A Brief Introduction to Systems Diagrams

Why systems thinking is important

Societies, organizations, and living beings are systems. The essence of the systems approach is to understand the "structure" of the system by understanding the relationships and interactions among its parts. The premise, a key principle of system dynamics, is that *the behavior of the system is determined primarily by its internal structure, not by external influences*.

It's not that external influences do not affect system behavior, it's that first we look for how the system itself may be creating (or will create) behavior. When an external influence is considered, the premise is that the system's response to that external influence is determined by its internal structure, not by the external influence. "Structure" is used in a very specific way in this context; it consists of the influences of system variables on each other. For example, all else being equal, increasing "travel time" decreases the "attractiveness of driving."

Because everything is connected to everything else, we can't simply "map or model the system." Determining the boundary of the system is a major, but necessary, challenge. We establish a system boundary by defining the problem to be addressed, not the system to be understood.

What is systems thinking?

Seeking to understand system behavior by examining "the whole" … instead of by analyzing the parts.

What is structure?

The influences and interdependencies among actions and measures, including feedbacks, that determine system behavior.

What is feedback?

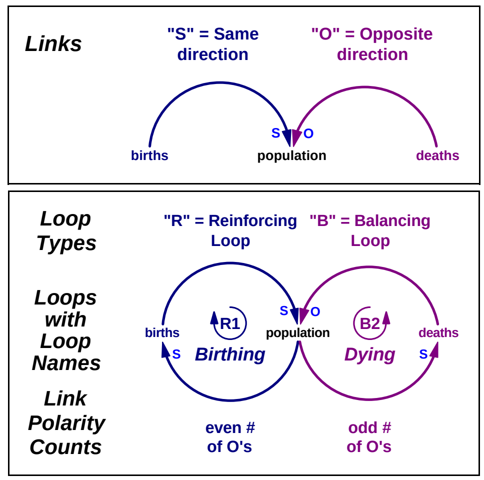
In this context, it is not "constructive criticism." It's when changes in one part of the system affect other parts of the system, which in turn affect the original part.

The language of causal loop diagrams (CLDs)

In a CLD:

- An "S" means an influence in the "Same" direction, e.g., *more* "births" give *more* "population," or *fewer* "births" give *less* "population" (than there otherwise would have been).
- An "O" means an influence in the "Opposite" direction, e.g., *more* "deaths" gives *less* "population" … or *fewer* "deaths" gives *more* "population" (than there otherwise would have been).
- Loops are reinforcing if there are an even number of "O" links (zero being an even number). The action of a Reinforcing Loop is to increase or decrease the amplitude of the behaviors associated with the loop.
- Loops are balancing if there are an odd number of "O" links. The action of a Balancing Loop is goal seeking, to decrease the variations in behaviors associated with the loop (though large oscillations can result if there are long delays).
- A slash across a link indicates that it has a significantly longer time delay than the other links.
- Diagrams may use + for S, and - for O. This is more rigorously correct, in that an influenced variable may be a positive or negative function of the influence; or, alternatively, the influence may be added to, or subtracted from the variable.

Links and Loops

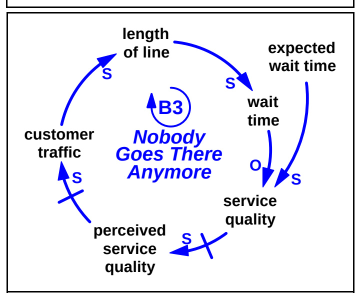


How to read CLDs

Though some diagrams are complex, they are relatively simple to read. The loops are essentially stories; follow the arrow links to read them. As an example, at right is a diagram that goes with a saying; read it like this:

- *More* "customer traffic" creates a *longer* "length of line."
- A *longer* "length of line" creates *more* "wait time."
- *More* "wait time" results in *lower* "service quality." [Note "wait time," compared to "expected wait time," determines "service quality." The *greater* the "expected wait time," the *better* the "service quality."]
- *Lower* "service quality" results in *lower* "perceived service quality" … after some delay. That is, it takes us time to perceive that the service quality is lower.
- After some delay (that is, after this happens to some people one or more times), *less* "perceived service quality" results in *less* "customer traffic."

"That place is too popular.
Nobody goes there anymore."
Yogi Berra

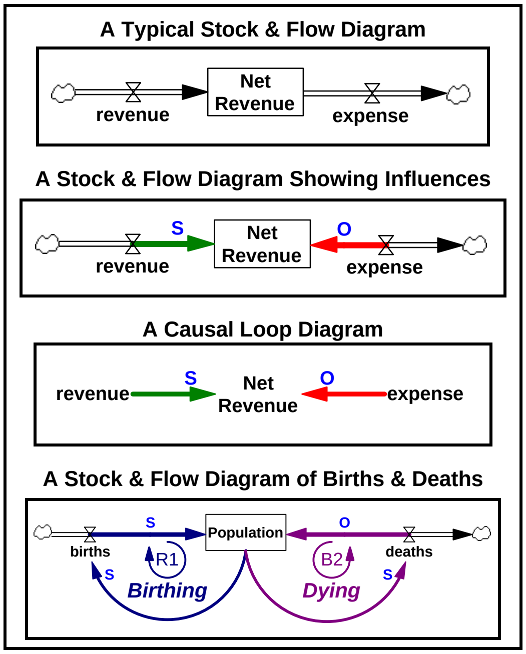


In this example we started with *more* "customer traffic" and completed the loop with *less* "customer traffic." The diagram's "story" can also be told in the opposite sense, starting with *less* "customer traffic," etc., and ending with *more* "customer traffic."

This is an example of a "goal-seeking" balancing loop, where going entirely around the loop creates an influence that counteracts the initial change.   A balancing loop's action is similar to that of a home heating system with a thermostat; in this case "expected wait time" is the thermostat setting. A thermostat-like reference is present for all balancing loops, either explicitly or implicitly (it's best to show it explicitly). This diagram shows that "customer traffic" increases until "wait time" equals the "expected wait time." If "wait time" increases above the "expected wait time," the influence will cause "customer traffic" to fall back to a level where "wait time" equals "expected wait time" … and perhaps then oscillate about that level (… the oscillation could be damped or undamped).

In the case of a reinforcing loop, going around the entire loop produces an action in the same direction as the original action … it produces an increasing or decreasing response (an increasing feedback example is the squeal of sound system feedback). Reinforcing loops are two-edged swords; they can be either virtuous or vicious cycles.

Stock and Flow (S&F) diagrams and how to read them



A S&F diagram distinguishes between stocks and flows; it shows the flows into and out of the stocks. A stock is represented by a rectangle and flows are indicated by valve-like structures. In the example at right, the "Net Revenue" is the difference between "revenue" and "expense."

A stock is the accumulation of the flows over time. Mathematically, a stock is the integral (the accumulation) of the flows over time. This sounds complicated, but it is our common experience. The water in a lake is the accumulation over time of the water flow into the lake minus the water flow out of the lake. This means that nature integrates!

The links between the valves and arrows have the polarity indicated. Note that, though the S&F "expense" flow arrow goes <u>*out*</u> of the "Net Revenue" stock (showing that cost is an outflow), the *influence* of the "expense" variable is <u>*on*</u> "net revenue" and the influence is negative.

As shown in the causal loop diagram format of the same structure, the arrow goes from "expense" to "Net Revenue." Note that the typical causal loop diagram does not distinguish between stocks and flows. And sometimes does not even show the Ss and Os.

It's good to remember though that in a S&F simulation model, whether a flow is actually in or out of a stock is determined by the equations governing the flow, not the direction of the arrows.

Why do loops matter?

Loops matter because nothing grows without a reinforcing process. And nothing grows forever, because limiting actions of some kind always arise. The influences and loops are structure. As noted above, though there are outside forces that act on a system, the response of a system to those external influences is determined by the structure of the system. Unless we understand the reinforcing and balancing feedbacks, the drivers of behavior, we cannot design policies to produce the behaviors we desire.

The diagrams form a "theory of the system." Theory is not just academic; it is very practical. The word "theory" comes from the same root as the word "theater" … both are ways of displaying our thinking. Systems thinking is an especially useful lens through which to gain insight; and it creates a framework for productive dialogue. Talking about the issues in the context of the diagrams can be very powerful. Beyond that, because we can't simulate even simple models in our heads, it's sometimes necessary that we create a system dynamics model, gather data to populate the model, then engage in simulation, testing, and dialogue … and iterate and iterate and ….

Questions to ask about models:

- Does the structure have the potential to create the behavior observed?
- Is there disagreement about the influences in the model? If so, the disagreement is an opportunity for learning. Often models can be altered to display the alternate competing effects … with *both/and* thinking, rather than *either/or* thinking. In other cases, disagreement can point to data that's needed to resolve the dispute.
- What measures are we missing that are needed to track what's happening? There's so much data that could be taken, we need theory to guide us in selecting the data to collect … the data that will be most useful in confirming or disconfirming theory.[1]
- Are there latent potential feedbacks that are not yet activated? They could affect the future behavior of the system.[2]

Models are always incorrect. They are only approximations, not the real thing. So they're not about their absolute correctness, but about their usefulness for as a foundation for dialogue and understanding the root of system behavior with respect to the problem being addressed.

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1 Every measurement is guided by some explicit or implicit theory that tells us that the measure is important. Unfortunately, we often manage based on the measures we happen to have, rather than the measures that are most important.

2 This points to a difficult aspect of modeling. Just because a model predicts the past does not mean it can tell us what will happen in the future. Dormant loops often become active and produce what we perceive as "surprising behavior." For this reason, using spreadsheets (which don't capture feedback) of past performance and projecting into the future with regression formulas is like driving while looking through the rear view mirror. This is a major weakness of econometrics.