Systems Thinking: A Tool for Municipalities

by Stephan E. Brown, M.A., and Daniel C. Lerch

> *Folks who do systems analysis have a great belief in 'leverage points.' These are places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything....*
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> *...I don't think there are cheap tickets to system change. You have to work at it, whether that means rigorously analyzing a system or rigorously casting off paradigms. In the end, it seems that leverage has less to do with pushing levers than it does with disciplined thinking combined with strategically, profoundly, madly letting go.*
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> —Donella Meadows, lead author, *Limits to Growth* (1972). From "Places to Intervene in a System," *Whole Earth,* Winter 1997.

Systems theory has been put to practical use in the business world for decades, helping organize global production processes and streamline multinational decision-making networks. More recently, systems thinking concepts have been incorporated into a number of strategic planning methods for local governments.[a] These and other tools can help municipalities better understand the complex systems that are within them, and of which they are parts. Systems thinking will also help municipalities to understand the role of key inputs like oil and natural gas and to identify how municipalities are vulnerable to changes in the availability and price of those inputs.

What is Systems Thinking?

"Don't miss the forest for the trees." This common figure of speech encapsulates the essence of systems thinking: when we think in terms of systems, all we're doing is looking at the whole forest, and not just the trees.

What exactly do we see when we look at a forest? We see trees, certainly, but also animals, brush, soil, water, and many other things. If we put a bunch of trees, a pile of dirt, a tub of water and a family of squirrels together in a big room, however, we clearly wouldn't have a forest: we'd have a mess (or a bad art project). What makes a true forest are the *relationships* between all of its parts: the soil and water nourish the trees, the trees shelter the animals, the animals eat the plants, and so on.

So, systems thinking is first and foremost about relationships. And when we think about how the parts of a system relate to each other, we also notice *changes*: as the soil nourishes the trees, the trees grow larger; when animals and plants die, they decompose and build up more soil. By observing the relationships and changes in a system, we start to develop a comprehensive picture of how the system works. It also spurs us to ask important questions that may help us understand the system better: What happens to the animals and soil as the trees get bigger, and eventually die? What happens to the trees as the soil and animals change?

This way of thinking can be very helpful for understanding why things work (and change) the way they do. It can be applied to anything that is a system—a collection of individual parts working together—whether it's a forest, a car, or a government program. It's useful because if we understand how complex things change, and *why*, we can make better decisions to direct those changes as we see fit.

For example, 60 years ago we tried to stop forest fires as quickly as possible because we thought that fires were simply destroying trees. Since then we've learned that fires are an important part of forest systems, helping kill destructive insects, spread certain seeds, and reduce deadwood that could fuel even more disastrous future fires. Today we contain some fires and let others burn, and manage our healthier forests simultaneously for timber products, wildlife habitat, clean water and recreation. The better we understand the complex relationships in the forest system, the better we are at managing them.

When we do systems thinking, we are thinking about changes (or what systems thinkers call "dynamics") in terms of the relationships underlying them. Systems thinking thus views problems as the products of some structure of relationships, in contrast to conventional linear thinking, which instead explains patterns in terms of simple causes and effects between separate things.

The Municipality as a System

Just about everything that your municipality does or is responsible for can be thought of as a set of relationships, and therefore as a system. For example, your town's budgetary process can be thought of as a system of relationships between incoming tax revenue, the expenses of municipal departments, the priorities of elected officials, and the services the municipality provides. Similarly, your town's street program can be thought of as a system of relationships between the needs of the local economy, the municipal Transportation Plan, the costs of street construction and maintenance, and the city's street maintenance activities.

We can visualize these relationships in a flowchart (Figure A-1). The flowchart below shows that the Municipal Transportation Plan is derived from the needs of the local economy and the costs of building and maintaining streets; the Transportation Plan then affects what will happen with the street maintenance activities. Street construction costs can change quickly, however, so these are also shown as influencing street maintenance activities. Compare all the information this flowchart tells us with the simple list we might have produced had we thought of the street program simply in terms of its components, and not its relationships (Figure A-2).

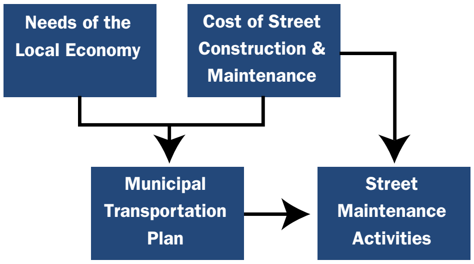

Figure A-1: Flowchart of Some Key Relationships that Characterize the Municipal Street Program

- Transportation Plan
- Traffic Signals
- Asphalt
- Concrete
- Fill
- Work Crews

Figure A-2: List of Some Key Components of the Municipal Street Program

Both of these representations are incomplete pictures, of course, but the flowchart contains more information and suggests additional questions we can ask to gain a more complete picture. Looking at this diagram, we might next say: "Well, what influences the costs of street construction? What happens when the streets are (or aren't) maintained?" With systems thinking, we keep asking questions and revising our picture until we have a model of a system that makes sense to us and tells us what we want to know. For example, after a few rounds of additions and revisions we may end up with a revised flowchart like this:

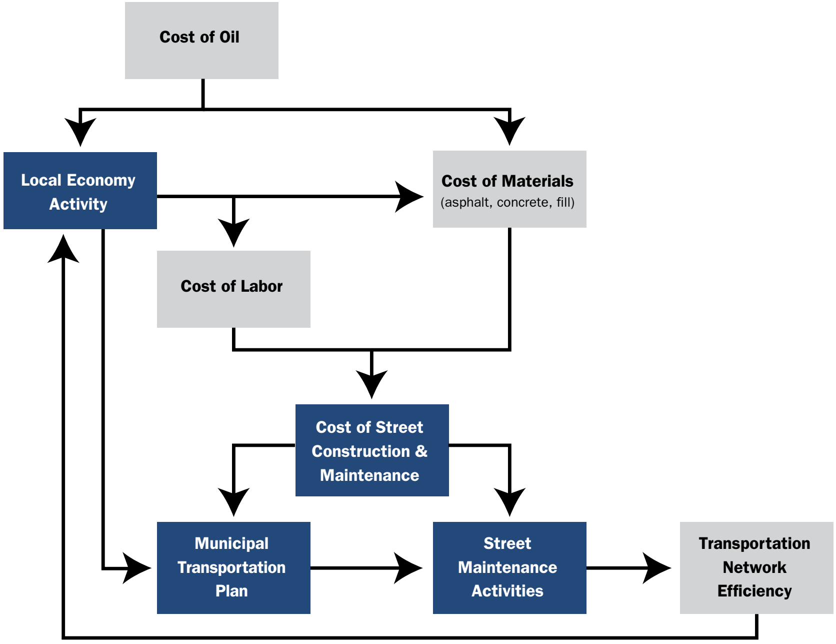

Figure A-3. Flowchart of Some Key Relationships that Characterize the Municipal Street Program (revised)

Asking about the costs of street construction got us thinking about the costs of materials and labor. The cost of labor is largely determined by the local economy, and one of the main material costs of street construction is asphalt, which is produced from oil, so we added these relationships to the picture. We also started to see additional relationships, such as the effect of street paving on transportation network efficiency, which in turn affects the local economy.

This flowchart is rather limited compared to true systems modeling techniques, but it demonstrates one of the main benefits of systems thinking: it gives us tools for identifying and exploring complex relationships. For example, if we developed this flowchart such that we could assign quantitative values to its elements, we could try changing certain variables to see how those changes ripple throughout the entire system. Or, we could use different techniques to identify weaknesses and trigger points, or test ways of improving the system's resilience to change.

Systems thinking gives us tools for identifying and exploring complex relationships.

Understanding Systems

Definition of a system

What is a system? All systems have two defining characteristics[b]: First, a system is made up of *component elements*, or **subsystems**, that are all related to each other in some way. Second, a system has a *structure*, or **metasystem**, that determines how these elements relate to each other.

Looking at Figure A-3, the street program flowchart, this definition tells us that (a) individual elements like "Cost of Labor" or "Transportation Network Efficiency" can be thought of as systems in their own right, and (b) the relationships between these individual elements are all part of a larger structure.

Boundaries

Whether we call something a "subsystem" or a "system" depends on our level of focus: a forest can be a system of trees, animals and streams, or it can be a subsystem of a larger ecological region. The level of focus we choose also determines the **boundary** of our system.

When we draw a system boundary, we're basically identifying which system elements are interacting with each other to produce the pattern of behavior that we're interested in explaining. The elements that receive inputs sit inside the boundary, and the elements that only provide inputs—but do not receive inputs themselves—are outside the boundary.[c] If we drew a boundary around our flowchart in Figure A-3, it would include everything except "Cost of Oil".

Choosing the right level of focus and boundary is important because if we're not clear about these things, we might not include relevant elements (or mistakenly include irrelevant ones) in our system and end up with a bad analysis—and then bad policy.

If we don't choose the right boundary we may end up with bad analysis – and then bad policy.

Feedback Loops

In systems thinking we differentiate between "simple" systems and "complex" systems. In simple systems, the chain of causes and effects between elements has a stopping point. Our first simple flowchart (Figure A-1), for example, would have been a simple system because it ended with "Street Maintenance Activities".

In a complex system, however, the chain of causes and effects doesn't have a stopping point—it becomes a **feedback loop**. Technically speaking, a feedback loop is a circular connection between two or more system elements in which a change in one element, or *input*, causes other elements to generate a response, or *output*, that eventually feeds back to the original element. In our more complex flowchart (Figure A-3), you can see a feedback loop flowing through the following variables:

Local Economic Activity
—> Municipal Transportation Plan
—> Street Maintenance Activities
—> Transportation Network Efficiency
—> Local Economic Activity

There are actually four distinct feedback loops in this figure—all starting and ending with "Local Economic Activity," but taking different paths through "Cost of Labor," "Cost of Materials" and "Cost of Street Construction and Maintenance."

Feedback loops can be either positive ("reinforcing") or negative ("balancing"). In a *positive* feedback loop, a change in one element will trigger changes that amplify, or reinforce, the original change. In a *negative* feedback loop, a change in one element will trigger changes that dampen, or balance, the original change. For example, if the feedback loop we described above is a positive loop, we could then say that the effects of a decrease in local economic activity would eventually result in *further* decreases in local economic activity.

Parameters and Leverage Points

Systems are also composed of **parameters**. A parameter is a constant factor of a process, for example, a fractional change rate such as "productivity," "fertility," or "depreciation." In systems, *time delays* are important parameters. A time delay is the time it takes for a particular element to respond to an input. Time delays can significantly impact how systems behave, sometimes even making the difference between system success and failure.

By saying that parameters are "constant" factors, we mean that they are constant with respect to a given level of system complexity. However, at a higher (more complex) level, parameters can, themselves, be variable; that is, parameters can have parameters of their own. For example, in our municipality's street maintenance program, the productivity of road paving may be constant up to a certain level of activity, and then suddenly increase beyond that level by the introduction of efficiencies of scale.

Leverage points are opportunities for changing system behavior with relatively little effort.

When we build a model of a system, we ultimately want to identify the key parameters and the parts of its structure that seem to significantly influence the system's overall behavior. These important parts are called **leverage points** because they represent opportunities for changing system behavior with relatively little effort. When we adjust a leverage point we generally make a small change to certain parameters or relationships impacting some reinforcing feedback loop(s); in doing so, we take advantage of that loop's reinforcing cycle to create a large effect in the larger system.

For example, if road paving productivity is a critical limiting factor on system performance and is itself coupled to other factors in a positive (reinforcing) feedback loop, then a change in productivity or one of its inputs could trigger a "virtuous cycle" of improvement in system performance. In this case, productivity (or an input to it) is the leverage point we would want to target.

Dynamic equilibrium, resilience and uncertainty

A particularly important system pattern is called **dynamic equilibrium** (or "steady state" equilibrium). Think of the typical household heating system that regulates room temperature using a thermostat and heater. Figure A-4 represents temperature change in a house.

Here, the vertical axis represents the house temperature, measured in degrees Fahrenheit, while the horizontal axis represents time, measured in hours. The behavior pattern above is called an *oscillation pattern* because the system fluctuates around a set point: in this case, 68 degrees F.

System thinkers call this pattern a "goal-seeking" behavior because it appears as if the system is continuously comparing its actual state to some "goal" state, and then adjusting itself to narrow the gap between the two. The entire system is governed by a *negative feedback loop* that operates with some time delay; it's this time delay that generates the oscillating pattern. This dynamic equilibrium pattern may seem inefficient, but it actually reflects **system resilience**.

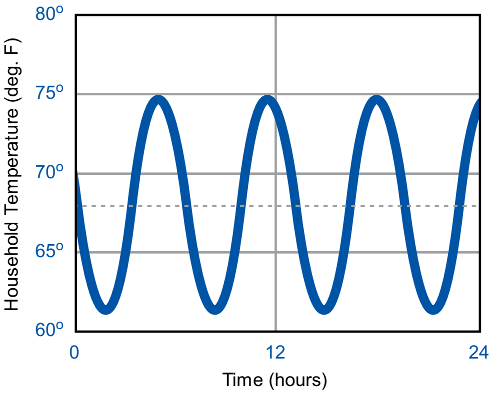

Figure A-4: Household temperature in dynamic equilibrium

Healthy systems are resilient against uncertainty. In systems thinking, the concepts of *resilience* and *uncertainty* start with the idea that any system faces some risk of disruption whenever it is confronted with a change it doesn't expect and for which it has no appropriate response. "Uncertainty" can be thought of as the amount of surprise the environment represents to a given system. It follows from this that the persistence over time of a pattern of behavior represents a *reduction in uncertainty* between a system and its environment.[d] "Resilience", on the other hand, is the capacity or flexibility of a system to respond to changing environmental inputs in a consistent manner.[e] In the example above, the household heating system demonstrates resilience against the uncertainty of outside temperature by creating an "artificial" environment (or "bounded uncertainty") it can in a sense predict and therefore control.

Learning and "satisficing"

Systems can also adapt to deal with changing environments. This system adaptation process is called "learning," which can be thought of as any process that promotes resilience by reducing uncertainty. For example, natural forest fires play an important role in some forest ecosystems by regulating forest undergrowth to prevent cataclysmic fires. We could say that a forest ecosystem like this has "learned" to deal with the potentially catastrophic threat of fire by having structured itself in such a way that fires only clear the undergrowth that has accumulated since the last fire, and therefore do not burn hot or long enough to kill mature trees. The forest ecosystem is therefore more resilient because its "learned" structure reduces the uncertainty posed by fire.

That structure, as you may remember from our original definition of a "system," is called the *metasystem*. A metasystem lends resilience by systematically changing its system in such a way as to produce a controlled environmental disturbance. Each time the system "overshoots the goal," it produces an error (called a "steady state error") that it then responds to. By producing its own errors, the (meta)system can anticipate them, effectively reducing uncertainty. This strategy by which a smaller problem is generated so as to head off a more serious problem is called "error-controlled regulation" or "satisficing," and is common in biological and even social systems dealing with complex and turbulent environments.[f]

Learning is a form of adaptation, but it can also be addictive. Have you worked with someone who ritualistically creates their own crisis because they prefer a familiar problem to the totally unfamiliar? Or consider the adage, "When the only tool you have is a hammer, every problem begins to resemble a nail"; we similarly tend to perceive only those types of problems for which we have a solution. So long as a particular arrangement functions, this "addiction" of creating problems to solve is not necessarily a problem. But we all know how difficult it can be to change a habit after the environment changes, even if it is plain to us that the habit no longer serves us. In such cases, we may end up treating the symptoms instead of the cause[g]. Systems thinking gives us a way of understanding both learning and the roots of resistance to learning: the two are deeply related.

Because any change requires an expenditure of resources, learning follows an "economy of flexibility" in which the capacity to adapt is purchased at the price of habit formation.[h] Alternatively, we can think of error—within an allowable range of tolerance, anyway—as the price we pay for our (always limited) capacity to respond to multiple environmental demands[i]. This trade-off applies to all kinds of learning, including the learning that ideally occurs in planning and policymaking. When we make municipal plans and policies, we act as "satisficing" metasystems learning about the urban system we are attempting to regulate.

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Modeling

These basic concepts provide only a brief introduction to systems thinking, but they are also useful tools in themselves for understanding complexity and change. The next step is to learn about modeling, which gives us a way of deriving practical lessons from an otherwise abstract picture of a system.

Systems thinking is fundamentally a decision-making process by which we create models of system behaviors, and then test them to understand the system better. We can use models to explain the causes of a system problem, and then develop solutions that will withstand the range of expected conditions. For example, using a model of a municipal system, we could propose various municipal policies by changing the structures or parameters that have been identified as leverage points and then proceed to test these policy solutions under different hypothetical conditions. Stakeholder-based or collaborative modeling can play a valuable role in policy "learning," starting with problem scoping or definition. Indeed, since much of municipal complexity arises from the diversity of experiences and perspectives, modeling should include stakeholders in the process as much as possible.[j]

Resources for Practical Applications

Systems thinking is still a relatively new tool for municipal policy and urban planning, but it holds great promise for managing complex problems such as energy and climate uncertainty. The resources listed below will help you further explore the practical applications of this exciting field.

Pegasus Communications (www.thesystemsthinker.com)
Pegasus is a leading provider of practical resources on systems thinking, management innovation, organizational change, and the next-generation workplace. Publisher of "The Systems Thinker" newsletter, a highly-accessible print and online resource for learning about systems thinking.

The Natural Step (www. naturalstep.com)
The Natural Step is a framework grounded in natural science that serves as a guide for businesses, communities, educators, government entities, and individuals on the path toward sustainable development. Developed in Sweden in 1988, The Natural Step framework encourages dialogue, consensus building, and systems thinking and creates the conditions for profound change to occur.

Appendix

Eco-municipalities (www.sjamesassociates.com; www.sekom.nu)
A quarter of all municipalities in Sweden have adopted the Natural Step framework as guiding policy. Known as eco-municipalities (*"ekokommuner"*), these jurisdictions have started a movement that has recently spread to the United States. Sarah James Associates (www.sjamesassociates.com) provides consultation and resources on pursuing the eco-municipality idea in the United States.

Resilience Alliance (www.resalliance.org)
The Resilience Alliance is a research organization comprised of scientists and practitioners from many disciplines who collaborate to explore the dynamics of social-ecological systems. The Resilience Alliance website includes an active discussion area and resource databases that occasionally touch on urban issues.

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Endnotes

a. Seymoar, N.-K., 2004.
b. cf. Lendaris, 1986.
c. Sterman, 2000.
d. Shannon & Weaver, 1975.
e. Walker et al., 2006.
f. Ashby, 1956; Simon, 1996.
g. Senge, 1990.
h. Bateson, 1979.
i. Simon, 1996.
j. Innes & Booher, 1999; Linstone, 1999; Mendoza & Sussman, 2005; Purnomo et al., 2004.