" an algebraic expression. The wires in Figure 7, make this latter use quite obvious.

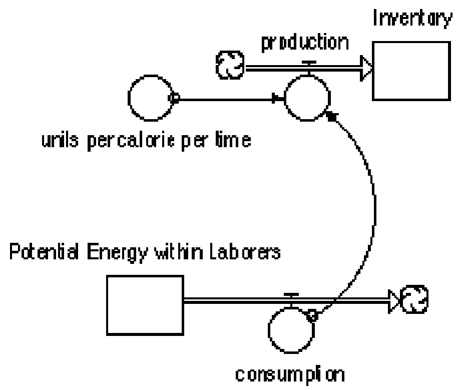


Figure 8. What's *Really* Going on with Labor and Production

Second, wires are being used as aggregation devices. The wire which runs from labor to production illustrates this third use of wires in our language. By "aggregation devices," I mean vehicles that aggregate up a relationship that the modeler has chosen not to explicitly represent in the model. In the case of Labor, for example, what's really going on is that something associated with Labor really is being consumed in order to generate the flow of production. However, that micro-level consumption process - illustrated in Figure 8 - is below the level of aggregation that's relevant for the issue at hand.

As such, the modeler has decided to simplify the reality by treating Labor as a "catalyst" (i.e., it's necessary for the reaction, but is not consumed in the process). The wire enables the modeler to make the more highly-aggregated, yet physically not quite inaccurate, statement that production is simply proportional to the amount of labor being applied to the production activity.

The wire which links consumption to production in Figure 8 is not "information about," either! It's a different kind of wire from either "information about" or "input to." It's the same kind of a wire that runs from Labor to production. We might call it a "production linkage."

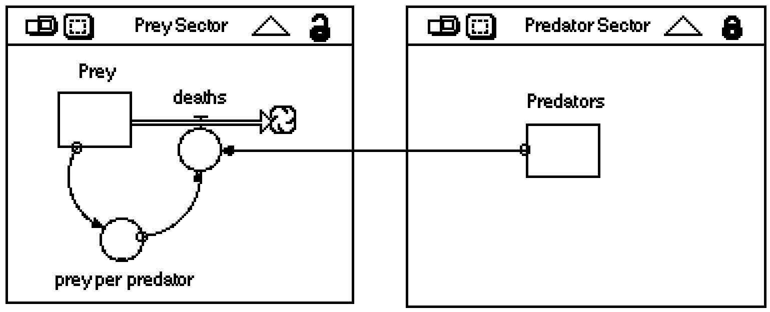
The problem in the current edition of our language is that we are using the same wire icon to represent three fundamentally different things. One type of wire ("information about") is used to radiate the information needed to serve as inputs to decisions. Another type ("input to"), is being used to flow-chart an algebraic expression. The third ("production linkage") is being used to show catalytic relationships (essentially, co-flows and aggregations of co-flow activities). We need to recognize that we are doing some "glossing over" by using the same icon to do triple duty. While we in the priesthood have learned how to recognize when we're using the wire in which way, novices and end-users can become extremely confused by our implicit understandings! We need to come to some agreement about the appropriate distinctions in wire icons that reflect the three different functions. Doing so will eliminate another impediment to the assimilation of the stock/flow language.

Meeting the three challenges I've identified - the abyss between mental model and stock/flow diagram, visual complexity, and ambiguity associated with the wire icon - will go a long way toward easing the assimilation burden associated with operationalizing operational thinking. I challenge you to think hard about how to best meet these challenges. I'll conclude by briefly discussing some promising approaches to the first two challenges that HPS currently is employing.

Some Promising Approaches to Meeting the Challenges to Dissemination: Many years ago, in the privacy of the cinder block cubicles they call married student housing at MIT, I had a long discussion with a brilliant System Dynamics PhD student named Ali Mashayekhi. Ali was on his way back to Iran, having just completed and successfully defended his dissertation. He wanted to take a moment before departing to convince me of the power of what he referred to as a "sector map." A sector map was basically a rendering of a system at a higher-level than the stock flow diagram. At the time, Ali was using larger, bevel-cornered rectangles to represent the sectors in a complex system. He then linked the sectors using arrows which showed the major linkages between them. The sector rectangles were not accumulations, but rather visual placeholders representing each of the "key actors" in the system. Because the sector icons were not accumulations, the arrows were not dimensionally-consistent flows (in fact, in most cases, the arrows represented a bundle of flows between any two sectors). Ali was using the sector map as a device for easing the transition from a mind's eye view of a very complex system, to his quite complex stock/flow-based rendering of this system. He was addressing challenge 1: traversing the abyss. His approach seemed to work!

Well, it's taken awhile, but HPS has finally gotten around to incorporating Ali's idea - or something close to it - into our software. And, no surprise, it too seems to work! In fact, it is easing the transition from mind's eye to stock/flow rendering in some ways that Ali didn't anticipate. Specifically, the use of the high-level mapping language is revealing some "sloppiness" in the way we traditionally draw our stock/flow diagrams. And, it now appears that this sloppiness is part of what often makes these diagrams so non-intuitive to the novice. I will provide two simple examples - one from an educational context, one from business. Figure 9 contains two, what would be considered "normal," stock/flow renderings of portions of two systems.

a. Predator/Prey Structure: *Predators eat Prey*



b. Human Resource/Finance Interaction

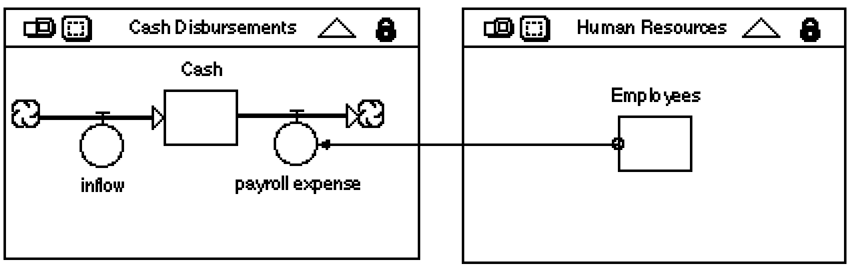


Figure 9. Portions of two "Normal" Stock/flow Diagrams

The first is taken from a predator/prey model, the second from a corporate model. The concept being represented in the first diagram is that predators eat prey. The concept in the second is essentially the same: employees "eat" money! I would argue that few System Dynamicists would have much trouble with these renderings (as far as they go; both clearly are incomplete and highly simplified). They look "normal." However, if you look at the high-level maps which correspond with these renderings, you'll discover something very interesting. Both high-level maps are reproduced as Figure 10.

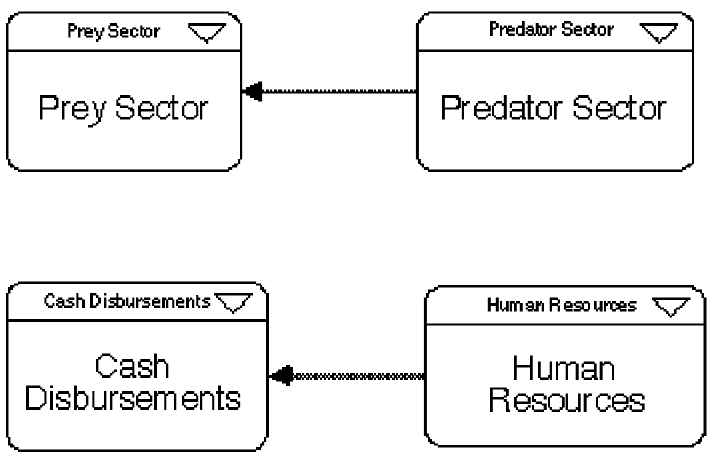


Figure 10. High-level Maps of the Two Illustrative Systems

We call the bevel-cornered, large rectangles "sector (or process) frames." The arrows linking the two frames in both cases are "information" linkages (as opposed to flows). Using words to interpret the two high-level maps would yield something like this: "Predators serve as an an input to Prey, and Human Resources serve as an input to Cash Disbursements." The former seems a little strange and appears to be missing something. The latter seems OK as far as it goes, but also incomplete.

To confirm this impression, I have asked a variety of non-System Dynamicists - completely unfamiliar with the stock/flow language - to use the high-level language (which, by the way is much easier for people to pick up) to render their mental model of the principal interactions between a predator and a prey population, and between employees and a cash disbursements process. In the vast majority of cases, I've gotten back high-level maps that look like what is reproduced in Figure 11.

Note that these maps are distinctly different than what appears in Figure 10. The "wires" pointing right to left are replaced by flows which point from left to right! In a few cases, people also have included the "wire" which runs from Human Resources to Cash Disbursements (in Figure 10). However, in no case have I gotten a wire that runs from predators to prey!

One interpretation of these results is that, what appears "normal" in a stock/flow diagram to a seasoned System Dynamicist, would not appear "normal" to a non-System Dynamicist. And, conversely, what does appear "normal" to most non-System Dynamicists has a tendency to be considered "non-normal" by most System Dynamicists!

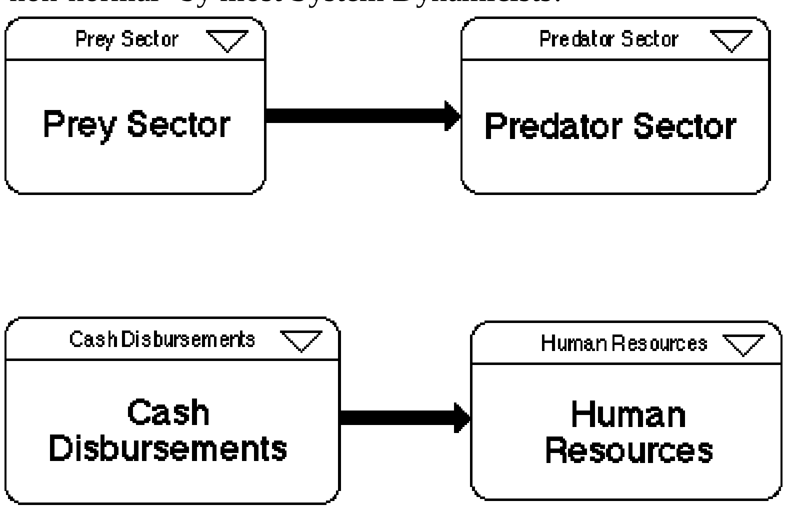


Figure 11. The Layperson's "Normal" High-level Maps

The most obvious thing about the relationship between predators and prey to "just plain folks" is that the former eat the latter. As such, most folks include a flow from Prey to Predators - the flow represents the somewhat gruesome process of body mass being consumed. However, because in most predator/prey models, the conserved flow of mass is "not what's important," most System Dynamicists pay no attention to this relationship - that's why we allow the death flow to terminate in a cloud. However, by paying no attention to the relationship, I will argue (based on empirical evidence), we are doing obvious violence to the mental models of most non-System Dynamicists. The proof is in their high-level maps! A similar argument can be made for the corporate example. The most compelling thing about the relationship within a corporation between a cash disbursements process and employees is that it is from the former that the latter's salaries flow. Here, again, since it is rare that we would choose to conserve the flow of money from corporate to individual coffers, this relationship is ignored in the stock/flow rendering. But, in doing so, we once again violate high-level, common-sensical understanding.

The solution is not to conserve the flow of either meat or money! The solution is simply to take a little more care in the placement of the associated clouds. If the stock/flow diagrams had been drawn as they appear in Figure 12, the associated high-level maps would have automatically included the two high-level flows that most non-System Dynamicists included in their high-level renderings. We'd still be considering the flows in question to be non-conserved. We'd have introduced no more complexity into the model or diagram. We would simply have been a little more careful in thinking about how these systems really work. But then, this is precisely our charge! Operational thinking!

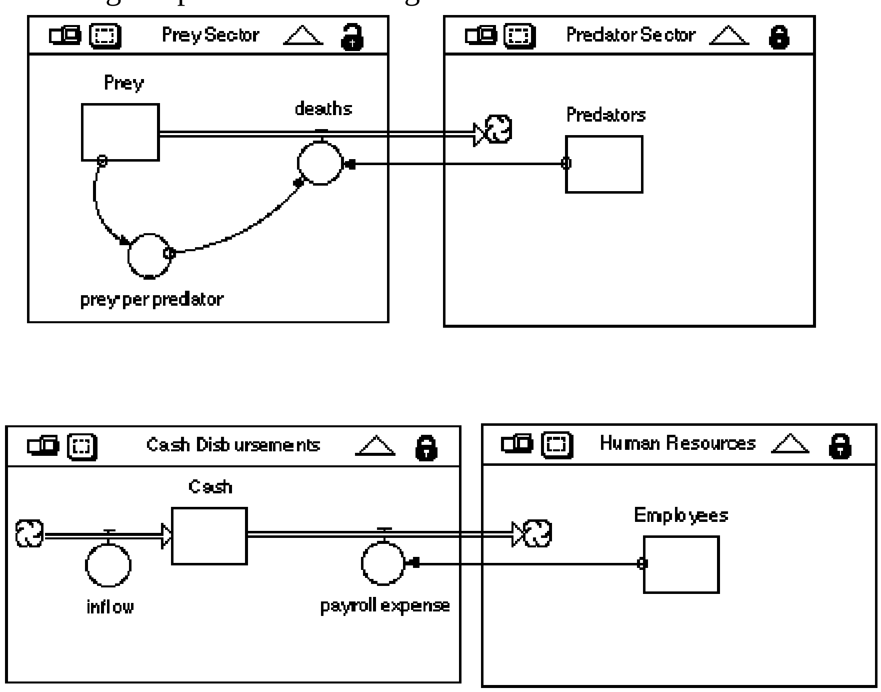


Figure 12. Exercising More Care in the Placement of Clouds

The high-level mapping language provides a much needed stepping stone between mental model and computer screen for both the novice model-builder, as well as those end-users of models who will play no role in the model construction process. But the stepping stone does not end at the high-level map. For each sector frame deposited at the high-level, the software automatically deposits a corresponding frame on the diagram level. This means that when the model-builder descends to the diagram level, they already will have the broad outline of a system to look at - no more blank screen, single-stock starts! If the high-level map indicates that a bundled flow or bundled connector exists between two sector frames, the model-builder's conceptualization energy is immediately focused on what those corresponding diagram-level counterparts might be. The high-level mapping exercise thus inspires the stock/flow conceptualization process. And, because the software enforces a one-to-one correspondence between the diagram-level and high-level map (the enforcement coming at run-time), model-builders will receive feedback on how well their stock/flow renderings match their high-level sketch (and vice versa). This feedback is helpful in ensuring a tighter coupling between the stock/flow diagram and the mental model.

Providing a high-level mapping language is a means of addressing the first barrier to the dissemination of Systems Thinking. The second barrier to dissemination is visual complexity. As already noted, the experienced System Dynamics modeler automatically "filters" the visual complexity of a diagram. Novices, and end-users, have no basis for doing so. As such, they can easily become overwhelmed by the visual complexity associated with even simple models.

Reproduced in Figure 13 is the Sales Force sector of Forrester's classic Market Growth model (Forrester, 1968). Most System Dynamicists would consider this diagram to be pretty straight-forward. Most non-System Dynamicists consider it at least a little intimidating.

What's needed is some way to visually simplify stock/flow representations, without losing (or diluting) their essence. We call our device for meeting this challenge the "space-compression object" (SCO).
Figure 14 depicts the same diagram, with the use of one SCO.

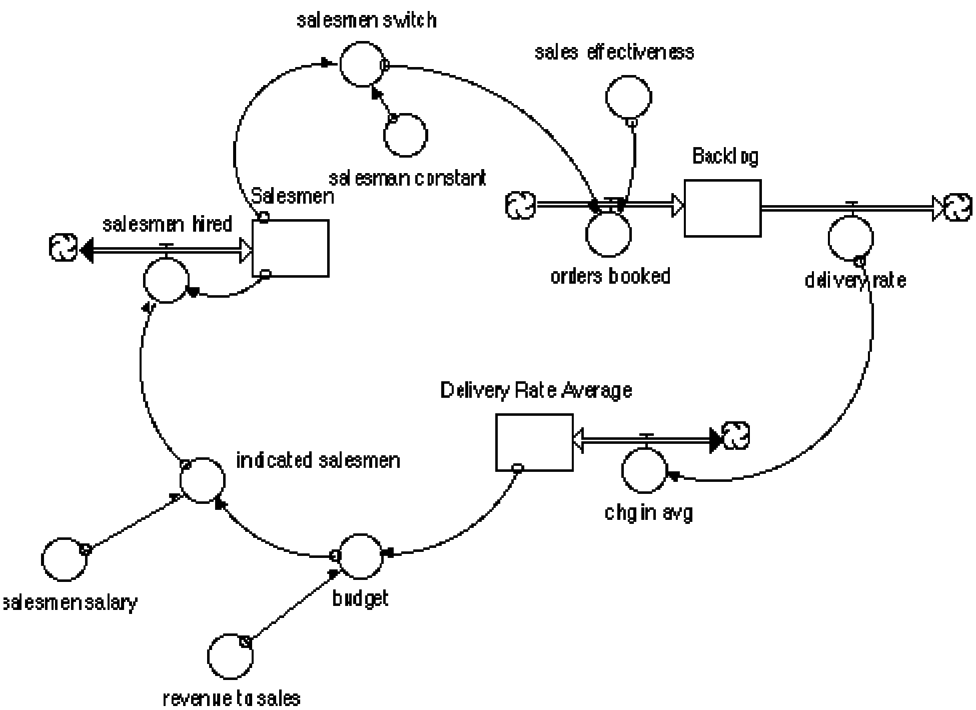


Figure 13. The Sales Sector of Forrester's Market Growth Model

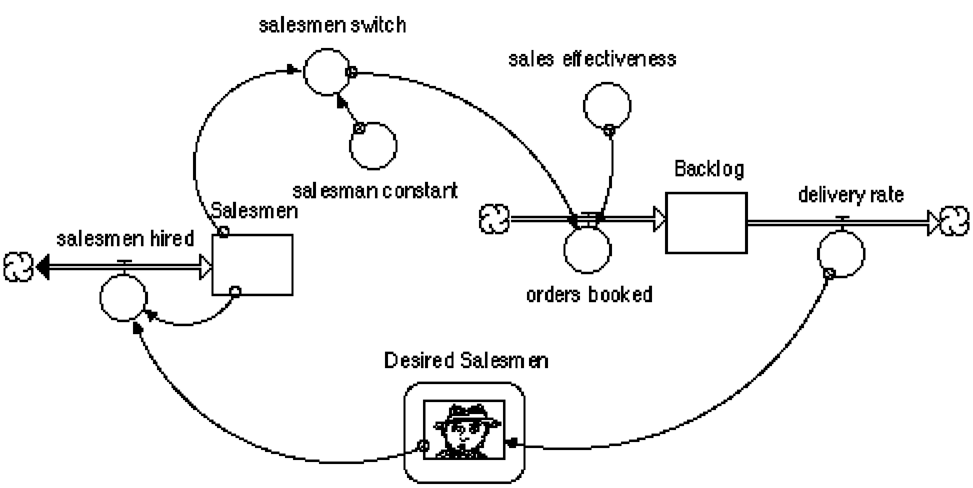


Figure 14. Sales Sector with Space-compression

The SCO is used to "roll up" the logic associated with the calculation of a desired level of sales force. On a first pass, the SCO enables people to grasp the higher-level concept that somehow delivery rate is being used as an input to the determination of the desired number of sales people, and that this desired number then is being used to determine sales force hiring/layoff rates. That's enough logic to swallow on a first-pass - both visually and conceptually. The use of the SCO enables someone first perusing the structure to skip quickly around the loop before getting into the detail of how the desired number of sales people is determined. When the person perusing the structure is ready to examine this detail, they simply double-click on the Desired Salesmen icon. When they do, the icon will open, and its contents will "de-compress," as shown in Figure 15.

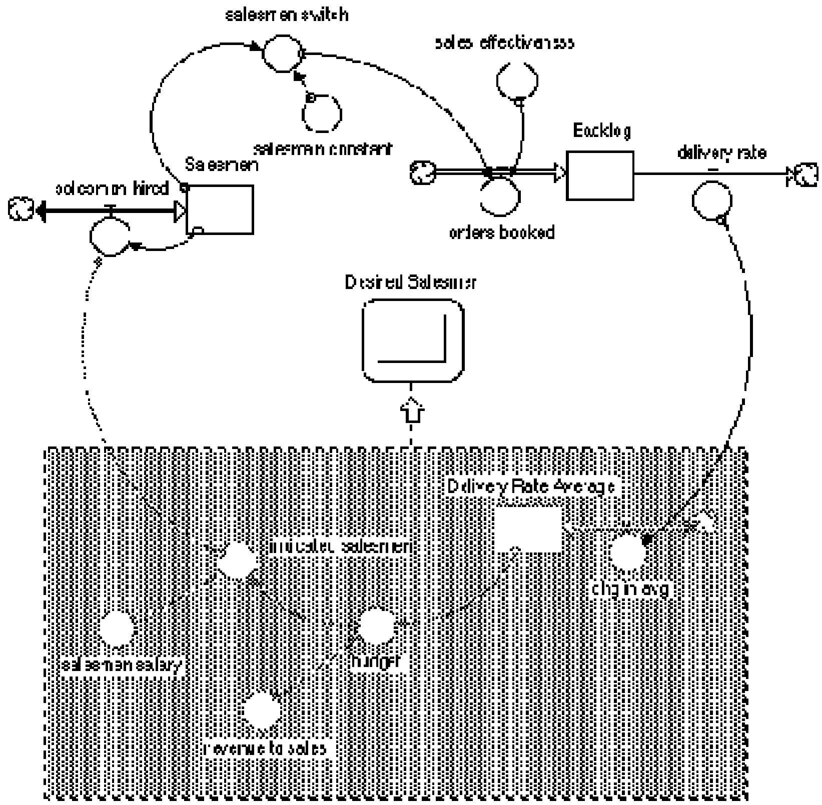


Figure 15. Sales Sector with Space-compression Object Opened

The logic of the Desired Salesmen calculation then can be imbibed. And because the de-compressed structure exists in the same window as the non-compressed diagram structure (i.e., as opposed to floating about in a separate window), the imbibing will unfold within the visual context of the rest of the system. After the detail is understood, it then can be retracted back up into the space compression icon.

By providing people with a way to remain "in control" of the visual complexity which almost inevitably accompanies most stock/flow diagrams, the space-compression object can serve as an effective vehicle for addressing the issue of visual complexity, and hence can help to accelerate the dissemination of Systems Thinking.

Parting Words: We should embrace the name "Systems Thinking" over "System Dynamics," while being certain to continue to acknowledge both the core contributions of the Founder of the field, Jay Wright Forrester, and the associated important shift in practice orientation (from "give fish," to "teach to fish"). It makes no sense to spend our limited energy quibbling over a name for our enterprise. Instead, we should spend it identifying the impediments to the assimilation of the stock/flow diagramming language, and its counterpart, operational thinking. Operational thinking is not yet easy, or natural, for most people to do. This is due, in part, to the fact that most people naturally think in an undisciplined, Laundry List way. However, it is also due to some issues associated with the stock/flow language itself. We must squarely face up to the challenges inherent in bringing about a major paradigm shift, and in improving our language. Shying away from these challenges by either consciously or unwittingly diluting the essence of what Systems Thinking has to offer is not the way to go - especially when doing so makes the task of assimilating operational thinking even more difficult (by tacking on an "un-learning" agenda), and also runs the risk of discrediting the field! Let's focus our energies on building the broad-based Systems Thinking capacity that's needed to improve the way the world works.

References

Forrester, Jay W., 1961 Industrial Dynamics, Productivity Press.

Forrester, Jay W., 1968 Market Growth as Influenced by Capital Investment, Sloan Management Review, p 83 - 105.

Forrester, Jay W., 1969 Urban Dynamics, Productivity Press.

Forrester, Jay W., 1971 World Dynamics, Productivity Press.

McKinsey, 1992 The CEO as a Designer, The McKinsey Quarterly, Number 2.

Meadows, et al 1972 The Limits to Growth, Universe Books.

Richmond, B., 1985 A User's Guide to STELLA®, High Performance Systems, Inc.

Richmond, Peterson, Vescuso 1987 An Academic User's Guide to STELLA, High Performance Systems, Inc.

Richardson, G., 1991, Feedback Thought in Social Science and Systems Theory, U of Pennsylvania Press.

Senge, P., 1990, The Fifth Discipline, Doubleday.
