CAUSAL LOOP CONSTRUCTION: THE BASICS

BY
COLLEEN LANNON

Systems thinking has been described as a language for talking about the complex, interdependent issues managers face every day. Within that framework, causal loop diagrams can be thought of as sentences that are constructed by identifying the key variables in a system (the “nouns”) and indicating the causal relationships between them via links (the “verbs”). By linking together several loops, you can create a concise story about a particular problem or issue.

A causal loop diagram consists of four basic elements: the variables, the links between them, the signs on the links (which show how the variables are interconnected), and the sign of the loop (which shows what type of behavior the system will produce). By representing a problem or issue from a causal perspective, you can become more aware of the structural forces that produce puzzling behavior.

By linking together several loops, you can create a concise story about a particular problem or issue.

Take the example of an HR team that has been responsible for integrating a Total Quality approach in an organization. In the beginning, there was much enthusiasm around the program, and demand for training was high. There were also some well-publicized successes in several local line teams. But over time, the TQM programs seemed to produce diminishing results, and interest in TQM activities slacked. What happened?

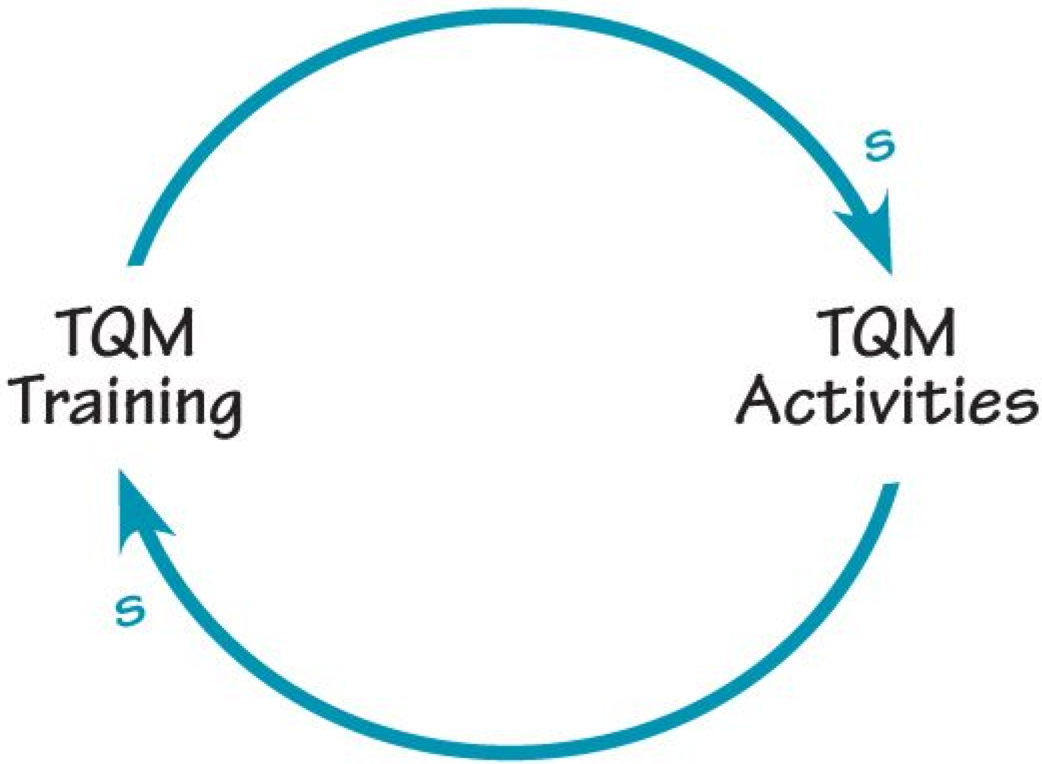
1. Create Variable Names

The first step in creating a causal “story” is to identify the nouns—or variables—that are important to the issue. Remember, a variable is something that can vary over time. In the TQM example, “TQM Activities” and demand for TQM Training” are important elements of the story. Upon further conversation, the team also agreed that the “Perceived Threat” of the new program was an important element, as was the “Resistance by Middle Managers” and their willingness to change.

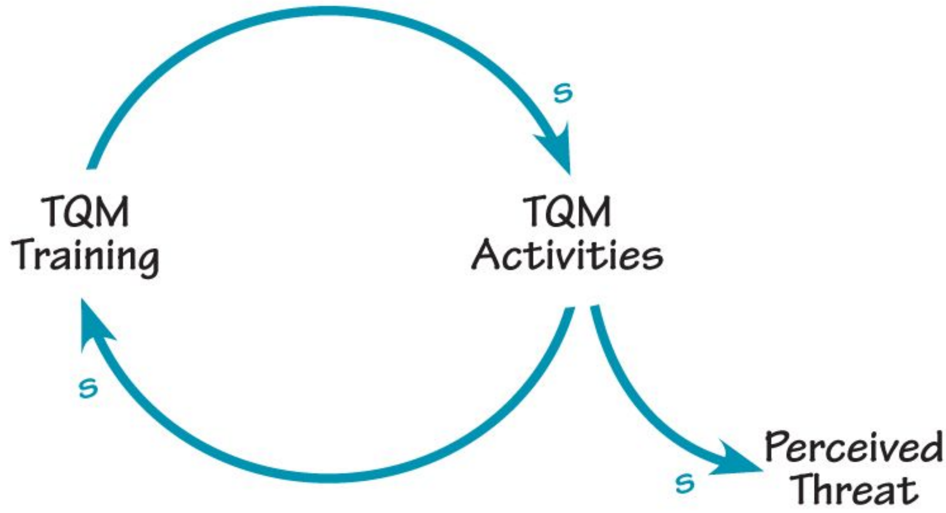
2. Draw the Links

Once you have identified the variables, the next step is to fill in the "verbs," by linking the variables together and determining how one variable affects the other. In the language of systems thinking, links are labeled with either an "s" or an "o."

If variable B moves in the same direction as variable A, the link from variable A to B would be labeled with an "s"(or "+"). In the TQM story, the team noticed that in the beginning, TQM activities generated demand for TQM training—as activities went up, training went up (indicated by an "s" link). Similarly, as training increased, it generated even more TQM activities—another "s" link.

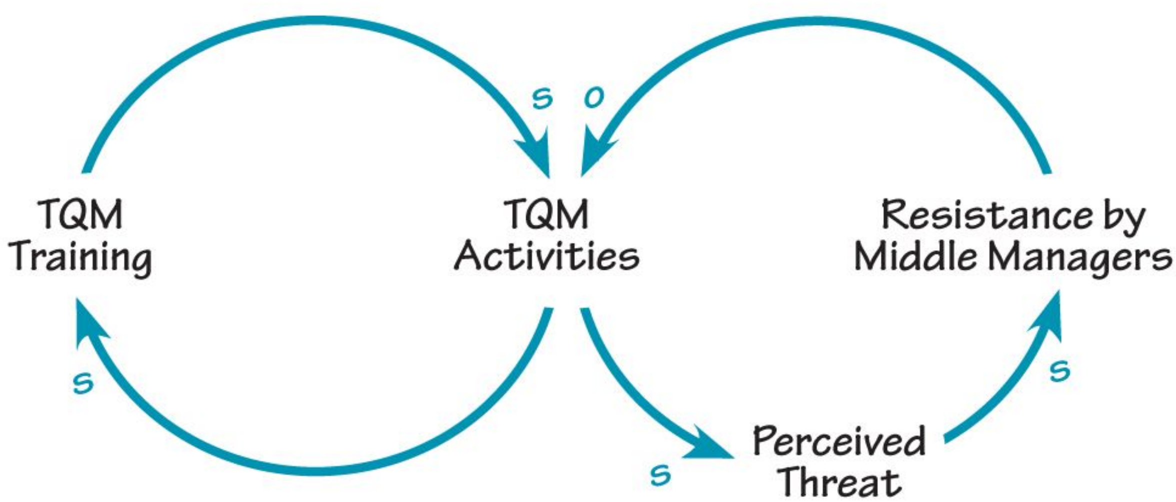


However, as TQM activities increased, the perceived threat of these activities also increased (another “s” link), which led to resistance by middle managers (another “s” link).



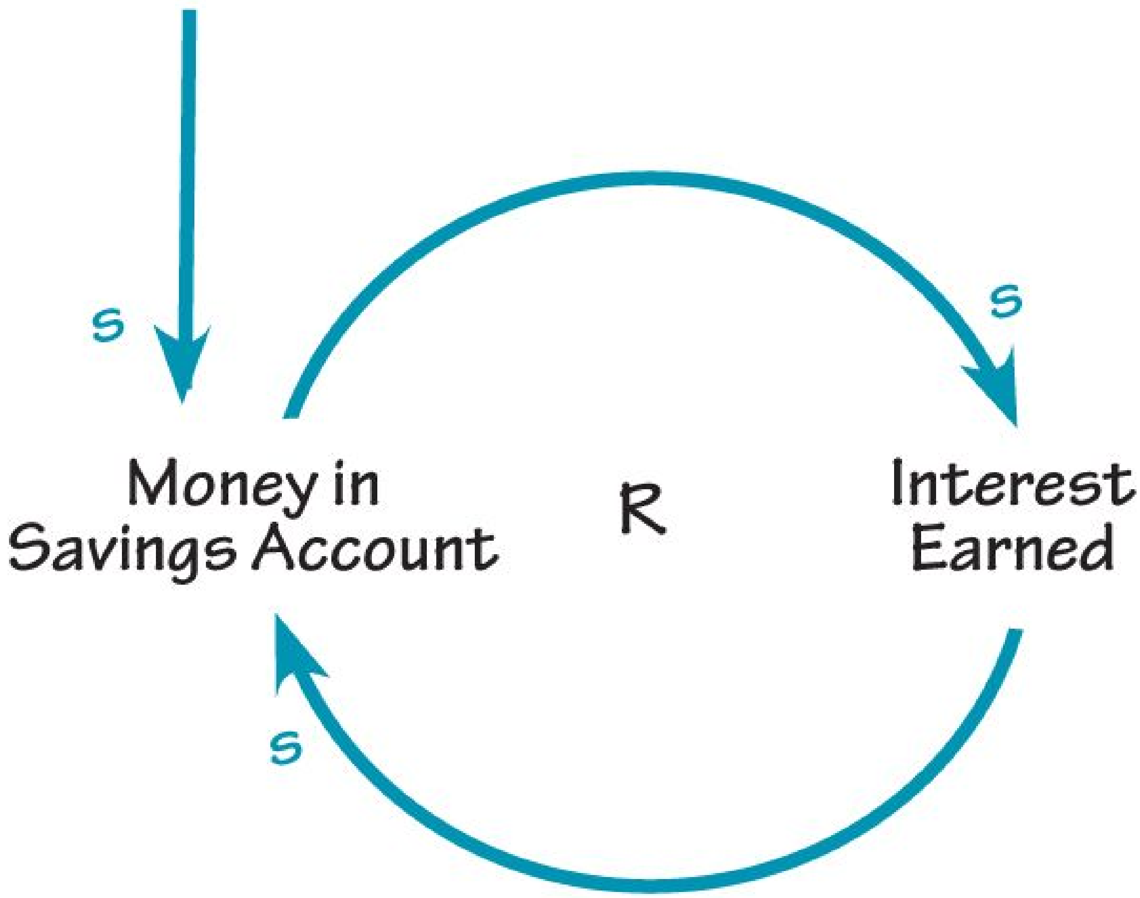
If variable B changes in a direction opposite of A (i.e., as A increases, B decreases), the link from A to B should be labeled with an “o” (or “-“). For example, the HR team noticed that, as the resistance by middle managers increased, the number of TQM activities decreased, which would be indicated by an “o.”

At this point, the causal “story” consists of two causal loops that are linked through the common variable “TQM Activities.”

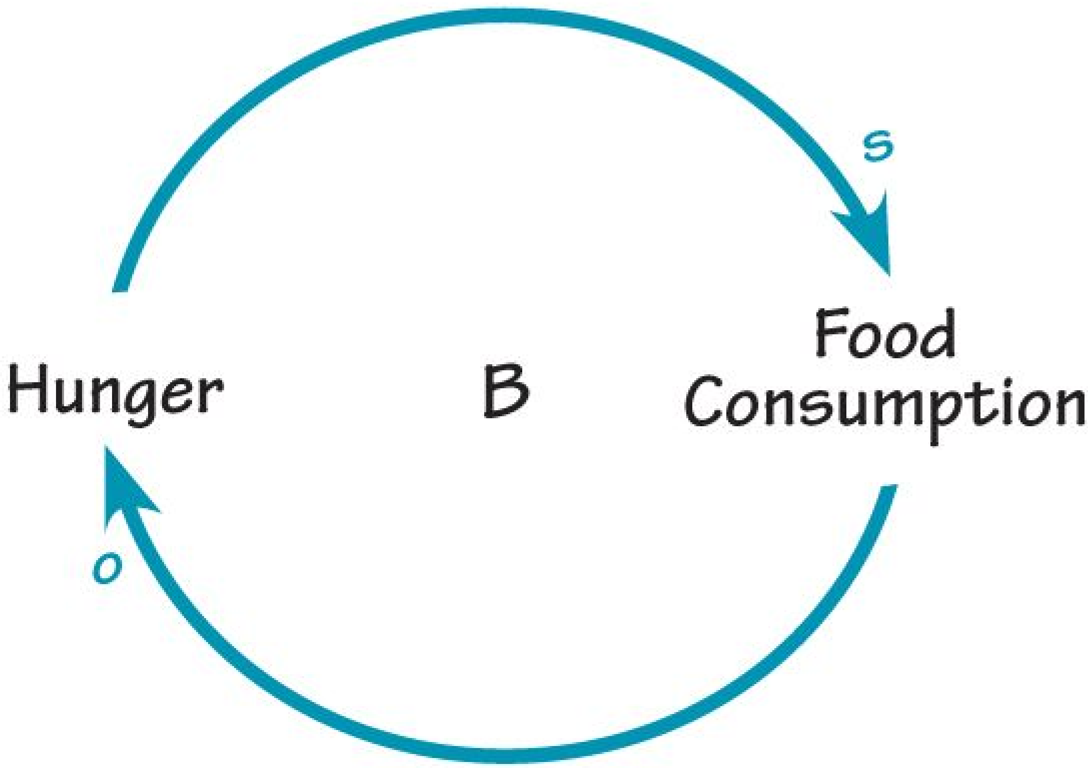


3. Label the Loop

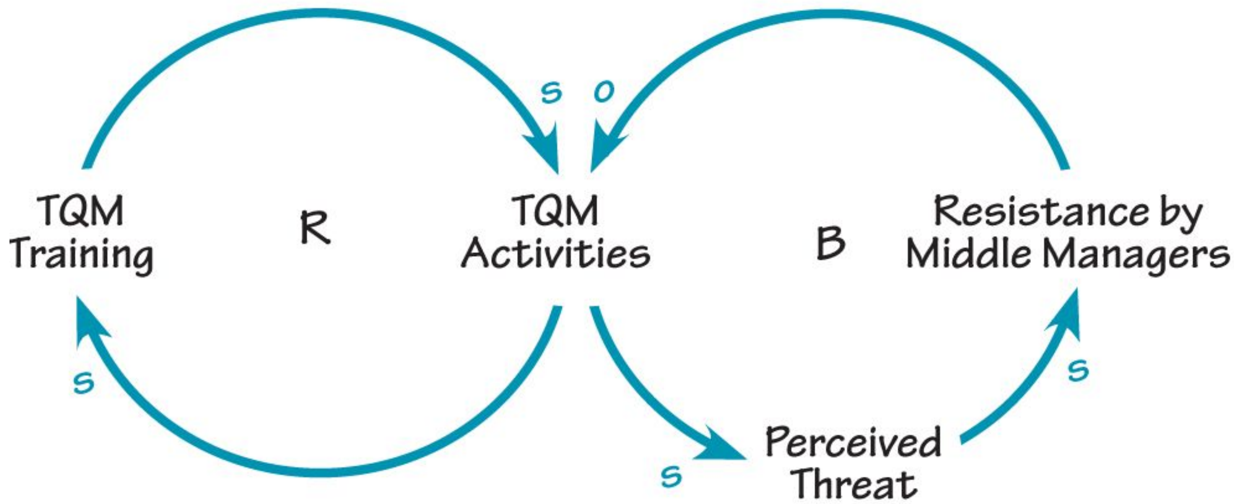
Once you have completed all of the links in the loop, you want to determine what type of behavior it will produce. In systems thinking, there are two basic types of causal loops: reinforcing and balancing. In a reinforcing loop, change in one direction is compounded by more change. For example, money in a savings account generates interest, which increases the balance in the savings account and earns more interest.



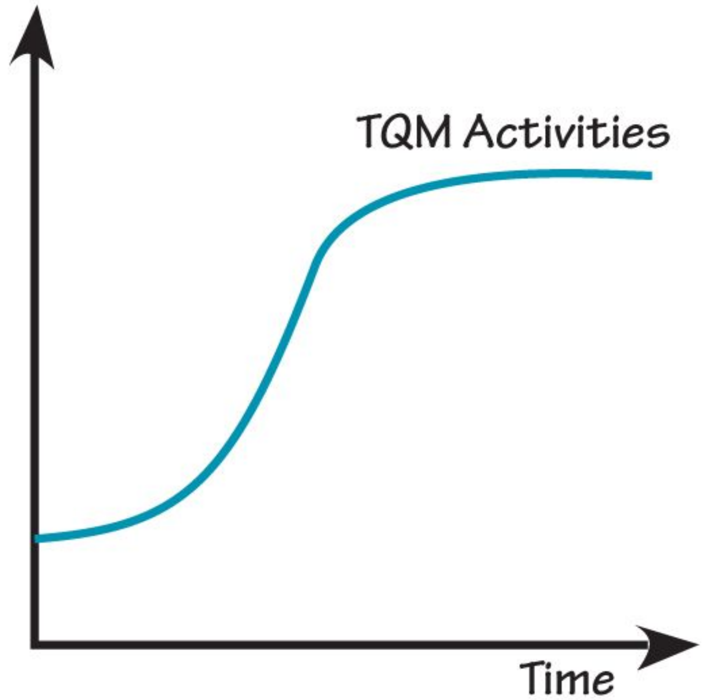
Balancing loops, in contrast, counter change in one direction with change in the opposite direction. Balancing processes attempt to bring things to a desired state and keep them there, much as a thermostat regulates the temperature in a house. For example, when we are hungry, our body sends a signal to our brain that it's time to eat, which appeases the hunger.



To determine if a loop is reinforcing or balancing, one quick method is to count the number of "o's." If there are an even number of "o's" (or none are present), the loop is reinforcing. If there are an odd number of "o's," it is a balancing loop. You should always double-check this method by walking through the loop to make sure the links are labeled correctly. In the TQM story, the "TQM Training" loop (which has two "s" links) is a reinforcing loop (labeled with an "R"), while the "Resistance by Middle Managers" loop (which has one "o" link) describes a balancing process that seeks to "balance" the growth in TQM activities (labeled with a "B").



TIP: Another way to double-check the expected type of loop is to draw the behavior of the system over time. A reinforcing loop shows exponential growth (or decay); a balancing loop tends to produce oscillation or movement toward equilibrium.



4. Talk Through the Loop

Once you have completed the causal loop diagram, it is wise to walk through the loops and “tell the story,” to be sure the loops capture the behavior being described. In the TQM example, the loops tell the following story: “Initial TQM activities led to an increase in TQM training, which led to more TQM activities throughout the company. However, as the number of activities increased, the perceived threat also increased, which led to increased resistance by middle managers, and a decrease in overall TQM activities.”

Storytelling

By using causal loop diagrams to create stories about complex issues, we can make our understanding of the interrelationships within a system’s structure more explicit. The resulting diagrams also provide a visual representation that can be used to communicate that understanding with others. With practice, we can become more adept at telling systems stories that help us recognize the multiple, interdependent effects of our actions.

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FINE-TUNING YOUR CAUSAL LOOP DIAGRAMS—PART I

BY
JOHN STERMAN

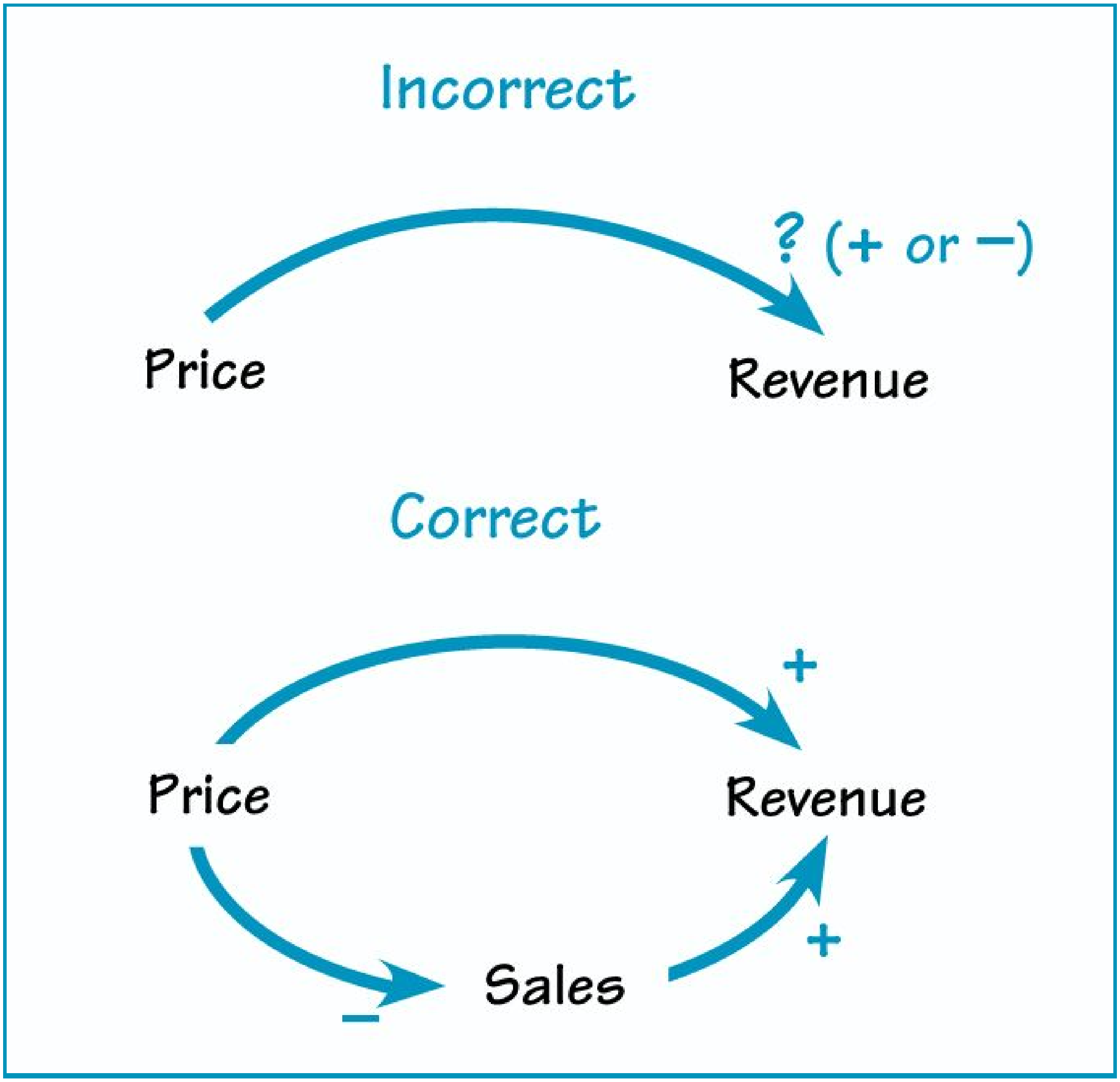
Causal loop diagrams are an important tool for representing the feedback structure of systems. They are excellent for

- Quickly capturing your hypotheses about the causes of dynamics;
- Eliciting and capturing the mental models of individuals and teams;
- Communicating the important feedback processes you believe are responsible for a problem.

The conventions for drawing CLDs are simple but should be followed faithfully. Think of CLDs as musical scores: At first, you may find it difficult to construct and interpret these diagrams, but with practice, you will soon be sight-reading. In this article, I present some important guidelines that can help you make sure your CLDs are accurate and effective in capturing and communicating the feedback structure of complex systems.

Avoid Ambiguity in Labeling Causal Links

AMBIGUITY OF LINKS



To be effective, your CLD should not include any ambiguous causal links. Ambiguous polarities usually mean there are multiple causal pathways that you should show separately.

People sometimes argue that a specific link in a CLD can be either positive or negative, depending on other parameters or on where the system is operating. For example, we might draw a diagram that relates a firm's revenue to the price of its product and then argue that the link between price and company revenue can be either positive or negative, depending on the elasticity of demand (see “Ambiguity of Links”). A higher price means less revenue if a 1 percent increase in price causes demand to fall more than 1 percent. This link would be labeled with a negative sign. But less elastic demand might mean a 1 percent increase in price causes demand to fall less than 1 percent, so revenues would then rise, resulting in a positive link polarity.

When you have trouble assigning a clear and unambiguous sign to a link, it usually means there is more than one causal pathway connecting the two variables. You should make these different pathways explicit in your diagram. The correct diagram for the impact of price on revenue would show that price has at least two effects on revenue: (1) it determines how much revenue is generated per unit sold (a positive link), and (2) it affects the number of units sold (usually a negative link).

'+' AND '–' VS. 'S' AND 'O'

In system dynamics modeling, the polarity of causal links is indicated by “+” or “-“. In recent years, some people (including THE SYSTEMS THINKER) began to use “s” and “o”. Pros and cons of each have been debated ever since. Following standard system dynamics practice, I recommend the “+” and “-” notation, because it applies equally correctly to ordinary causal links and to the flow-to-stock links present in all systems, while “s” and “o” do not. For further information, see George Richardson, “Problems in Causal Loop Diagrams Revisited,” System Dynamics Review 13(3), 247-252 1997), and Richardson and Colleen Lannon, “Problems with Causal-Loop Diagrams,” TST V7N10.

Is It Reinforcing or Balancing?

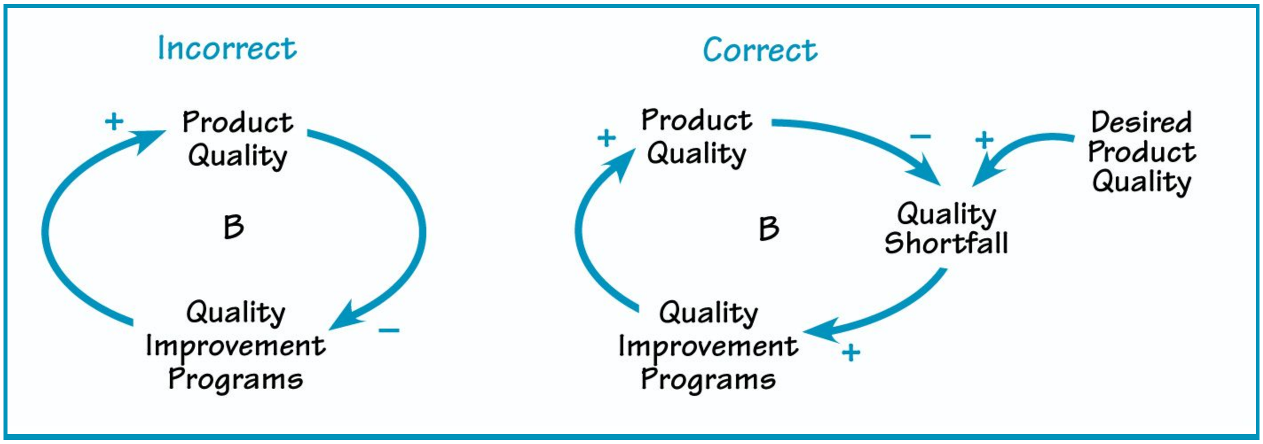
There are two methods for determining whether a loop is reinforcing or balancing: the fast way and the right way. The fast way, which you may have learned when you first started working with CLDs, is to count the number of negative links—represented by “-” or “o”—in the loop (see “‘+’ and ‘-’ Vs. ‘s’ and ‘o’”). If the number is even, the loop is reinforcing; if the number is odd, the loop is balancing. However, this method can sometimes fail, because it is all too easy to mislabel a link's polarity or miscount the number of negative links.

The right way is to trace the effect of a small change in one of the variables around the loop. Pick any variable in the loop. Now imagine that it has changed (increased or decreased), and trace the effect of this change around the loop. If the change feeds back to reinforce the original change, it is a reinforcing loop. If it opposes the original change, it is a balancing loop. This method works no matter how many variables are in a loop and no matter where you start.

Make the Goals of Balancing Loops Explicit

All balancing loops have goals, which are the system's desired state. Balancing loops function by comparing the actual state to the goal, then initiating a corrective action in response to the discrepancy between the two. It is often helpful to make the goals of your balancing loops explicit, usually by adding a new variable, such as "desired product quality" (see Desired Product Quality in "Explicit Goals"). The diagram shows a balancing loop that affects the quality of a company's product: The lower the quality, the more quality improvement programs the company initiates, which, if successful, correct the quality shortfall.

EXPLICIT GOALS



Making goals explicit in balancing loops encourages people to ask questions about how the goals are formed. For example, what drives a company's desired level of quality?

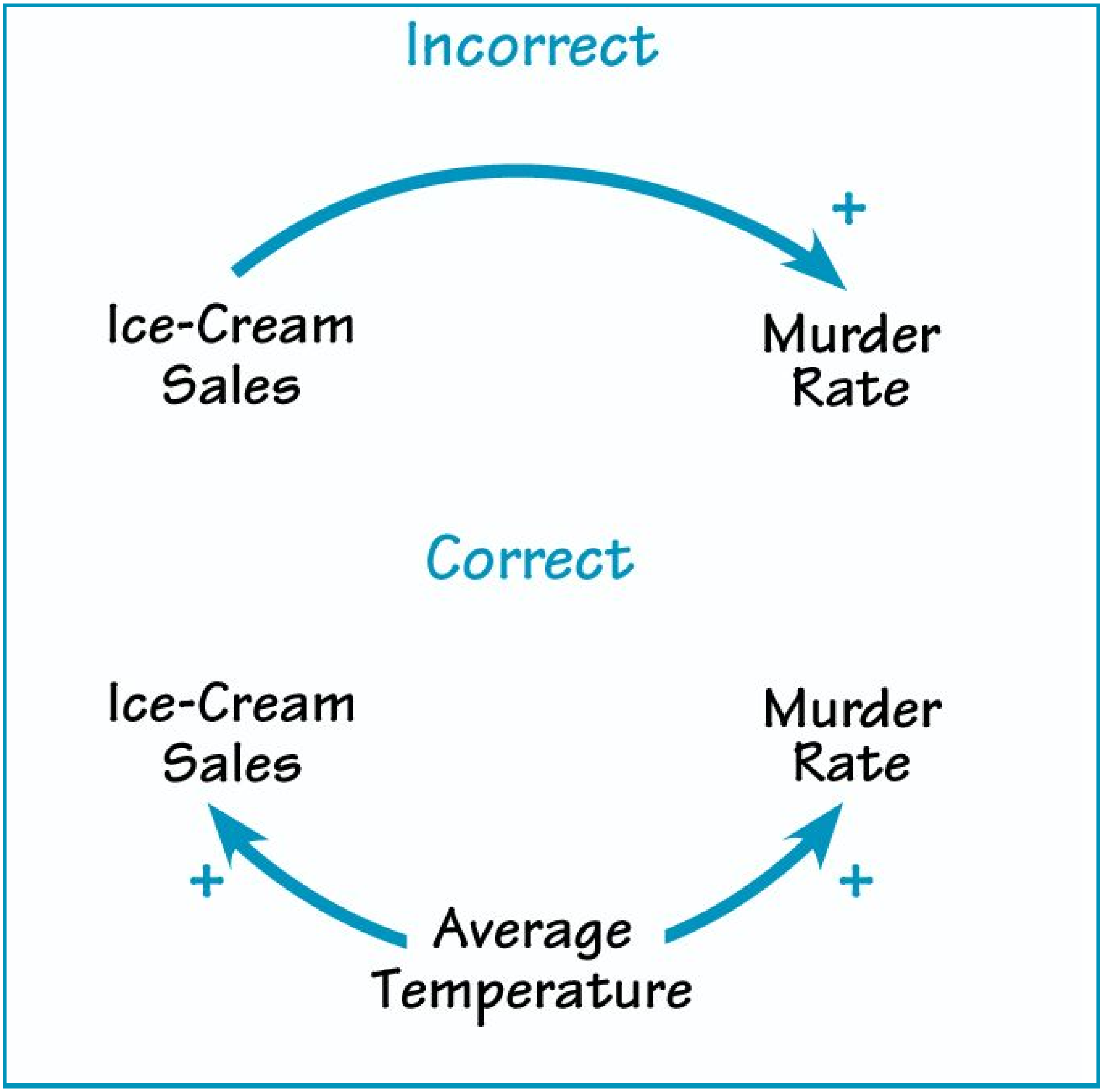
Making goals explicit encourages people to ask how the goals are formed; for instance, who determines desired product quality and what criteria do they use to make that determination? Hypotheses about the answers to these questions can then be incorporated in the diagram. Goals can vary over time and respond to pressures in the environment, such as customer input or the quality of competing products.

Making the goals of balancing loops explicit is especially important when the loops capture human behavior—showing the goals prompts reflection and conversation about the aspirations and motives of the actors. But often it is important to represent goals explicitly even when the loop doesn't involve people at all.

Represent Causation Rather Than Correlation

Every link in your diagram must represent what you and your colleagues believe to be causal relationships between the variables. In a causal relationship, one variable has a direct effect on another; for instance, a change in the birth rate alters the total population. You must be careful not to include correlations between variables in your diagrams. Correlations between variables reflect a system's past behavior, not its underlying structure. If circumstances change, if previously dormant feedback loops become dominant, or if you experiment with new decisions and policies, previously reliable correlations among variables may break down.

ICE-CREAM SALES AND MURDERS



Causal loop diagrams must include only what you believe to be genuine causal relationships, never correlations, no matter how strong.

For example, though sales of ice cream are positively correlated with the murder rate, you may not include a link from ice-cream sales to murder in your CLD. Such a causal link suggests that cutting ice-cream consumption would slash the murder rate and allow society to cut the budget for police and prisons. Obviously, this is not the case: Both ice-cream consumption and violent crime tend to rise in hot weather. But the example illustrates how confusing correlations with causality can lead to terrible misjudgments and policy errors (see “Ice Cream Sales and Murders”).

While few people are likely to attribute murders to the occasional double-dip cone, many correlations are more subtle, and it is often difficult to determine the underlying causal structure. A great deal of scientific research seeks the causal needles in a huge haystack of correlations: Can eating oat bran reduce cholesterol, and if it does, will your risk of a heart attack drop? Does economic growth lead to lower birth rates, or is the lower rate attributable to literacy, education for women, and increasing costs of child-rearing?

Do companies with serious quality improvement programs earn superior returns for stockholders?

Scientists have learned from experience that reliable answers to such questions are hard to come by and require dedication to the scientific method—controlled experiments; randomized, double-blind trials; large samples; long-term followup studies; replication; statistical inference; and so on. In social and human systems, such experiments are difficult, rare, and often impossible. You must take extra care to determine that the relationships in your CLDs are causal, no matter how strong a correlation may be.

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This article is part of a 2-part series. Click here to view the second part.

balancing,
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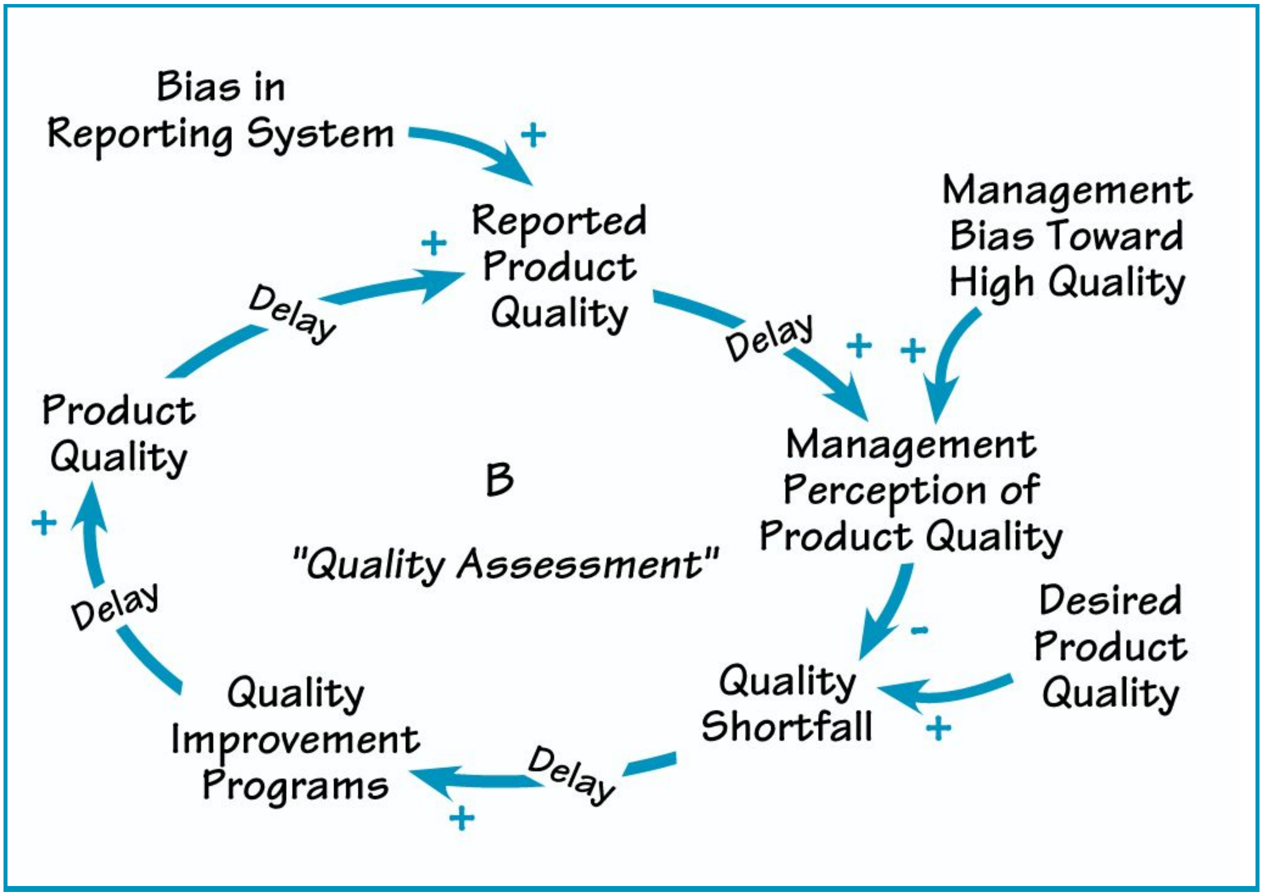
FINE-TUNING YOUR CAUSAL LOOP DIAGRAMS—PART II

Distinguish Between Actual and Perceived Conditions

Perceptions and reality often differ, and it is usually important to capture these differences in your causal diagrams. The true state of affairs can be very different from the perception of that state by the actors in the system.

WHAT IS THE QUALITY OF OUR PRODUCTS?



Distinguishing between actual and perceived conditions adds important information to a model for the management of product quality.

People's perceptions can be influenced by reporting delays, measurement error, bias, or other distortions, causing people to make different decisions than they would if they had more accurate information.

For example, do the top managers of a firm know the true quality of their products? How do they respond if there is a quality shortfall? In drawing a CLD depicting this situation, separating perceived and actual conditions helps prompt questions such as, How long does it take to measure quality? To change management's opinion about quality even after data are available? To implement a quality improvement program? To realize results? You might discover that there are significant delays in assessing product quality and in changing management's opinion about quality (see "What Is the Quality of Our Products?").

In addition, bias in the reporting system may cause reported quality to differ from quality as experienced by the customer. Customers don't file warranty claims for all problems or report all defects to their sales representatives. Sales and repair personnel may not report all customer complaints to the home office. Sub ordinates, wishing to avoid delivering bad news, may filter the quality assessment in formation that reaches senior management. The diagram shows these biases, helping to explain how management might come to hold a grossly exaggerated view of product quality. Such a model can serve as the basis for conversation about ways to shorten the delays, overcome the biases, and avoid quality erosion.

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Don't Forget Delays

Delays are critical in creating dynamics. Delays give systems inertia, can cause oscillations, and are often responsible for trade-offs between the short- and long-run effects of our policies. Your CLDs should include delays that are important to the dynamics you are trying to represent or are significant relative to the time horizon relevant to your issue.

For example, when the price of a product rises, supply will tend to increase, but only after significant delays while new capacity is ordered and built and while new businesses enter the market. It's therefore important to include these delays (by writing the word "delay" or drawing hash marks over the relevant link) because they will affect the system's behavior over time. Remember that there are both physical, or material, delays, such as the delay between ordering and receiving materials, and information, or perceptual, delays, such as the time required to report sales data, revise forecasts, and make decisions. Both types of delays should be represented in your causal maps.

It's also useful to remember that delays always involve stock and flow structures. This is why it is doubly important to include delays in your diagrams—they will remind you that there is a stock and flow structure embedded in that particular relationship. You can then explore whether it is useful to make that structure explicit in your diagram. Make stock and flow structures explicit if doing so is important in communicating the basis for the dynamics your map seeks to explain.

Don't Put All the Loops into One Large Diagram

Our short-term memory can hold from five to nine chunks of information at once. This limits the effective size and complexity of a causal map. Presenting a complex CLD all at once makes it hard to see the loops, understand which are important, or determine how they generate certain behaviors. Resist the temptation to put all the loops you or your client have identified into a single comprehensive diagram.

How then do you communicate the rich feedback structure of a system without oversimplifying? Build up your model in stages, with a series of smaller causal loop diagrams. Each diagram should correspond to one part of the story being told. These diagrams can have enough detail to show how the process actually operates. Then combine simpler versions of the diagrams into a high-level overview to show how they interact with one another. (For more details about ensuring the clarity of your diagrams, see “Tips for CLD Layout.”)

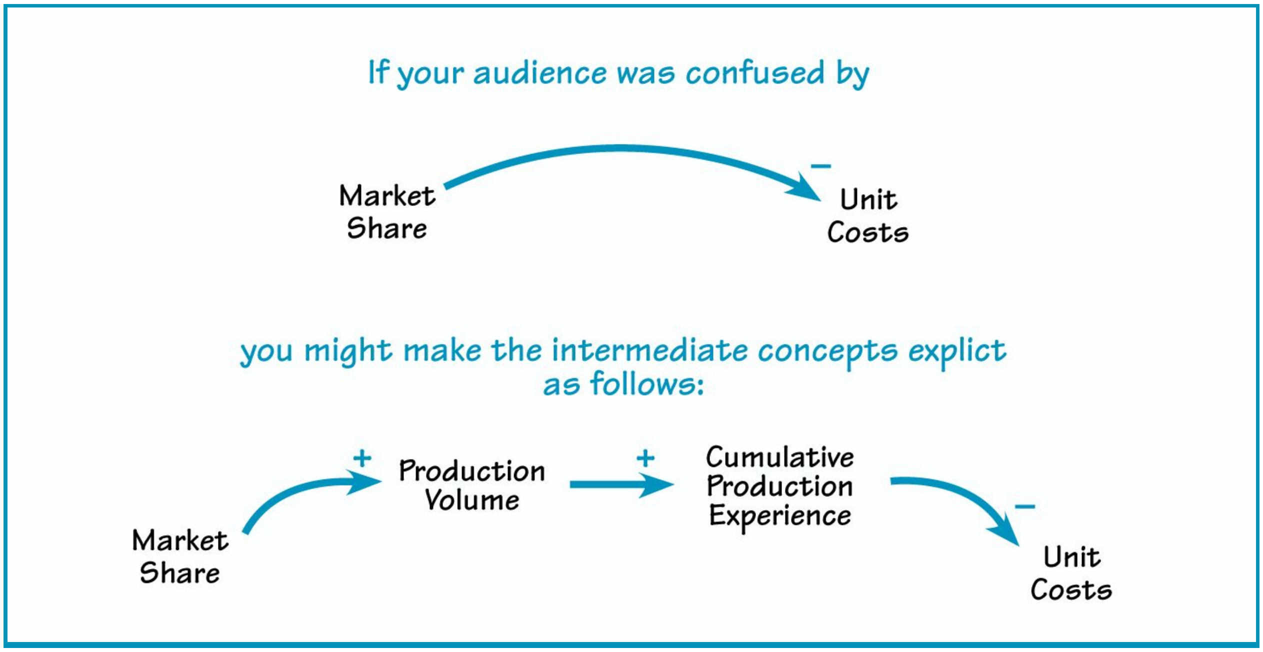
TIPS FOR CLD LAYOUT

To maximize the clarity and impact of your CLDs, follow some basic graphic design principles:

- Use curved lines.
- Draw important loops with circular or oval paths.
- Organize your diagrams to minimize crossed lines.
- Don’t put circles, hexagons, or other symbols around the variables. Symbols without meaning only serve to clutter and distract (the exception is when you need to make a stock and flow relationship explicit).
- Iterate. Because you often won’t know what all the variables and loops will be when you start, you will have to redraw your diagrams, often many times, to find the best layout.

Check to make sure your audience is following the logic of the causal links. If they are not able to follow the thinking without assistance, you may need to include more detail or make some of the intermediate variables more explicit. “Making Links Explicit” shows an example.

MAKING LINKS EXPLICIT



Make intermediate links explicit to clarify a causal relationship.

Once you've clarified the logic to the satisfaction of all, you often can "chunk" the more detailed representation into a simpler, more aggregate form. The simpler diagram then serves as shorthand for the richer, underlying causal structure.

Name Your Loops

Whether you use CLDs to elicit clients' mental models or to communicate the important feedback processes that you believe are responsible for a problem, you will often find yourself trying to keep track of more loops than you can handle. Your diagrams can easily overwhelm the people you are trying to reach. To help your audience navigate the network of loops, give each a number and a name. Numbering the loops R1, R2, B1, B2, and so on helps your audience find each loop as you discuss it. Naming the loops helps your audience understand the function of each loop and provides useful shorthand for discussion.

When working with a client group, it's often possible to get them to name their own loops. Many times, they will suggest a whimsical phrase or some organization-specific jargon for each loop. For instance, if you have a loop that depicts how working too much overtime might eventually undermine productivity, the group might label it "Burnout." They might call a loop that shows how schedule pressure can lead to increased errors "Haste Makes Waste." Loop names make it easy to refer to complex chunks of feedback structure, leading to productive conversations and, ultimately, changes in deeply ingrained behavior.

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