System Dynamics: A Brief Intro

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PRESENTED TO: NREL| GOLDEN, CO

Acknowledgements:
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Overview

Wednesday AM: Introduction to System Dynamics

- What is SD?
- Reference Behavior Patterns
- Feedback Loops
- Causal Loop Diagrams
- SD Frameworks
- Stock/Flow Maps
- Rules of Grammar
- Connectors/Converters
- Generic Activity Templates

Wednesday PM: The Stella Software

- Basic Operations
- Building/extending models
- Inputs/outputs
- Units of measure
- Conveyors
- Arrays
- Built-in functions

Thursday AM: Working with Models

- Case Studies
  - Capstone exercise
  - Bass Diffusion (adoption)
  - Predator/prey
- NREL
  - Waste-To-Energy (WESyS) model
  - Biomass Scenario Model (BSM)
  - LiBRA

What is System Dynamics? -- History

- The field began in the late 1950s and was extended with Professor Jay Forrester's Industrial Dynamics in 1961.
  - An MIT professor, Forrester was the pioneer of this approach and its implementation.
  - Forrester trained a number of practitioners over the years and established MIT as a center of excellence for this methodology that exists even today.
  - Forrester's protégés often use the phrase *System Dynamics*.
- The field received a "kickstart" in 1994 with the publication of The Fifth Discipline, Dr. Peter Senge's best-selling book.
  - Senge was a student of Forrester's at MIT.
  - His work tried to take the more technical aspects of the approach to a more "accessible" level by discussing concepts, not simulation models.
  - Senge's proponents tend to use the phrase *Systems Thinking*.
- Business Dynamics, the definitive work in the field, was published in 2000 by Dr. John Sterman.
  - Sterman's years of experience with this methodology, both as an MIT professor and with corporate clients, are reflected in this volume.
  - The book details technical aspects and successful implementation of the approach.
  - Sterman uses the terms *Business/Economic Dynamics* and *Dynamic Modeling*.

What is System Dynamics?

One definition…

System Dynamics is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems. In fact it has been used to address practically every sort of feedback system. While the word system has been applied to all sorts of situations, feedback is the differentiating descriptor here. Feedback refers to the situation of X affecting Y and Y in turn affecting X perhaps through a chain of causes and effects. One cannot study the link between X and Y and, independently, the link between Y and X and predict how the system will behave. Only the study of the whole system as a feedback system will lead to correct results.

--System Dynamics Society (www.systemdynamics.org)

Another, related definition…

System dynamics, born in the 1950s at MIT, uses computer models and simulation to analyze the collective impact of cause-effect relationships in a physical or organizational problem. Analysis factors in time delays and examines feedback loops: A causes B, which changes A, which worsens B or causes C. The methodology deals with multiple complex relationships …

--Worcester Polytechnic Institute blurb
(http://www.admissions.wpi.edu/Academics/Programs/sd.html)

What is System Dynamics?

System Dynamics: A framework, consisting of a *language* and a *set of key concepts*. These are embedded in a *process* for representing, understanding, explaining, and improving how dynamic systems …

- are put together
- perform over time

Stella was developed to support this approach, and is . . .

- a broadly-accessible tool kit for modeling dynamic systems
- visual, graphically-oriented
- relatively easy to learn and use (straightforward mechanics; no complex math)
- simulation-capable (thus linking structure to performance)

Using these techniques, you and your colleagues can…

- build better individual and collective mental models
- simulate them more reliably
- communicate them more effectively

What is System Dynamics?

System Dynamics can be viewed as a "package" with some key components:

Language

- Stocks & Flows (clouds)
- Language Grammar
- Connectors
- Converters
- Generating Action/Activity
- Model "Fine Structure"
- Structure/Behavior Pairings

Key System Concepts

- Feedback Loops
- Main chains
- Delays
- Inertias
- Unintended Consequences
- Generic Structures

"Geeky Stuff"

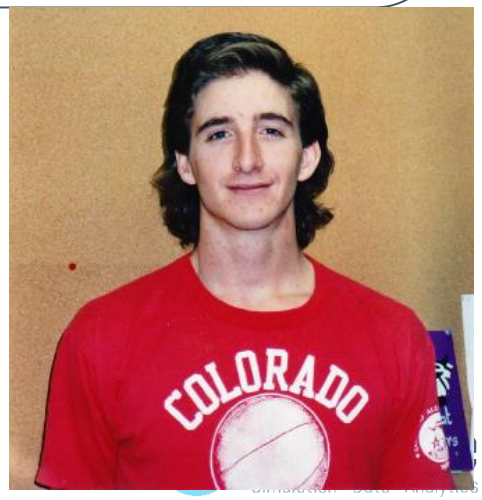
- DT
- Simulation Algorithms
- Sensitivity Analysis
- Steady-State
- Sub-Models
- Builtin functions
- Arrays
- …

Software Toolkit

- Multiple views
- Basic mapping operations
- Basic modeling/eq'n writing operations
- Output devices (table, graph)
- Input devices (e.g., slider)
- Tools for "packaging" (e.g., button, text box, storytelling)

Process

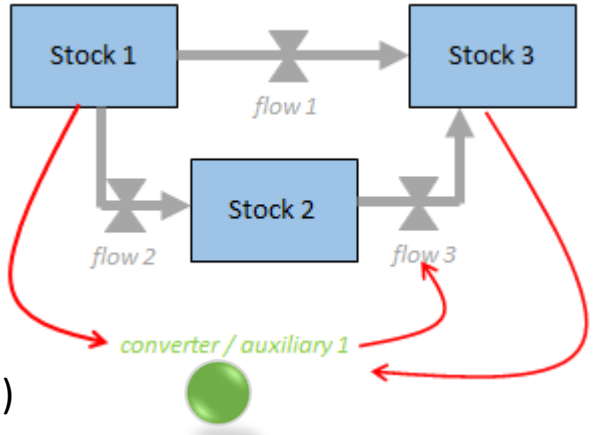
- Defining purpose/problem
- Setting the boundary
- Mapping the process
- Modeling (eq'ns, numbers)
- Simulating
- Debugging
- Designing Experiments
- Packaging for Consumption
- Generating discussions



System Dynamics – Key Components

- A system's behavior is dictated by its structure.

- Circular chains of cause-and-effect relationships drive (often non-linear) behavior. These feedback loops can either:
  - Accelerate change (Reinforcing feedback)
  - Counteract change (Balancing feedback)



- Structure is made up of operational elements:
  - Where stuff accumulates (stocks)
  - What activities fill or drain those accumulations (flows)
  - What additional information impacts these activities (converters/auxiliaries)
  - How variables are inter-related to determine the magnitude of activities (connectors)

- A system's stock/flow structure and associated feedback mechanisms can be simulated in order to understand:
  - How it is likely to behave over time (in its current form)
  - How it might respond to:
    - Parameter changes
    - Policy initiatives/alternate decision rules/strategic decisions
    - Structural modifications

System Dynamics: Why…

COMPARING SYSTEMS AND THINKING PROCESSES

While systems are…	**…our thinking processes often…**
Constantly changing	…are static, equilibrium oriented
Tightly coupled/interdependent	…draw very narrow boundaries around issues and problems
Rich in feedback	…treat drivers of performance as external and independent
Nonlinear	…assume linear responses
History dependent	…neglect to consider path dependence, accumulations, and delays
Adaptive and evolving	…fail to pay sufficient attention to the sources of unintended consequences

Adapted from Sterman, Am J Public Health, 96:3 (March 2006)

System Dynamics: Essential practices and tools

CHARACTERIZING THE SPACE

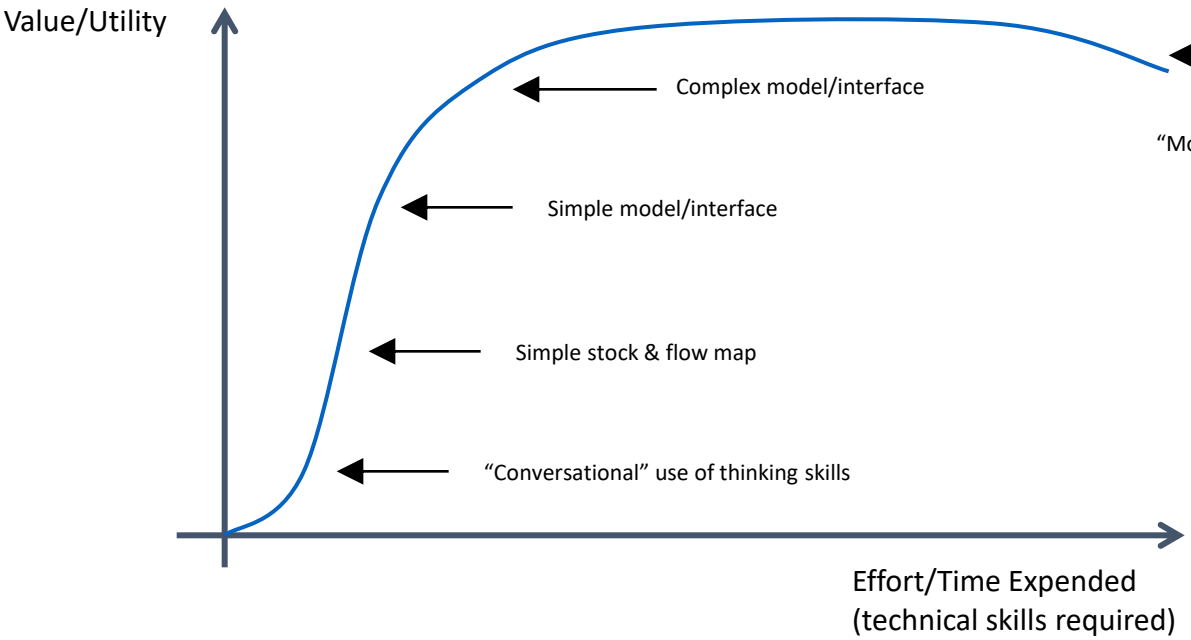
"...System dynamics emphasizes a multifaceted process for testing models, identifying errors, and comparing model assumptions and behavior to data. The process of model testing and improvement is iterative. Discrepancies between mental models, formal models, and data stimulate improvements in each"

--Am J Public Health. 2006; 96:505-514

- Dynamic thinking—behavior over time
- Operational thinking—stocks and flows, physical representation
- Feedback thinking
- A set of practices
- Tools for modeling and simulation (Stella, Vensim, Powersim…)

Potential and Pitfalls

A CHALLENGE: GETTING TO SOMETHING USEFUL UNDER TIME CONSTRAINTS



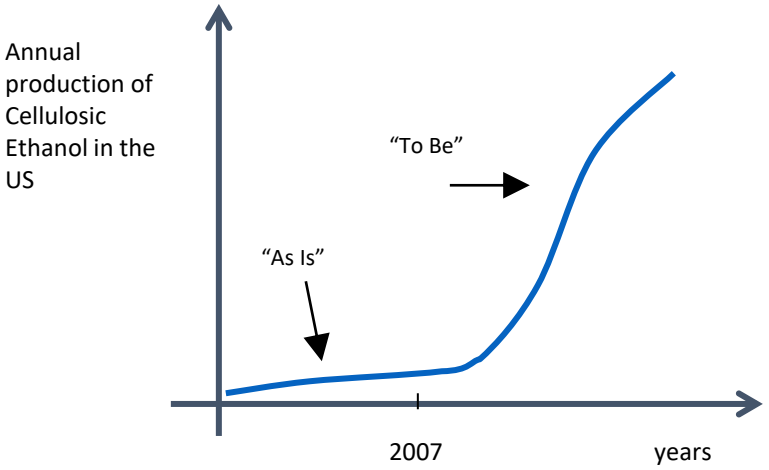
"Any intelligent fool can make things bigger and more complex. It takes a touch of genius and a lot of courage to move in the opposite direction."

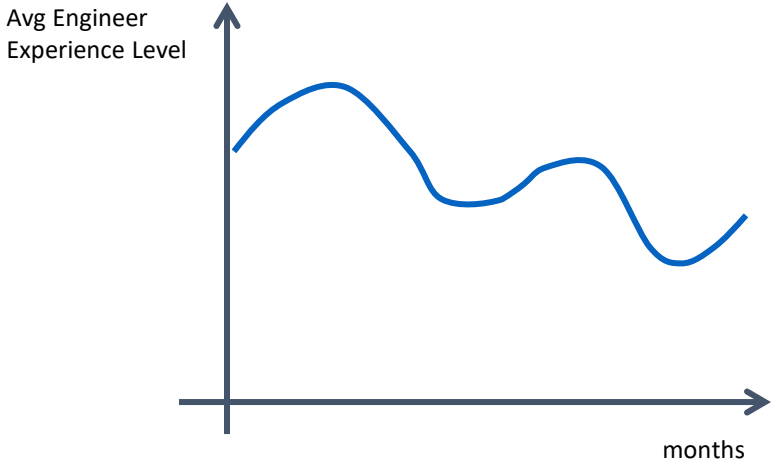
—A. Einstein

Lexidyne Simulation Data Analytics

Reference Behavior Patterns

- A reference behavior pattern is a graph over time that captures the essence of a problem or issue of interest.
- RBPs often contain a historical ("as is") component as well as a projected ("to be") component.
- The unit of time (femtosecond, fortnight, year, etc.) for the RBP helps to set a temporal boundary for what to include in your analysis.
- Examples:





RBP Exercises

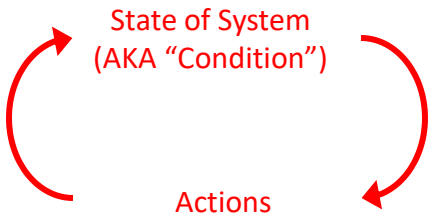
1. Sketch an RBP that relates to a phenomenon in your personal or professional experience. Be sure to provide appropriate labels for both the time axis and the vertical axis.

2. Steve Peterson is well known as a “coffee fiend” during the delivery of workshops. Create a RBP that might characterize the level of caffeine in his bloodstream over a 24 hour period, beginning at 6.00 AM.

Feedback Loops

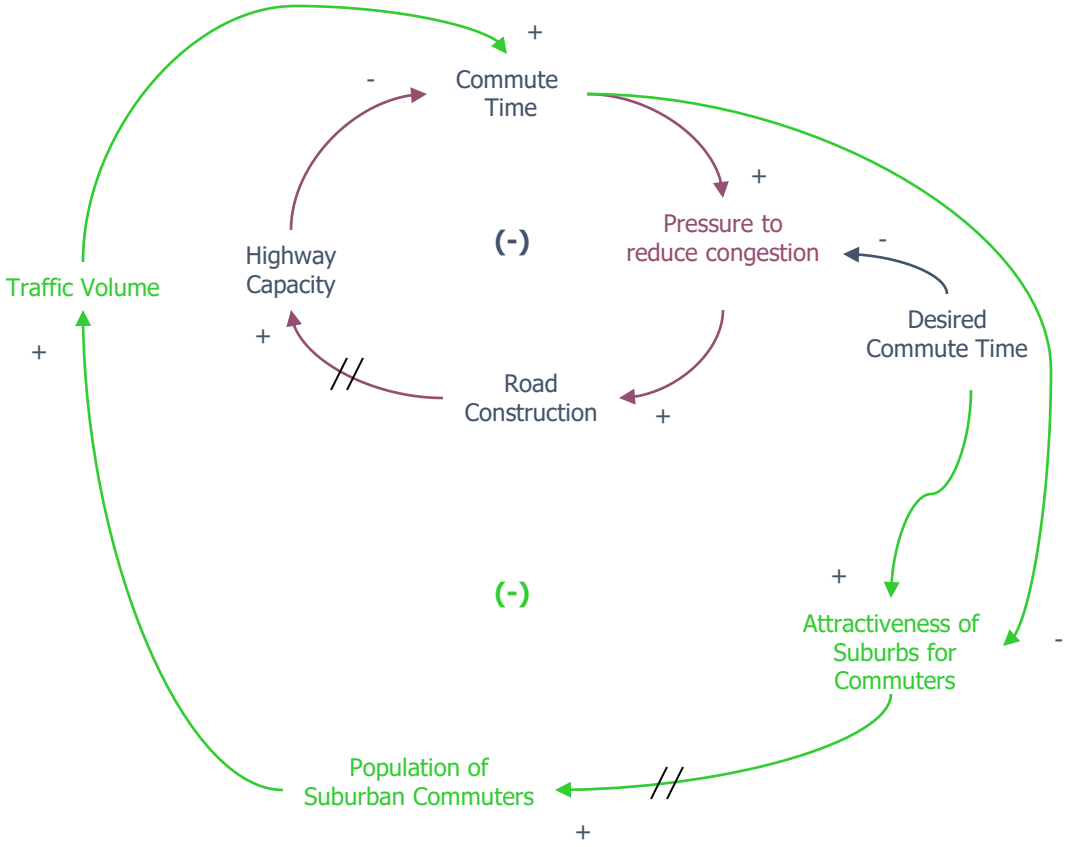
A feedback loop exists whenever the current state of the system leads to activities which further change the state of the system.

- Reinforcing loops
  - Amplify change
  - Run away from status quo
  - AKA positive feedback loops; AKA vicious/virtuous cycles
  - "Positive" doesn't necessarily mean "good."
- Counteracting loops
  - De-Amplify change
  - Seek to maintain status quo
  - AKA negative feedback loops; AKA balancing feedback loops
  - "Negative" doesn't necessarily mean "bad."



Creating Causal Loop Diagrams—An Illustration

In many metropolitan areas, traffic planners respond to lengthening commuting delays by constructing more highways….

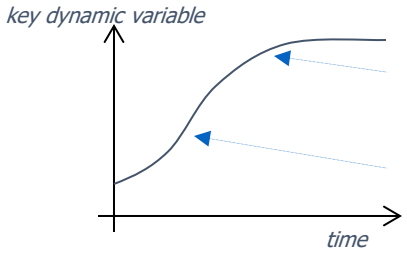


…but shorter commute times increase the attractiveness of suburbs for commuters, thereby, facilitating housing and population growth. This in turn leads to an increase in traffic volume!

Creating Causal Loop Diagrams—Guidelines

1. Think about the Dynamics.

- Start with the dynamic to be explained. Helpful to draw a graph of behavior over time. Helpful to describe the dynamic using a sentence or two.
- Ask: What are the relationships that underlie the dynamic?

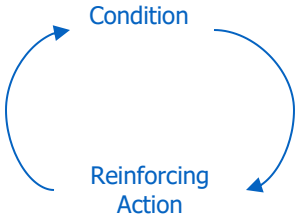


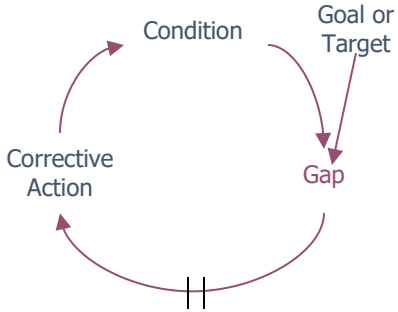
"Homing in" behavior tends to be driven by negative feedback

Runaway growth/decline tends to be underwritten by positive feedback.

2. Map the loop(s)

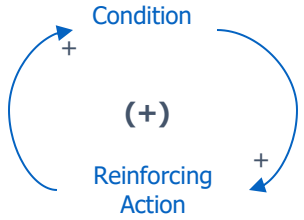
- Ceteris paribus world
- Use nouns and noun phrases
- Avoid modifiers like *more* or *less*
- Consider *goals* and *gaps*
- Draw arrows from cause to effect
- Close the loop(s)
- Indicate delays with || in arc
- Keep it simple.

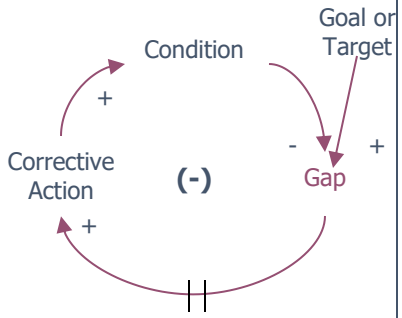




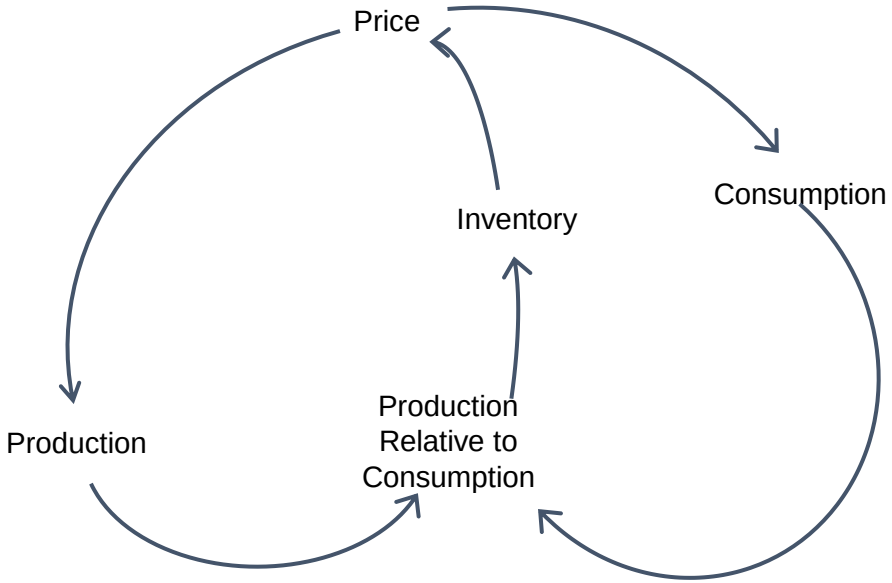
3. Assign link and loop polarity

- Look at each link in isolation.
- When change in cause causes effect to move in same direction, link is positive. Indicate with " + "
- When change in cause causes effect to move in opposite direction, link is negative. Indicate with " – "
- Walk around loop. Does initial change in one variable lead to further change in same or opposite direction when you trace around the loop?
- Change in same direction → positive loop. Indicate with (+ or "R") in center.
- Change in opposite direction → negative loop. Indicate with (- or "C") in center.





CLD Exercises – Label the Loops



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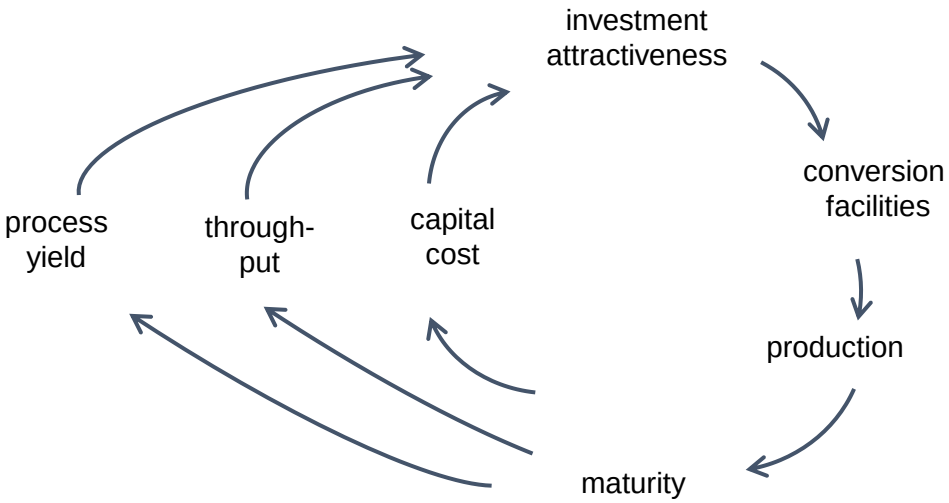


CLD Exercises

Draw one or more RBPs to show the behavior of key variables over time. Then map and characterize the feedback mechanism(s) described below as reinforcing or balancing loops.

1. Self-fulfilling prophecy

   In response to news reports about falling supplies of gasoline at retailers, motorists went to gas stations in droves, further driving down supplies.

CLD Exercises

Draw one or more RBPs to show the behavior of key variables over time. Then map and characterize the feedback mechanism(s) described below as reinforcing or balancing loops.

2. Get the work done

   At a local personal injury law firm (affectionately known as “Torts for the Masses”), the managing partners add to the size of their legal staff as case loads grow beyond desired levels.

CLD Exercises

Draw one or more RBPs to show the behavior of key variables over time. Then map and characterize the feedback mechanism(s) described below as reinforcing or balancing loops.

3. Is it getting hot in here or what?

For those who worry about global warming, the "albedo effect" can be a source of lost sleep. Here's how it works: As snow or ice melts, a larger portion of the earth surface is exposed. Because of its lower albedo, the earth surface warms, accelerating the melting process.

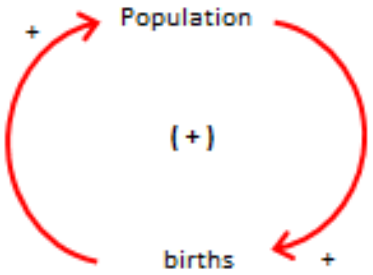
CLD Exercises

Draw one or more RBPs to show the behavior of key variables over time. Then map and characterize the feedback mechanism(s) described below as reinforcing or balancing loops.

4. Econ 101

   Economic theory teaches that price works to equilibrate supply and demand. When quantity supplied relative to quantity demanded is not in balance, price rises or falls, which in turn leads to an adjustment in quantity supplied and quantity demanded.

(Potentially) practical advice on CLDs



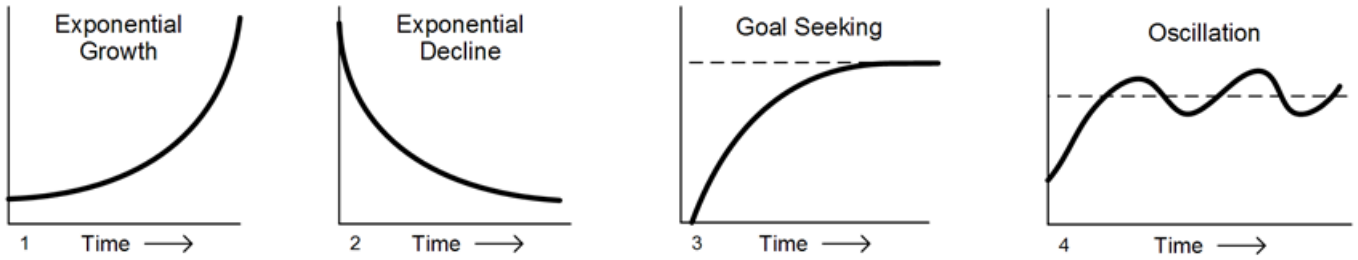
- Knowing how to read and write CLDs is useful.
- As with all approaches, CLDs have limitations.
- Awareness of diminishing or negative returns is important.
- High-productivity uses can include:
  - Brainstorming (individually or in a group)
  - Capturing notes or insights in a conversation or when reading
  - Explaining to someone else a simple feedback process that underwrites dynamics of interest

Types of SD Frameworks

- Most SD facilitators ask participants to characterize the issue space with time-based behavior(s).
  - Behavior Over Time Graph (BOTG)
  - Reference Behavior Pattern (RBP)
- Three (very) different approaches to represent system structure:
  - Archetypes
  - Causal Loop Diagrams (CLDs)
  - Stock/Flow Diagrams (SFDs)
- Practitioners tend to stick with one approach (and undervalue the others)

Archetype Behavior Focus

- Does the historical behavior of key model variables match frequently observed patterns that result from common structures?



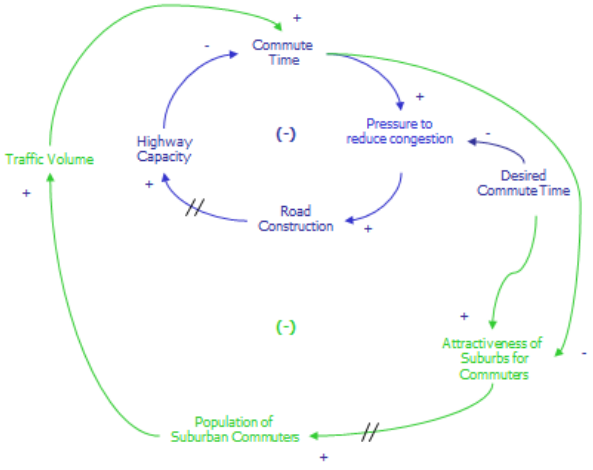
- Pros
  - Gets audience thinking about behavior over time
  - Easy to establish corresponding structure
- Cons
  - Behavior in question may not “map” to these archetypes
  - Oversimplification
  - Difficult to apply in situations with no historical data/analogs

Archetype Behavior Focus – System Archetypes

- In The Fifth Discipline (1994), Peter Senge identifies several common situations featuring reinforcing and/or balancing loops.
  - When You're Hot, You're Hot
  - Eroding Goals
  - Escalation
  - Shifting the Burden to the Intervener
  - Tragedy of the Commons
  - Worse Before Better
  - Success to the Successful
- Some SD practitioners of this approach try to first identify archetypes present in business/economic situations and then build a dynamic model from that evaluation.
- Our experience suggests that this approach is sub-optimal.
  - "Force fitting" an archetype onto an unwarranted situation is common
  - Not all interesting dynamic problems have an archetype at their core
  - Archetypes may ignore important, operational stock/flow structure

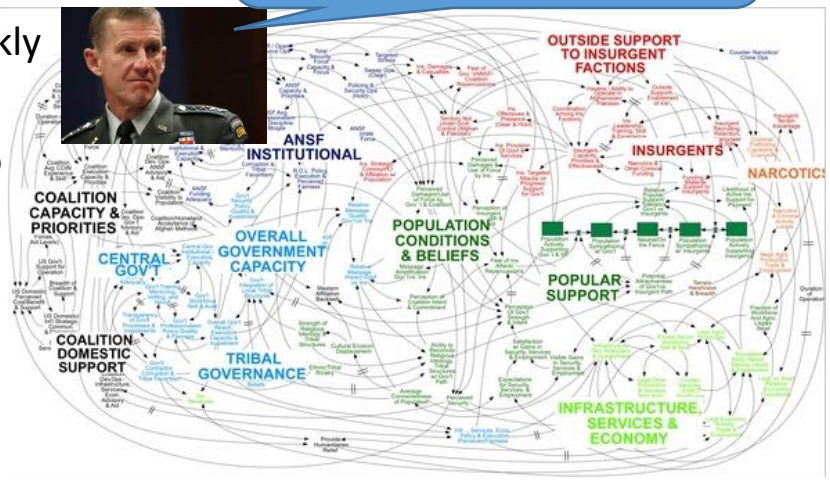
Causal Loop Diagram Focus

- Can a high-level influence diagram capture the relationships in the system?
- Pros
  - Gets audience thinking about dynamics, interactions and feedback
  - Easy to create, and extend
  - Participants leave session “feeling good”
- Cons
  - Often wrong; sometimes stupid
  - Can get overly complex very quickly
  - Difficult to mentally simulate
  - Requires significant translation to produce a simulatable model.



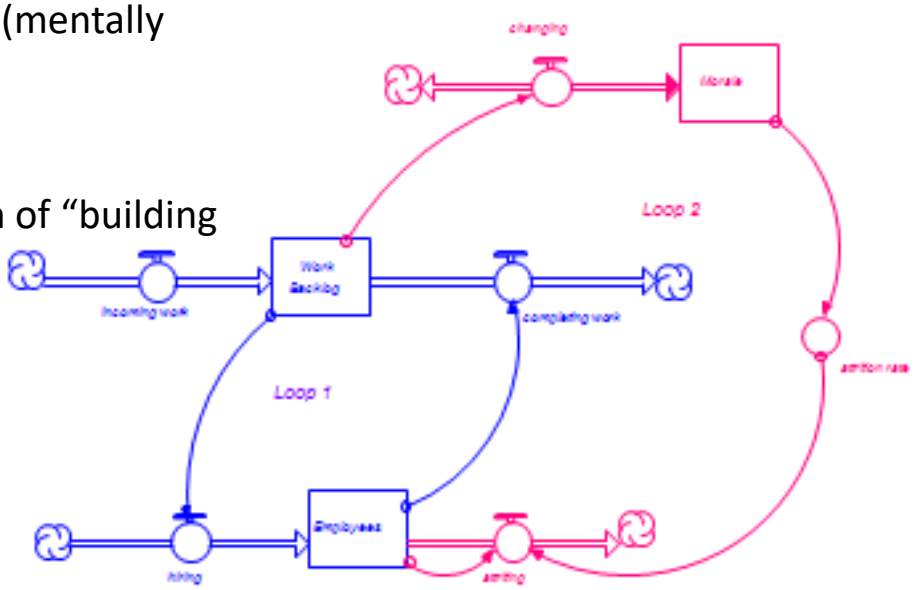
“When we understand that slide, we’ll have won the war…”

--General Stanley McChrystal



Stock/Flow Diagram Focus

- What are the fundamental accumulations and associated flows in the system, and how are they connected via feedback?
- Pros
  - Gets audience thinking operationally
  - Easy to create (whiteboard and/or computer)
  - Diagram matches resulting STELLA model
  - Can quickly be simulated (mentally and/or computer)
- Cons
  - Requires the introduction of “building blocks”



SD Frameworks – Conclusion

- In Lexidyne's (decades' worth of) experience, the stock/flow mapping process is the quickest and most effective way to:
  - Get at the "heart" of a dynamic problem = Operational Essence
  - Engage participants in an interactive mapping exercise
  - Facilitate communication between people of different functions in an organization
  - Create a model structure that builds consensus
  - Translate the results of a "white board" model-building exercise to a computer simulation
  - Build confidence that the resulting simulation isn't:
    - Oversimplified
    - "Black Box"
- A not-uncommon response: "This is the first time I've really understood this 'systems stuff'."

Thinking operationally

An example: What's wrong with this picture?

Milk production = *f(GDP, feed prices, interest rates, bond yields, …)*

Year	Milk Production (billion gallons/year)	GDP	Avg Feed Price/ton	10yr Tbill	LIBOR	Milk Price/gallon
1990	2.31	1.8	67.60	1.74	0.47	1.29
1991	2.48	1.9	0.90	1.56	0.15	1.32
1992	3.65	2.0	74.84	1.05	0.16	0.16
1993	5.79	2.1	68.44	2.92	0.93	3.12
1994	0.97	2.3	59.54	2.10	0.42	0.07
1995	1.38	2.5	91.19	2.87	0.44	2.34
1996	0.30	2.6	68.32	0.24	0.07	3.49
1997	3.86	3.0	95.62	2.95	0.12	0.40
1998	1.10	3.1	0.64	1.48	0.38	0.18
1999	5.75	3.4	45.21	1.55	0.22	0.84
2000	1.22	3.6	21.43	1.03	0.55	0.69
2001	2.03	3.5	34.50	0.16	0.17	0.28
2002	1.61	3.9	53.03	0.40	0.19	2.42
2003	4.61	4.1	55.21	0.21	0.05	1.35
2004	3.77	4.2	17.37	1.68	0.05	3.27
2005	4.88	4.3	78.95	2.88	0.06	3.30
2006	5.15	4.4	26.95	2.82	0.67	2.46
2007	3.34	4.5	85.65	0.76	0.34	0.59
2008	5.92	4.6	43.23	2.03	0.82	2.40
2009	3.94	4.7	54.89	2.55	0.37	3.18
2010	1.87	4.8	84.58	1.75	0.94	3.33

Identifying Stocks and Flows

Stocks: Nouns. Represent the current state, magnitude, or condition. Freeze action, and stocks persist. Accumulators. Balance sheet items.

Two fundamental stock types:

90%

Reservoir: Most common form of stock. Think of it as a bathtub.

10%

Conveyor: A "moving sidewalk." Use it to represent a process at the highest possible level, or to represent a pipeline delay process.

Flows: Verbs. Represent actions/activities that fill or drain stocks. Freeze action, and flows disappear. Income statement items. Helpful to use "ing" endings.

98%

2%

Uniflow: Most common form of flow. Flows in one direction only.

Biflow: Flows in both directions. Use whenever the same process causes the stock to build *or* decline.

Simple Structure-Behavior Pairings: Exercises

The Mysteriously Expanding Body

A friend of mine (we'll call him John because that's his name) found himself gaining weight over the past several months. He didn't like this at all, and engaged in two initiatives in response. First, he stopped his mid-morning and mid-afternoon trips to the pastry cart. Second, he began and sustained an aerobic exercise program.

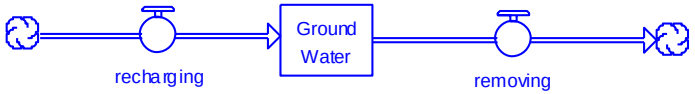
After one month of engaging in these initiatives, John found that he had continue to gain weight! Use stocks and flows to think through how this might happen.

Note: There are no "tricks" here. For example, John didn't compensate for his lack of pastry cart by eating more at regular meals. Nor does the solution have anything to do with the difference in density between muscle and fat.

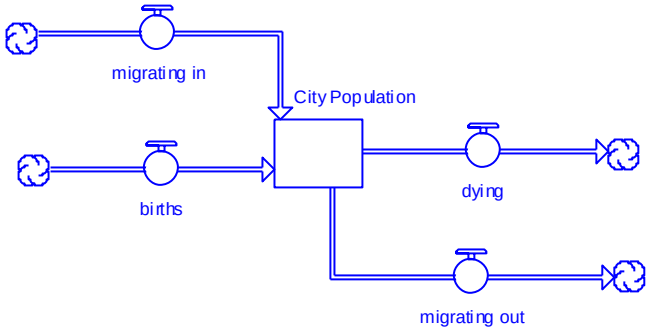
Identifying Stocks and Flows

Stock/flow connections can …

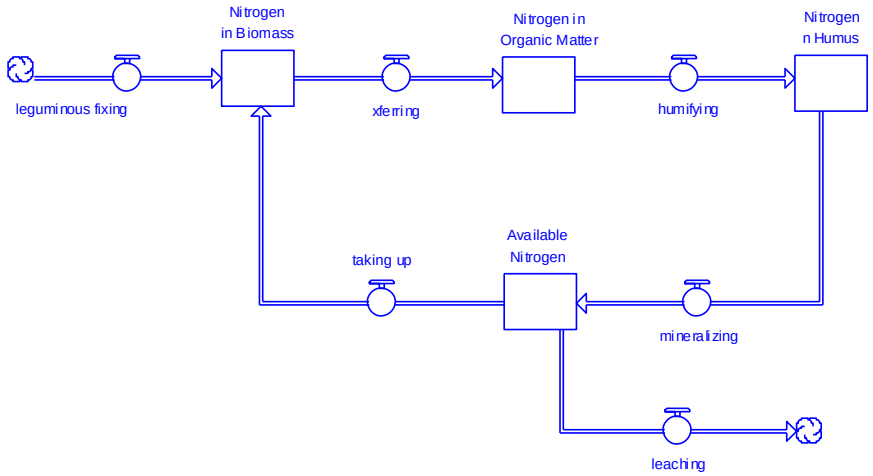
- …be very simple



  - …include multiple flows:



- …be used to form “main chains”



Two Rules of Grammar

To take advantage of the power inherent in the language of stocks and flows, you must…

Respect Unit Consistency

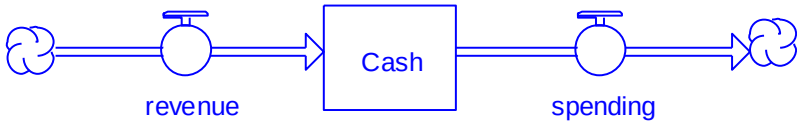
and

Respect Conservation Laws

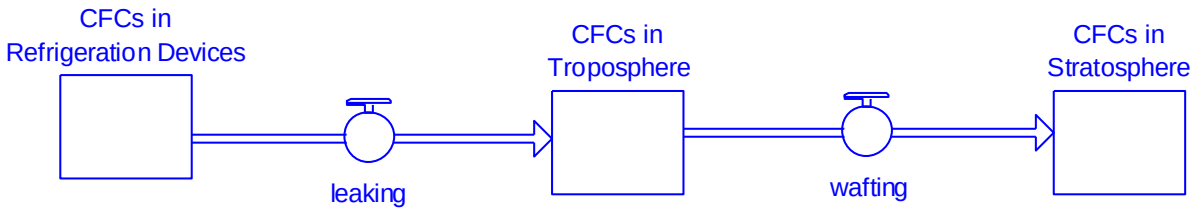
Two Rules of Grammar

Rule 1: Respect Unit Consistency

- Each flow into or out of a stock must use the same units of measure as the stock itself, except for “per time.”



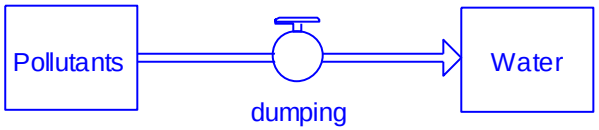
- All stocks in a main chain must use the same units of measure.



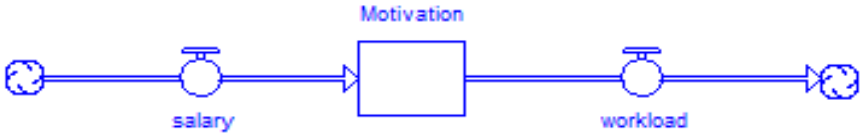
Two Rules of Grammar: Exercises

What's wrong with each of these pictures? Think about the units of measure—is the stock and flow representation respecting unit consistency? Conduct a mental simulation of the map to help you assess the goodness of the representation.

1. "Pollutants are being dumped into our water supply."



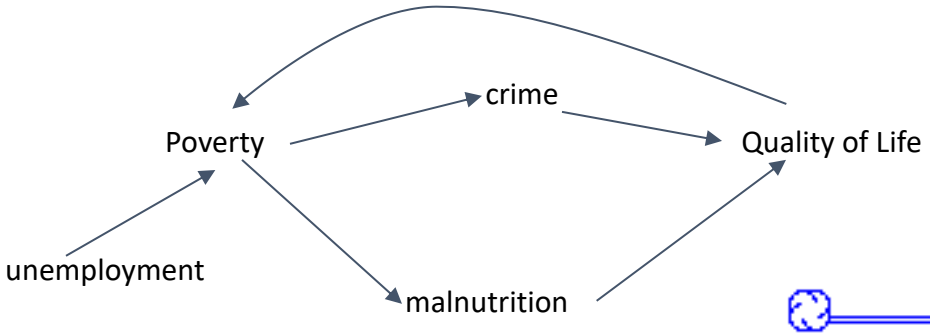
2. "Salary builds motivation but heavy workload depletes it."

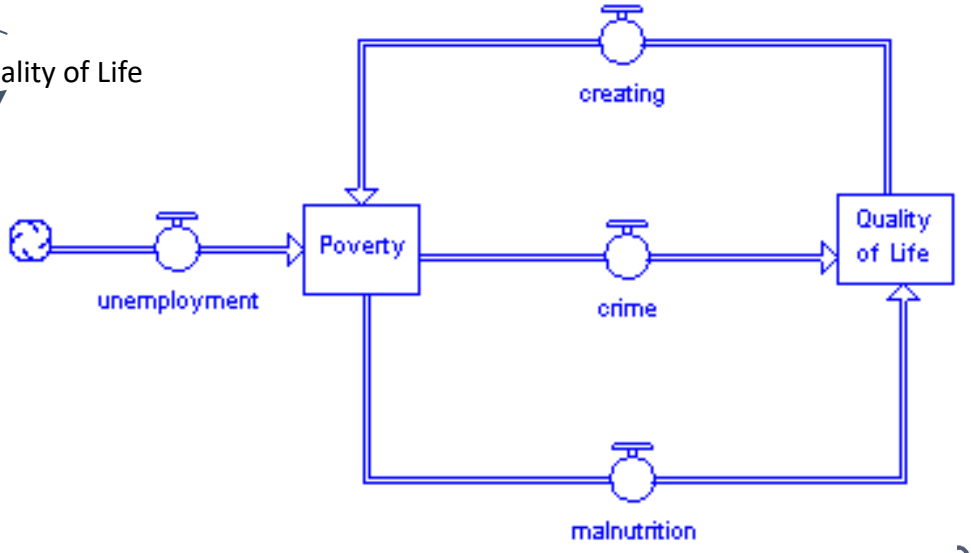


Two Rules of Grammar: Exercises

What's wrong with each of these pictures? Think about the units of measure—is the stock and flow representation respecting unit consistency? Conduct a mental simulation of the map to help you assess the goodness of the representation.

3. "Unemployment affects poverty, which in turn causes crime and malnutrition, thus impacting quality of life which in turn creates even more poverty."

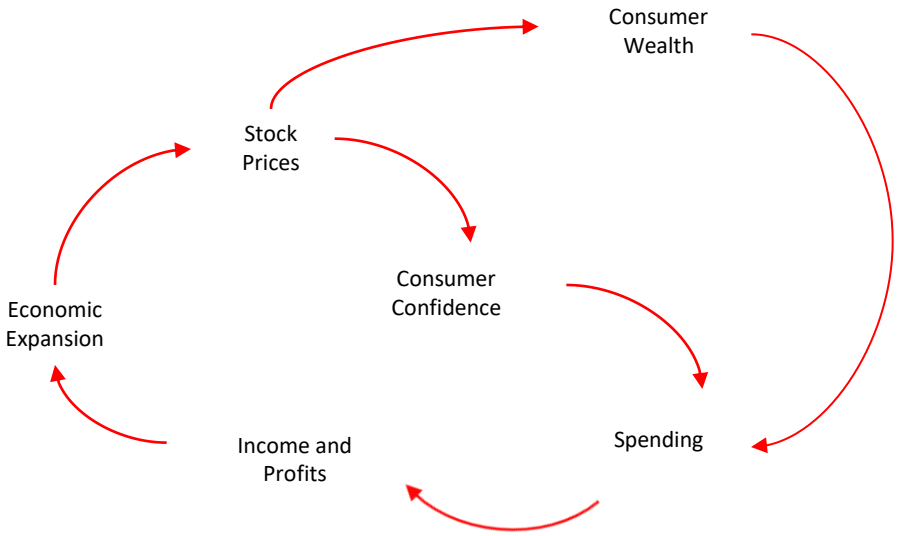


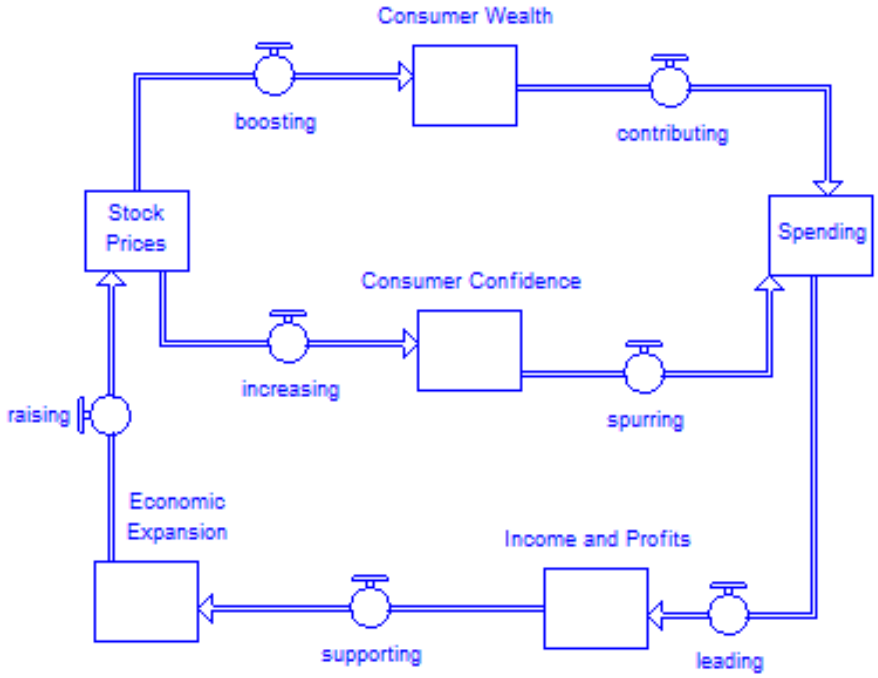


Two Rules of Grammar: Exercises

What's wrong with each of these pictures? Think about the units of measure—is the stock and flow representation respecting unit consistency? Conduct a mental simulation of the map to help you assess the goodness of the representation.

4. "Higher stock prices will boost consumer wealth and increase confidence, which can also spur spending. Increased spending will lead to higher incomes and profits that, in a virtuous cycle, will further support economic expansion." - Federal Research Chairman Ben Bernanke (in justifying the Fed's 2010 purchase of long-term Treasury notes)

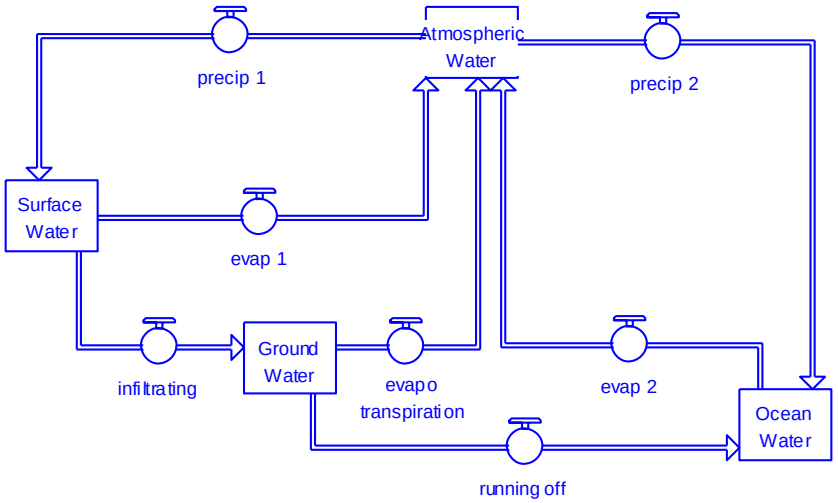




Two Rules of Grammar

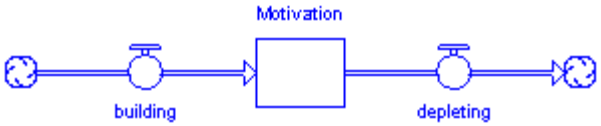
Rule 2: Respect Conservation Laws

- In the *physical* world, all flows come from somewhere (depleting some feedstock) and go to somewhere (filling some repository).



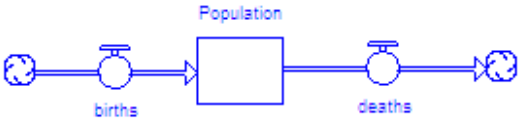
In building a model, you must make a conscious choice about conserving physical flows. It's a decision about the *model boundary.*

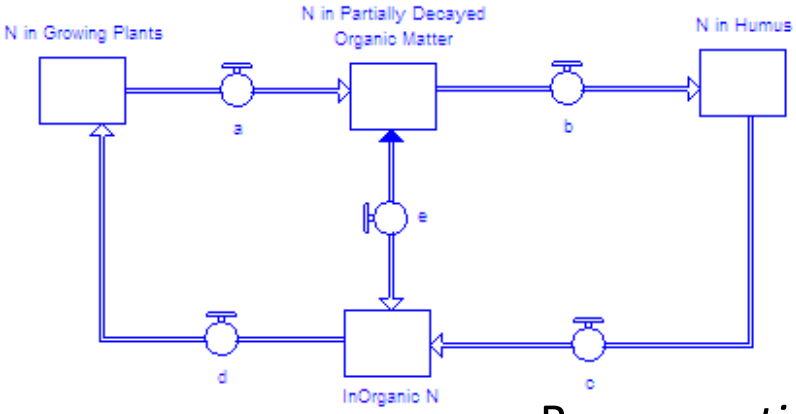
- In the *non-physical* world, virtually all flows come out of/vanish into thin air!

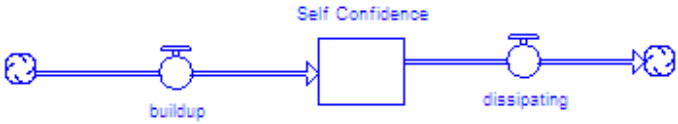


Telling only part of the story…

By themselves, stock and flow maps provide an important framework, but they tell only part of the story…





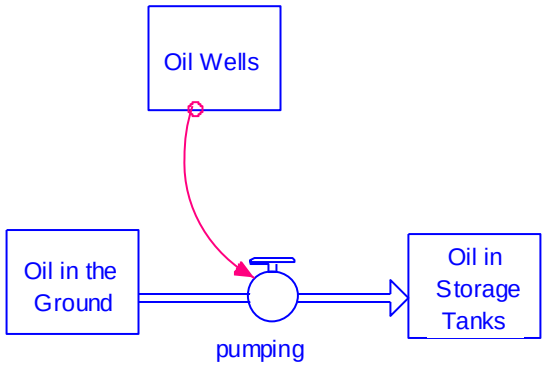


By *generating* flow activity it's possible to develop a deeper understanding of connection between structure and performance…providing some leverage into changing the performance of the system.

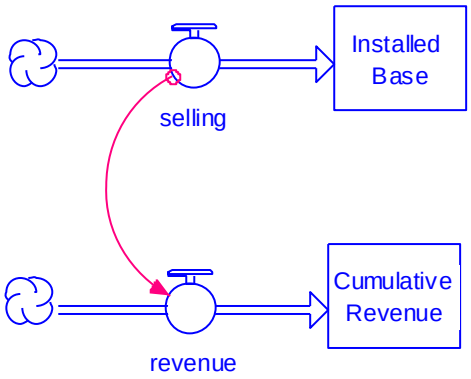
The connector drives activity generation

Two ways to do it:

Use a connector to connect a Stock to the flow



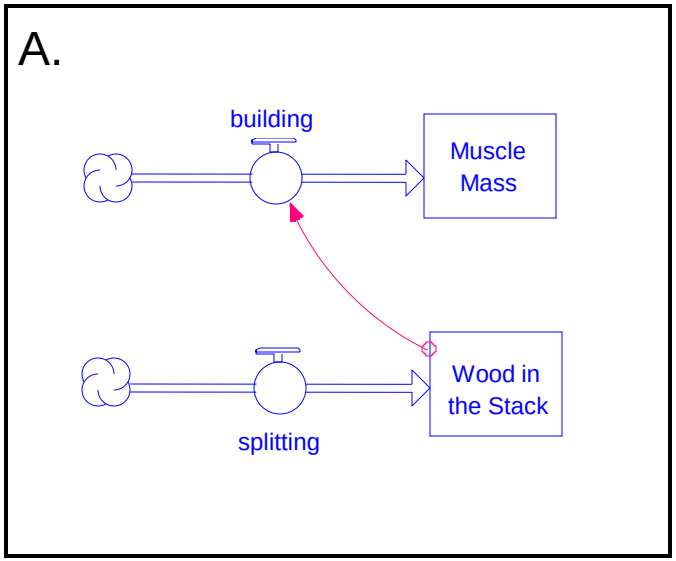
Use a connector to connect a flow to the flow

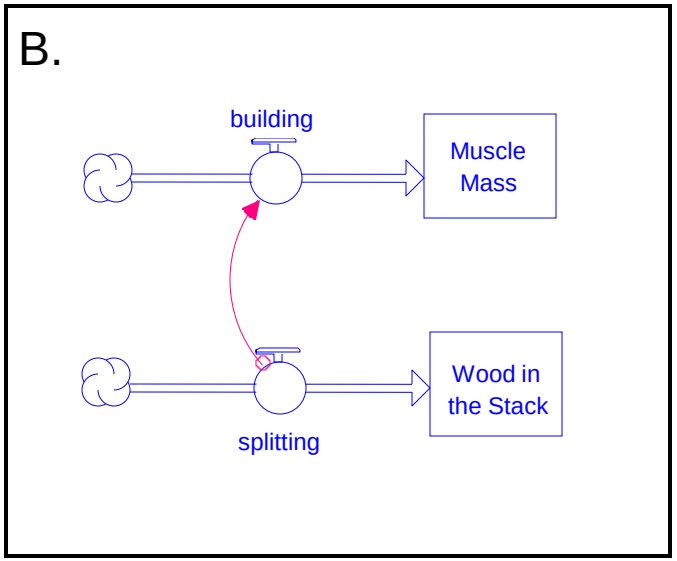


Why care? Big differences in dynamics!

Wood for thought

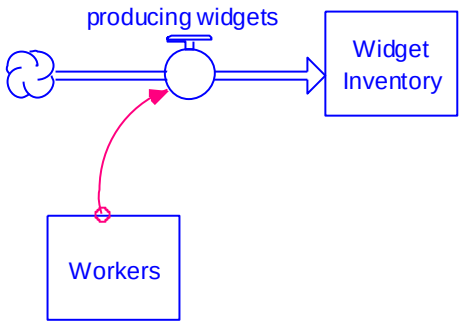
Here are two representations of the process of building up muscle mass, associated with the splitting of wood. Mentally simulate each representation. Which representation is better? Why?

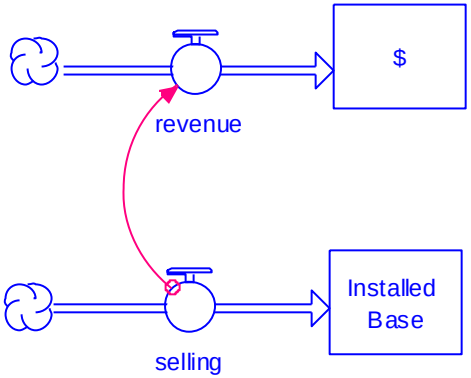




Why you need converters!

- There's a subtle but important issue with the maps we've seen thus far:



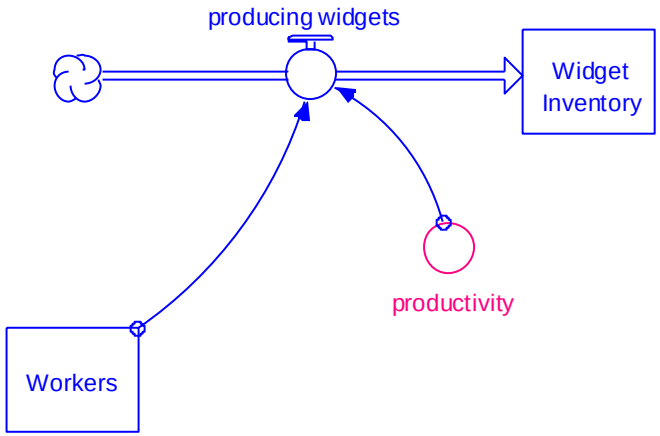


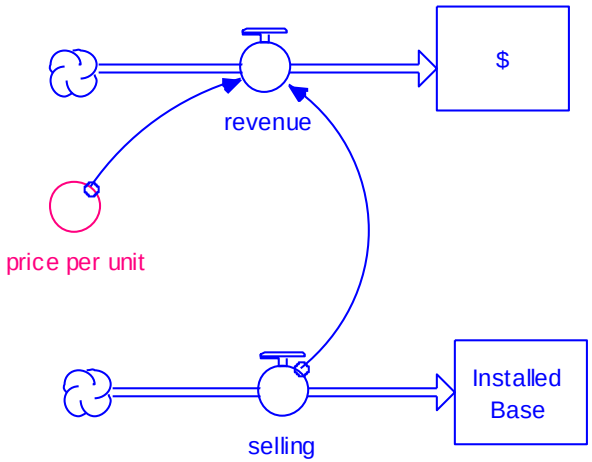
- If you take a close look at the units of measure of the flow vs. its "driver," you'll see an inconsistency.

- The *converter* is the language element that enables us to fix these problems.

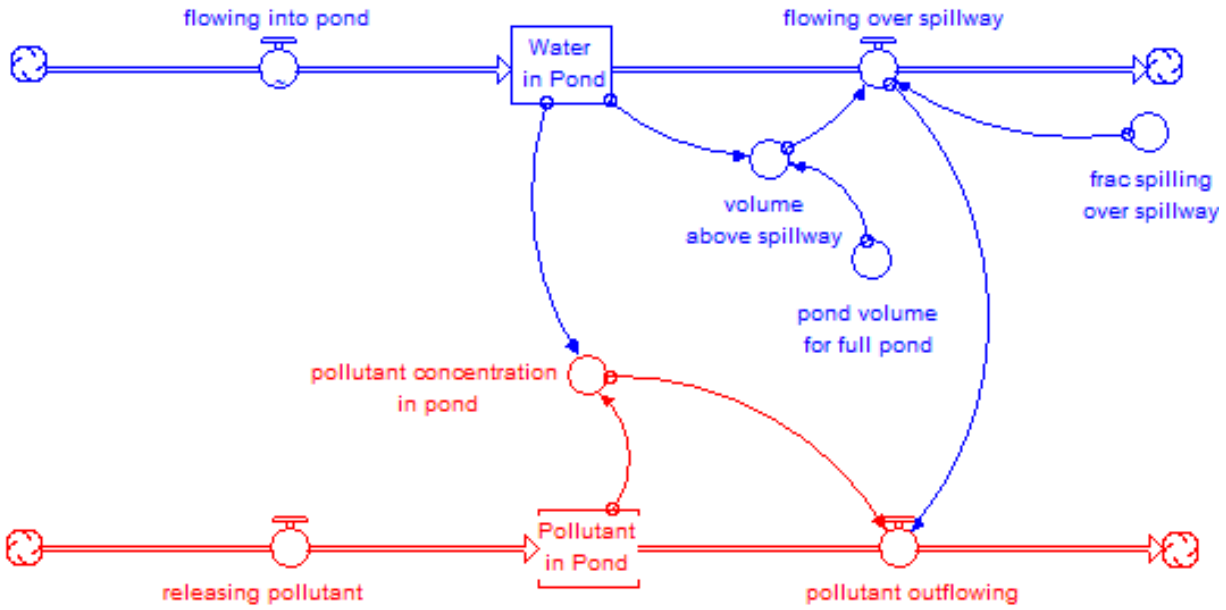
Converters: Adverbs and productivity terms

- They tell how quickly or slowly action is unfolded by the driver of a flow
- In this role, you can think of converters as productivity terms. They tell how productive the stock or flow is, in generating a flow.





Aside: connectors and converters are also used to knit together model inputs and outputs



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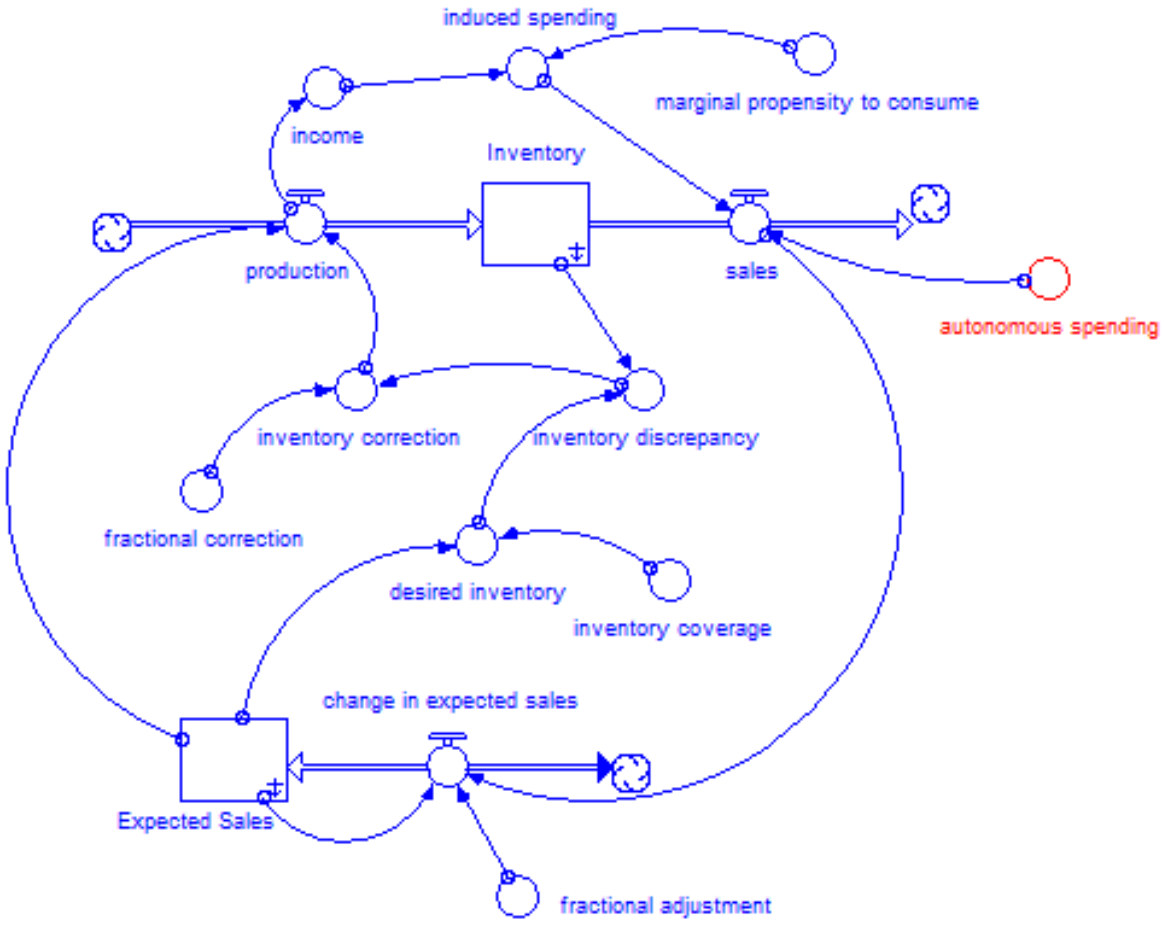
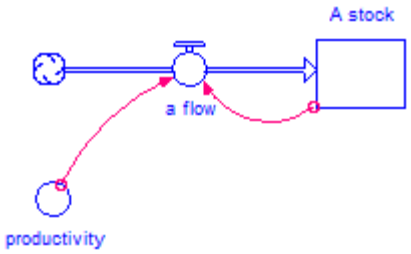


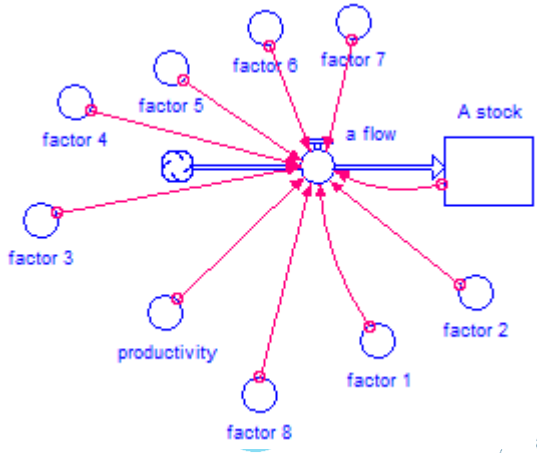
Representing flows simply: Generic Activity Templates

- The stock-to-flow and flow-to-flow linkages are simple and effective ways to *operationally specify* flows in your maps and models.
- It's helpful to view these linkages as *generic* in nature. In our experience, *five* generic templates can form the basis for generating maybe 80 - 90% of the flows in your models.
- Using these specifications (as opposed to ad-hoc approaches) can keep you in control of the modeling effort.

Good!

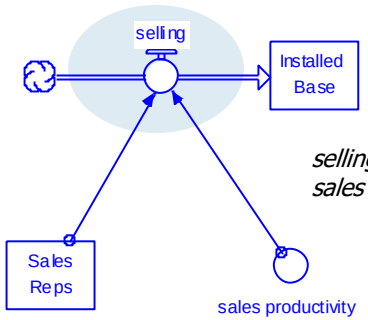


Icky!



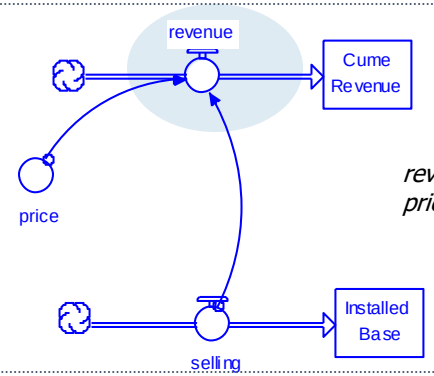
Five Generic Activity Templates

External Resource Template



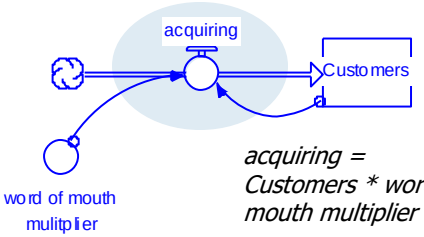
*selling = Sales Reps * sales productivity*

Co-Flow Template



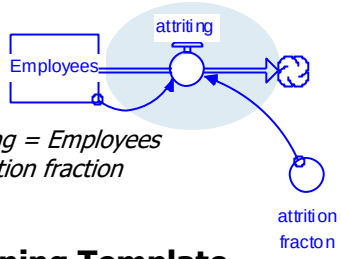
*revenue = selling * price*

Compounding Template



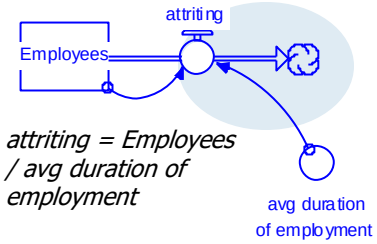
*acquiring = Customers * word of mouth multiplier*

Draining Template



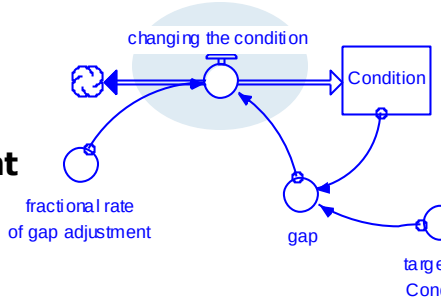
*attriting = Employees * attrition fraction*

OR



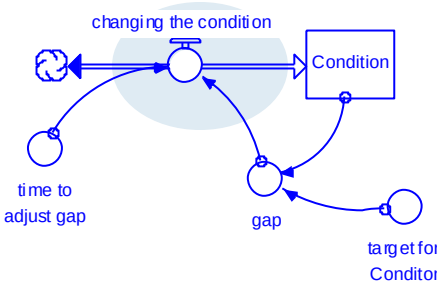
attriting = Employees / avg duration of employment

Gap-Adjustment Template



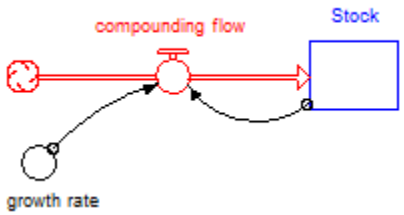
*changing the condition = gap * fractional rate of gap adjustment*

OR



changing the condition = gap / time to adjust gap

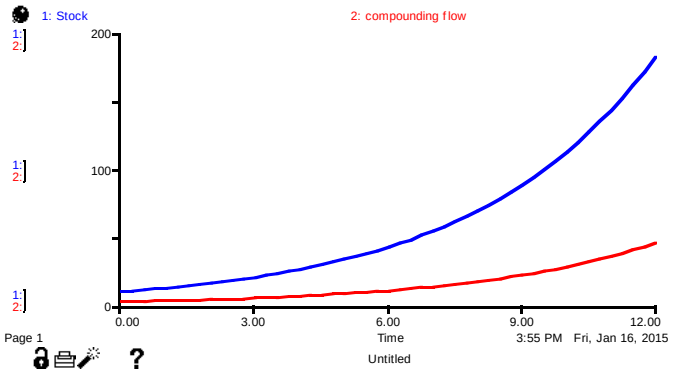
Generic Activity Templates: Compounding



Compounding Template Diagram

Compounding flow= stock * growth rate

Eq'n for Flow



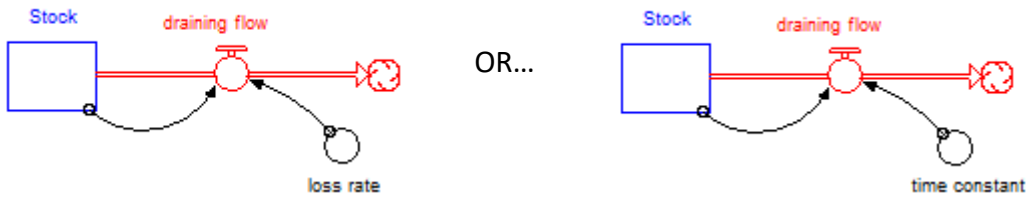
Behavior of system in isolation

Use this template when the stock is doing the work of generating its own inflow.

Potential applications include

- Population growth
- Financial dynamics
- Word-of-mouth
- Viral phenomena

Generic Activity Templates: Draining



Draining Template

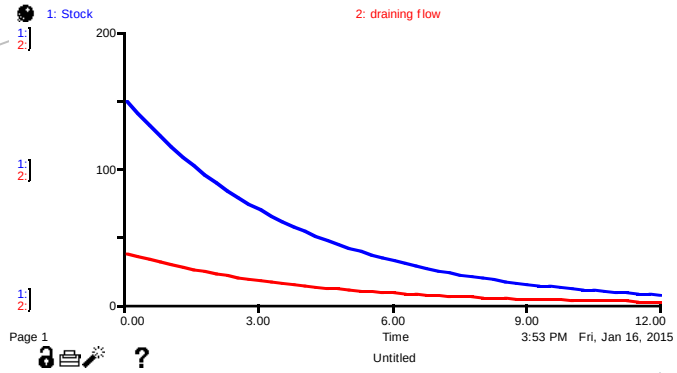
draining flow = Stock * loss rate

Or

draining flow = Stock / time constant

Eq'n for Flow

Losing 50% of your stuff each year is the same as saying on average, stuff sticks around for 2 years!



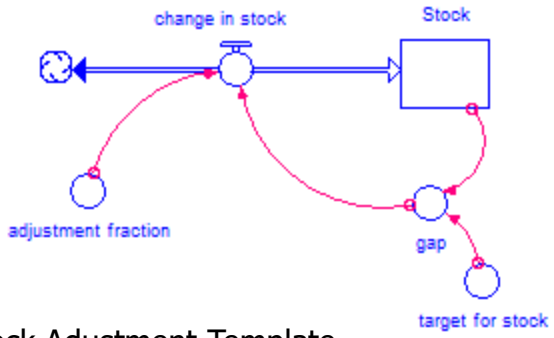
Behavior of system in isolation

Use this template when the stock is doing the work of generating its own outflow, or when you want to represent a passive decay process.

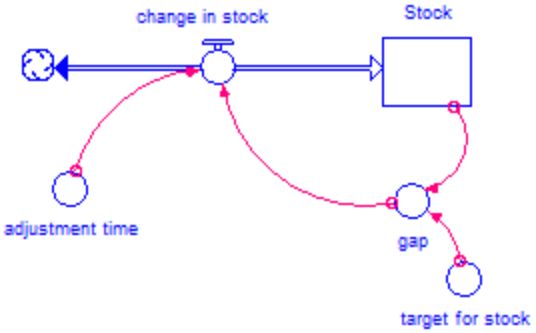
Potential applications include

- Aging processes
- Mortality, attrition, and other system losses
- Radioactive decay

Generic Activity Templates: Stock-adjustment



OR…



Stock-Adustment Template

change in stock= gap * adjustment fraction OR change in stock = gap / adjustment time

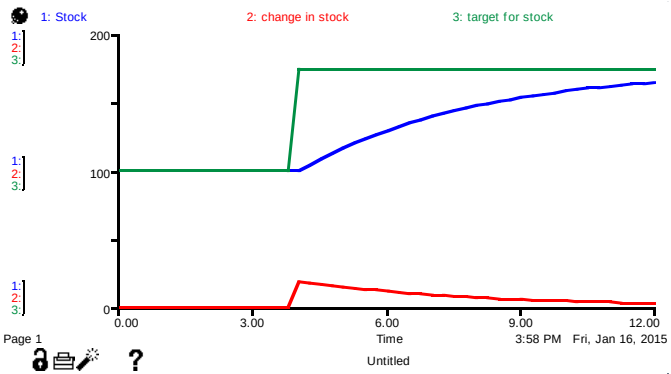
Eq'n for Flow

Often used to represent perception processes (seeking some target or actual condition).

Also used to represent "goal seeking" physical processes

Potential applications include

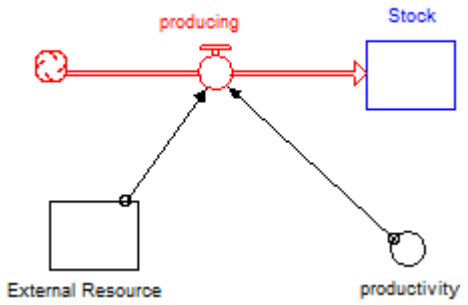
- Moving averages
- Heat transfer (Newton's law of cooling)
- Hiring
- Perceptions



Behavior of system in isolation

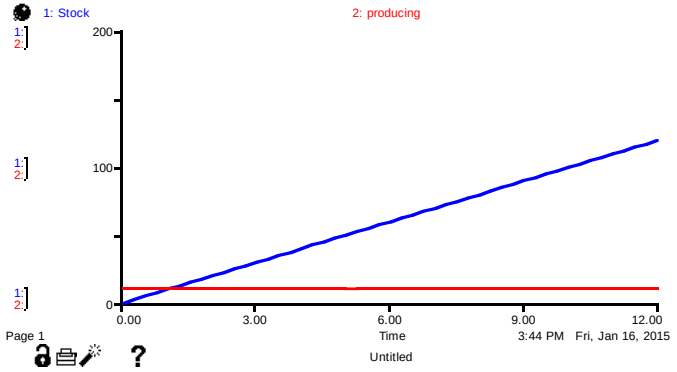
Generic Activity Templates: External Resource

External Resource Template



Producing = External Resource * productivity

Eq'n for Flow



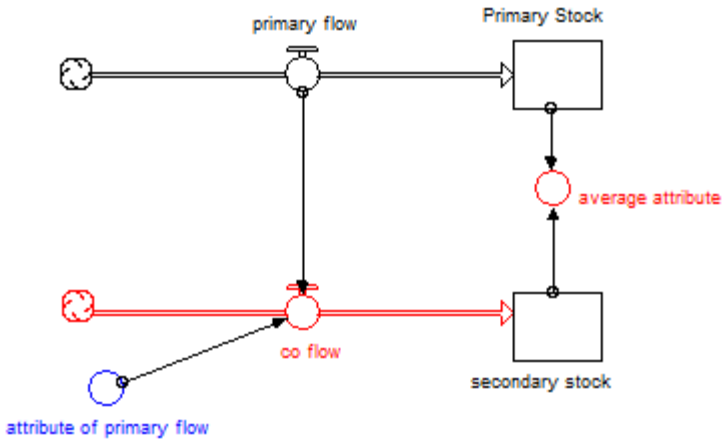
Behavior of system in isolation. Things get more interesting when there are flows attached to the eternal resource

Use this template when some stock, but not the stock that is accumulating or de-cumulating this flow, is doing the work of generating the flow.

Potential applications involve producing stuff, in the most generic sense…

- Widgets
- Intellectual property
- Sales

Generic Activity Templates: Co-flow



Co-Flow Template

Behavior of co-flow depends on what's happening with the primary flow and productivity term.

co flow = primary flow* attribute of primary flow

average attribute = secondary stock/Primary Stock

Eq'n for co-flow and average attribute

Use this template when two flows move in concert, or when you want to keep track of attributes as stuff moves through a system

Potential applications include

- Tracking pollutant concentrations
- Connecting sales to revenue
- Activity based costing
- Corporate average fuel efficiency

Generic Activity Templates: Exercises

1. Bugs

The software engineers at the Rugged Macro software company have discovered that in the process of coding, they inadvertently introduce bugs into their software. Specify the processes of *writing code* and *introducing bugs.*

2. Greenhouse Gases

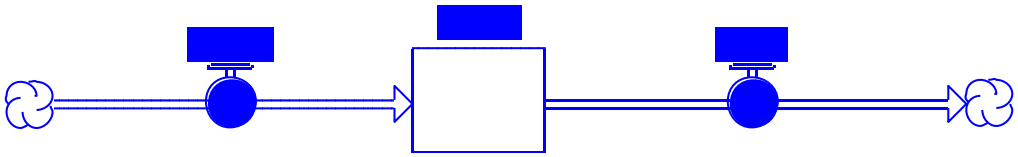
The greenhouse gas carbon dioxide is a natural by-product of any respiration activity. Whenever we breathe, we are emitting greenhouse gases! However most of the concern around the emission of greenhouse gases is not focused on people's breathing processes. Rather, it is focused on the burning of fossil fuels. As fossil fuels are burned, for example in coal-fired power plants or in automobiles, greenhouse gases are necessarily emitted.

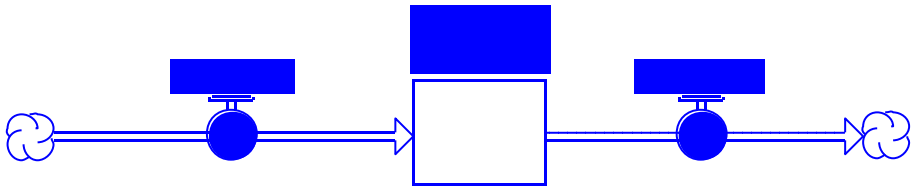
Use generic activity templates to *generate* the flow of emitting greenhouse gases. You may wish to consider two inflows to greenhouse gases—one generated by burning fossil fuels in power plants, the other generated by the burning of fossil fuels in cars.

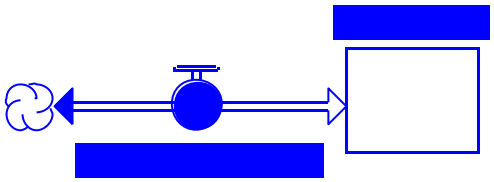
Generic Activity Templates: Guidelines

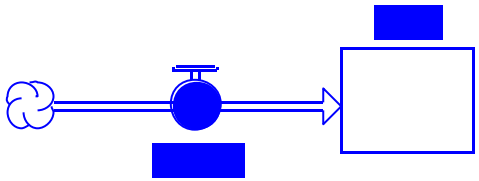
- Ask, "How does this process work?" DON'T ASK, "What are the factors that influence this flow?"
- Then, work to match the nature of the process against one of the templates
  - Determine whether the flow is stock-generated vs. flow-generated.
  - If some external resource is doing the work, use the external resource template.
  - If the flow moves in concert with some other flow, use the co-flow.
  - If the stock is generating its own inflow, use the compounding template.
  - If the flow out of the stock is best characterized as a "passive decay," use the draining template.
  - If there is some adjustment towards a goal or target, consider stock-adjustment
- Use mental simulation to test your choice of flow specification.
- Resist the temptation to have more than TWO wires into a flow.
- Resist the temptation to use an ad hoc specification.
- Don't forget the productivity term.

Generic Activity Templates: In-class exercise









Use generic flow templates to specify each flow. Use the text below to help you select the appropriate templates.

Clients generate work; professionals complete it.

The firm gains new clients through word-of-mouth.

The firm loses a certain % of its clients each year.

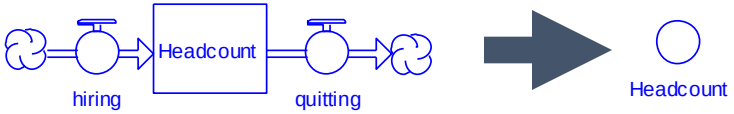
Professional headcount is adjusted to a target headcount. Don't concern yourself (yet) about how this target is set.

Professionals build skills by completing client work; their productivity in doing this work is primarily determined by their skill level.

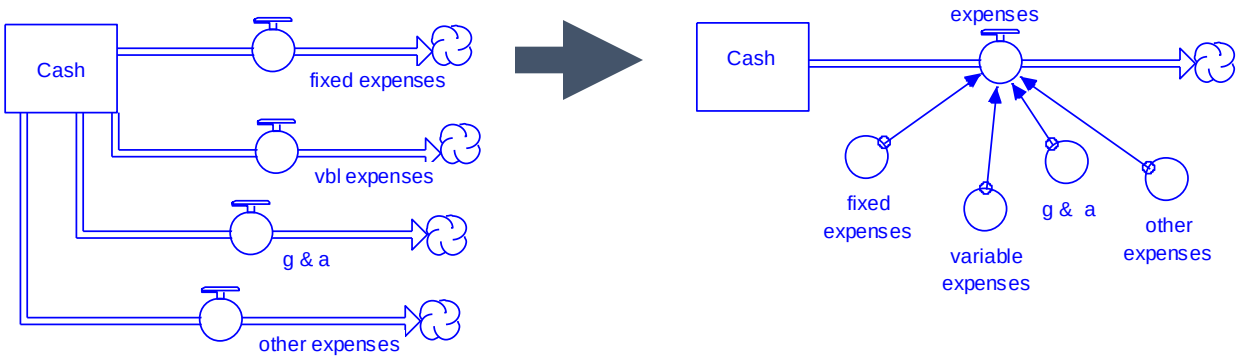
Lexidyne
Simulation Data Analytics

Other roles for the converter

- Low-cost stock substitute…

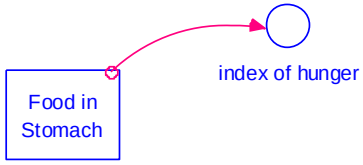


- Container for flow logic…

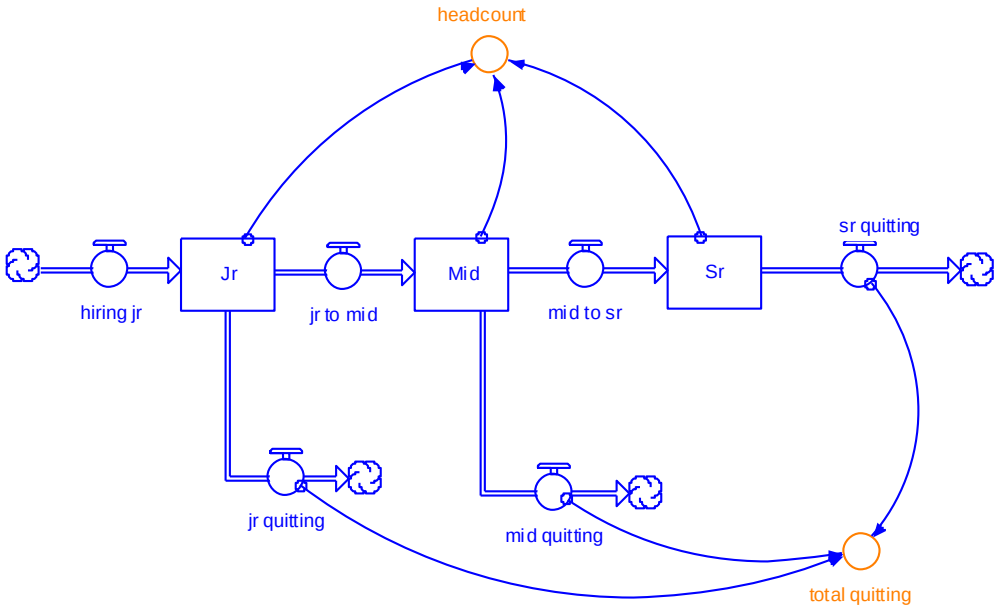


Other roles for the converter

- Alternate unit of measure for stock…

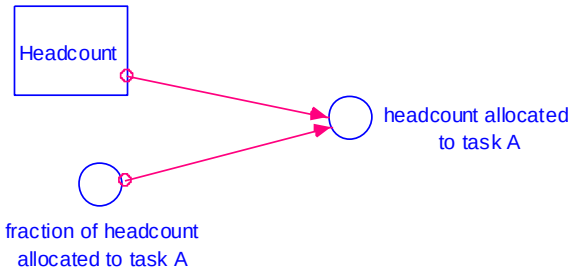


- Roll-up of multiple stocks or flows…



Other roles for the converter

- Repository for cheap algebra…



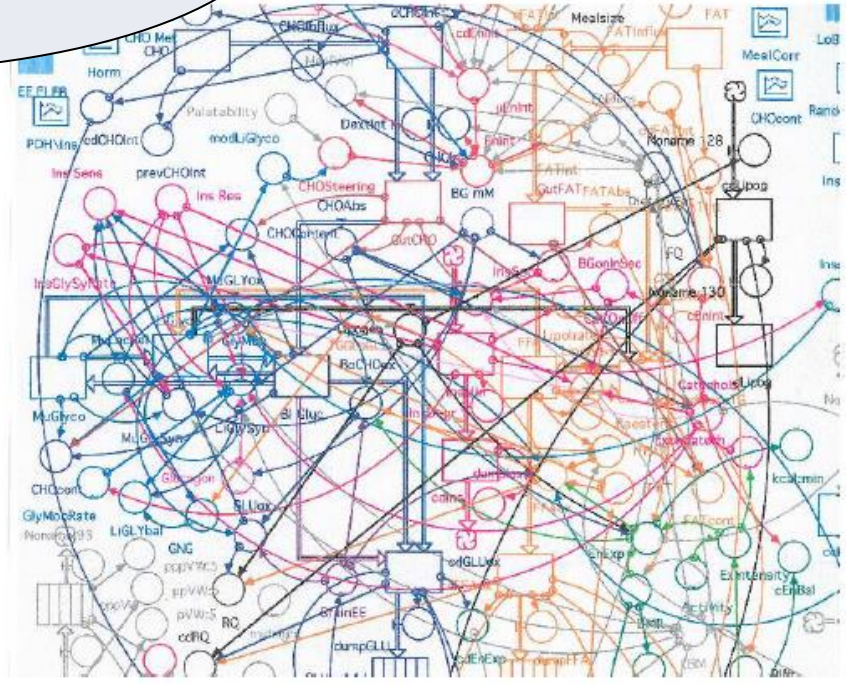
- Housing for model inputs…

Model Extremes (from A to Z)

A

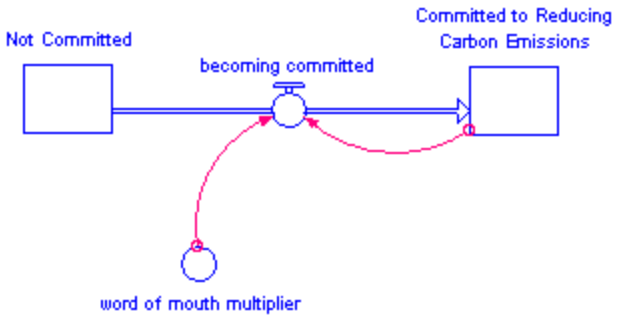
"Sweet Spot" = A simple (but not simplistic!) framework that provides insight into the structure/behavior of a complex, dynamic system.

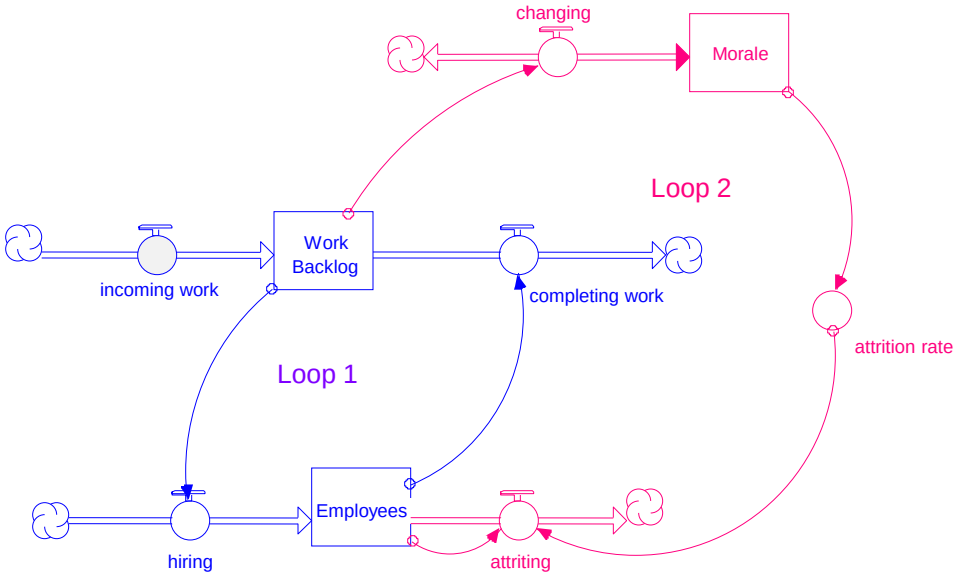
Z



Feedback loops – Stock/Flow Framework

- A feedback loop exists whenever the current state of the system leads to activities which further change the state of the system.
- There's a feedback loop in place whenever a stock is connected to a flow that changes the magnitude of the stock. The connection can be direct, or more tortuous.





System Dynamics Modeling Progression

1. Why are we building this model? **Purpose Statement**
2. What's the behavior of the system over time? **Reference Behavior Pattern(s)**
3. What's accumulating? **Stocks**
4. What's filling/draining the accumulations? **Flows**
5. What simple, operational processes are driving the flows? **Generic Activity Templates**
6. What interconnections exist between model elements? **Feedback Loops**
7. How does the simulation respond to changing inputs/scenarios/policies? **Model Testing**

Reflect and Iterate!!!!

Potential and Pitfalls

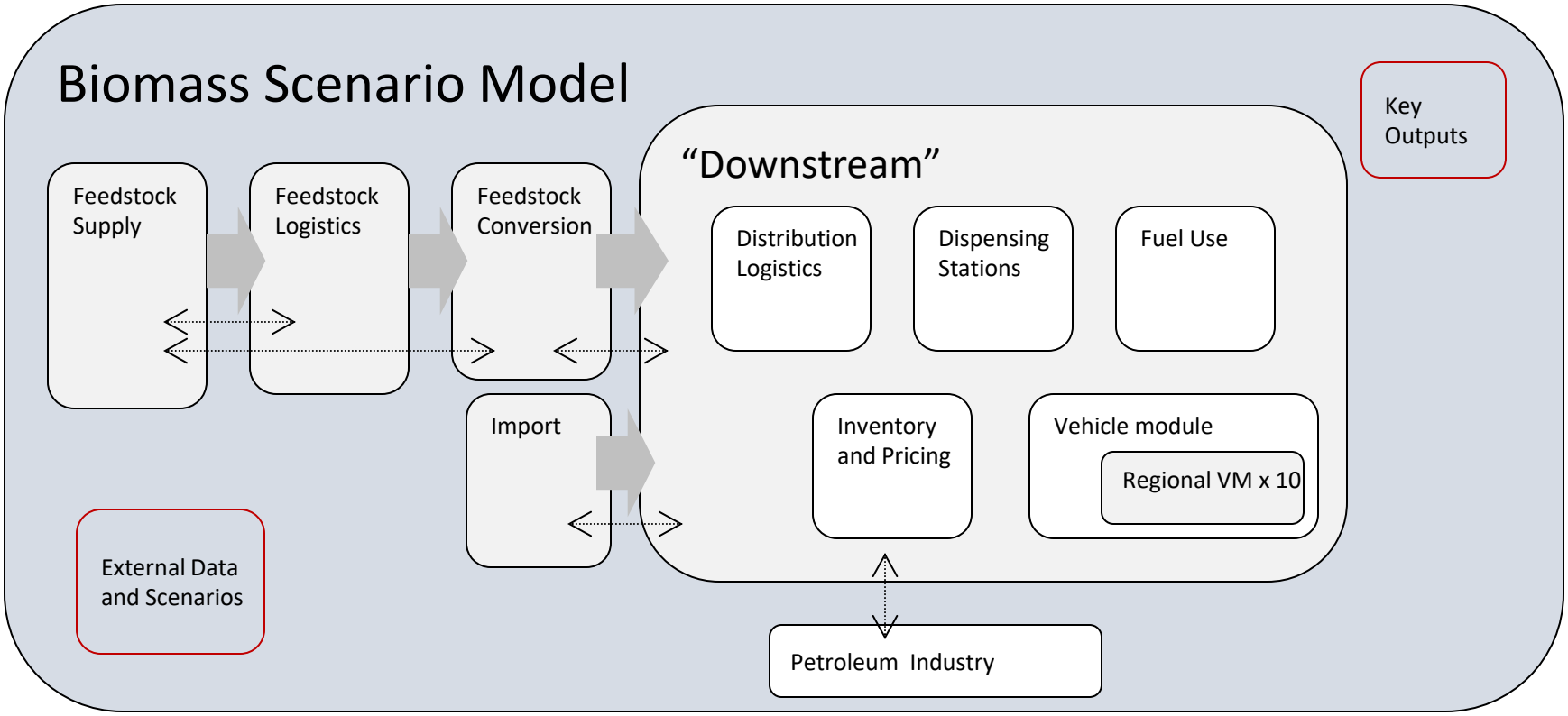
ONE FRAMEWORK FOR THINKING ABOUT MODEL EFFECTIVENESS

Protective Model	Reflective Model
Prove a point	Promote inquiry
Obscure assumptions	Expose hidden assumptions
“Cherry pick” data	Identify data weaknesses
“Prove” preconceptions and preselected answers, while covering biases	Challenge beliefs while support multiple perspectives and involving a broad community of interests
Promote the authority of the modeler	Promote the empowerment of clients

Adapted/revised from Sterman, 2000, from Isaacs and Senge, 1992

Potential and Pitfalls

HIGH-LEVEL SCHEMATICS => GOOD INTRODUCTION TO SD MODELS



Generate scenarios focusing on the evolution of supply chain for biofuels

Material flow (e.g., Feedstock, fuel)

Information flow (e.g., relative fuel price)

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A Brief Bibliography

Resource	Author/Publisher	Notes
Business Dynamics	John Sterman, Wiley (2000)	Encyclopedic coverage. Great reference book. Primarily business focused.
Competitive Strategy Dynamics	Kim Warren, Wiley (2002)	Stock and flow perspective applied to strategy. Clear and accessible.
Modeling the Environment	Andrew Ford, Island Press (1999)	Accessible treatment of how to apply dynamic modeling to environmental issues and problems
The Fifth Discipline	Peter Senge, Doubleday (1994)	Qualitative treatment of broad array of dynamic modeling skills and topics. Popularized "systems thinking" approach. Many follow-on "field books" published over the years.
Modeling Dynamic Biological Systems	Bruce Hannon, Matthias Ruth Springer-Verlag (1999)	Good reference book. Uses iThink/STELLA models. Note that Bruce Hannon has co-written several other books on dynamic modeling published by Springer
Feedback Thought in Social Science and Systems Theory	George Richardson, Pegasus Communications (1999)	Scholarly. Traces development of feedback concept from ancient times to the present.
The Systems Thinker Newsletter	Pegasus Communications www.pegasuscom.com	Newsletter format. Pegasus website is a clearinghouse for a host of dynamic modeling/system dynamics/systems thinking resources.
Modeling Dynamic Systems: Lessons for a First Course	Diana Fisher, iseesystems (2005)	Nice introductory treatment
Industrial Dynamics	Jay Forrester, Pegasus Communications, (1961)	Classic book on system dynamics, written by the founder of the field.
Introduction to Systems Thinking	Barry Richmond, iseesystems (2002)	Extremely accessible work produced by one of the leading lights of the field.
Tracing Connections: Voices of Systems Thinkers	isee systems/The Creative Learning Exchange (2010)	Real-world examples from multiple practitioners. Wide variety of contexts. A good read.

STELLA Specifics

SOFTWARE DETAILS

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Simulation Data Analytics

Conveyor: A special kind of stock

Conveyor Inflows

Multiple inflows to Conveyor allowed

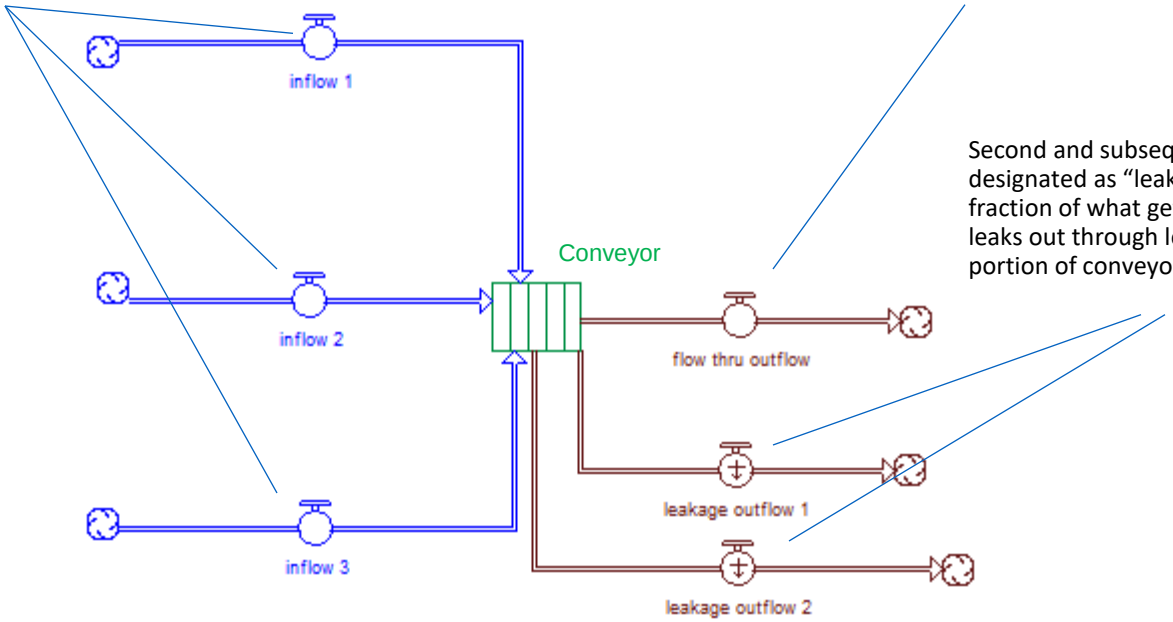
Flows can come from clouds (shown here) or from other stocks

Conveyor Outflows

Multiple outflows allowed

First outflow you draw = "flow-thru" flow. Flow-thru captures whatever does not leak as it moves through the conveyor

Second and subsequent outflows are designated as "leakage" flows. Can specify fraction of what gets on the conveyor that leaks out through leakage flow. Can specify portion of conveyor that is prone to leakage



Stuff has to be "pulled out of" a reservoir.
Stuff is "pushed through" a conveyor!

Conveyor: A special kind of stock

Conveyor Flow-thru

Nothing to define here under most circumstances. Transit time is handled in conveyor dialog; Leakage captured by leakage dialog. Whatever makes it to the end goes through this flow.

Conveyor Leakage

Set beginning and end of no leak zone.

Conveyor

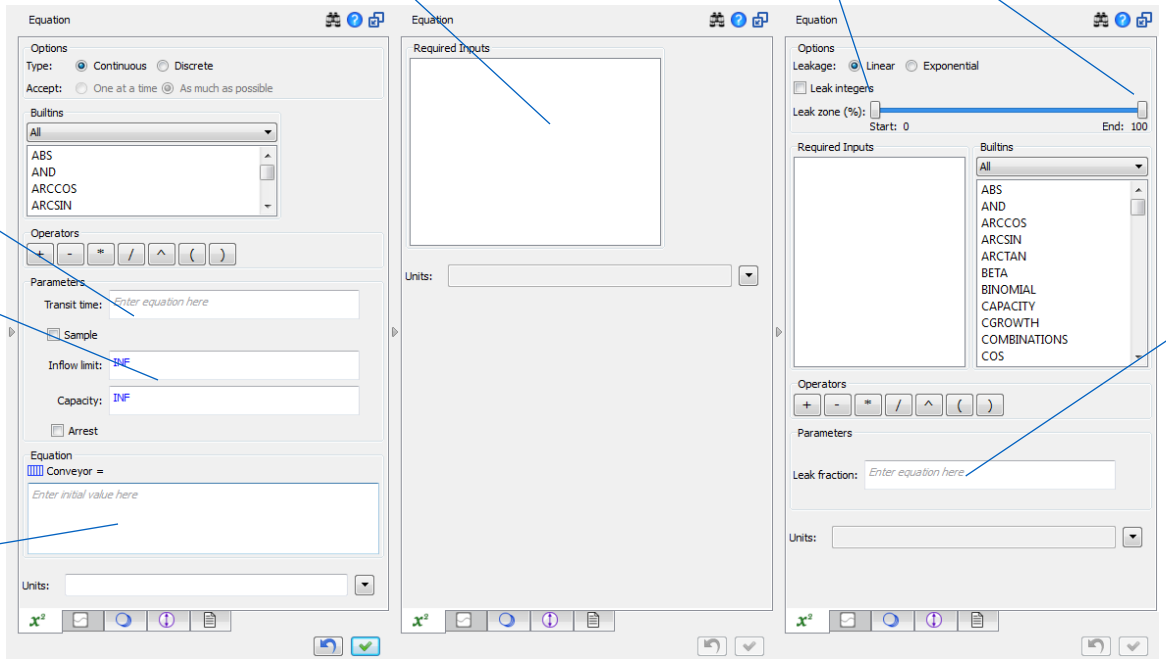
Define variable or constant transit time. Drag and drop a variable to put variable transit time box into the dock.

Possible to specify constant capacity and/or inflow limit.

Inflow limit acts as bottleneck at entrance to conveyor, constraining inflows to not exceed specified volume per unit time

Capacity automatically constrains conveyor inflows to prevent total "weight" of conveyor from exceeding specified value

Define initial value for conveyor in the equation box.



Use required inputs, builtins, or constant to define leak fraction

Guidelines for Using Conveyors

Consider using a Conveyor when…

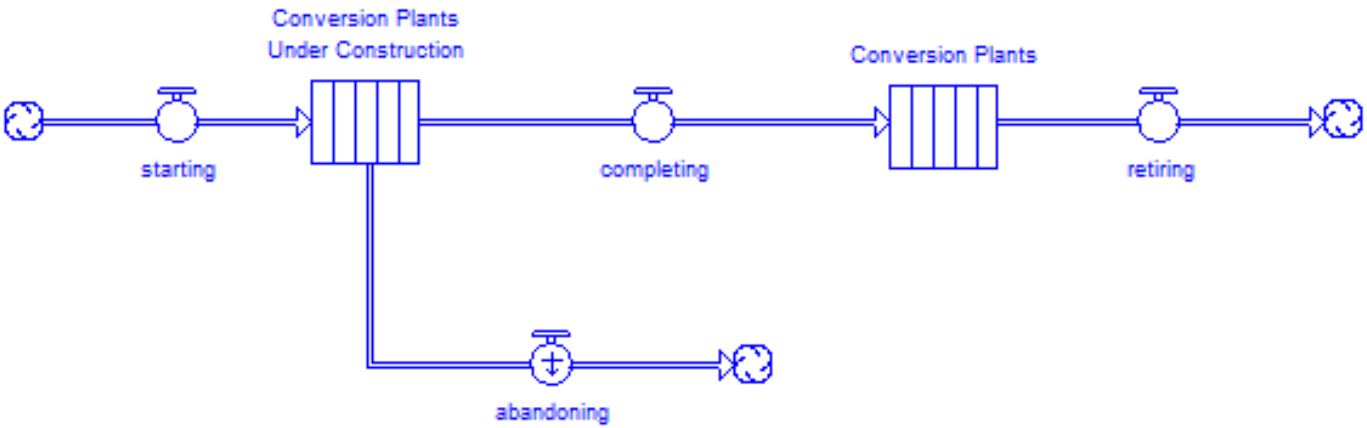
- You want to capture the dynamics of a "pipeline delay"
- You want to capture a process (such as a development process) at the highest possible level
- Your major concern is the amount of time that material spends "in process"
- It's important to maintain "arrival integrity"
- You're modeling a discrete (vs continuous) process

Consider using a Reservoir when…

- You need explicit control over the outflows from the process
- Material in the stock can be appropriately handled as a "mixed" quantity
- There are many outflows from the stock (4+)
- You want to represent the physics of the flows (as opposed to just "time in process")

Conveyor Example

Industries relying on heavy capital investment often experience significant lags based on construction delays. An empty construction pipeline today can mean lack of capacity tomorrow! Below is simple stock-flow diagram depicting the capacity pipeline for a new generation of biofuels conversion plants.

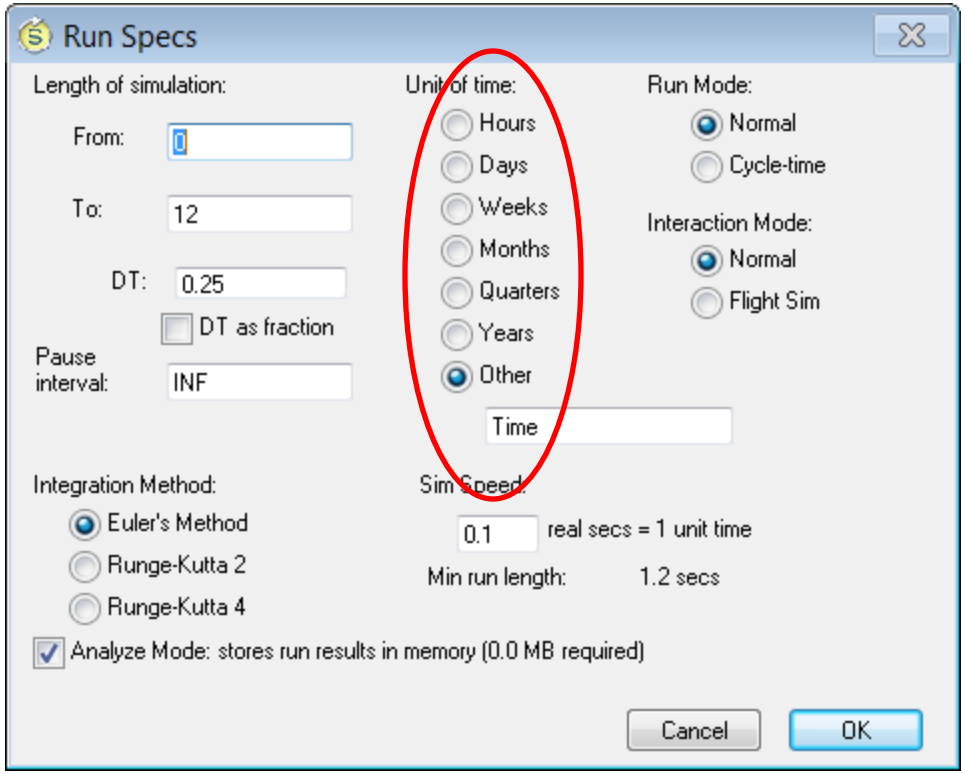


Using Unit Checking in Stella: Context

- Dimensional analysis is simple yet powerful way to increase the rigor of your thinking.
  - If units on left hand and right hand side of equation resolve to the same thing, your equation passes a first level of plausible
  - If LHS and RHS are inconsistent, you've got problems
    - Bad theory?
    - Stupid equation?
    - Silly mistake (adding when you should have been multiplying)
- ALWAYS a good idea to do a mental unit check on each eq'n before you hit OK
- Stella has built-in checking capability that can (and will!) catch errors in your mental check

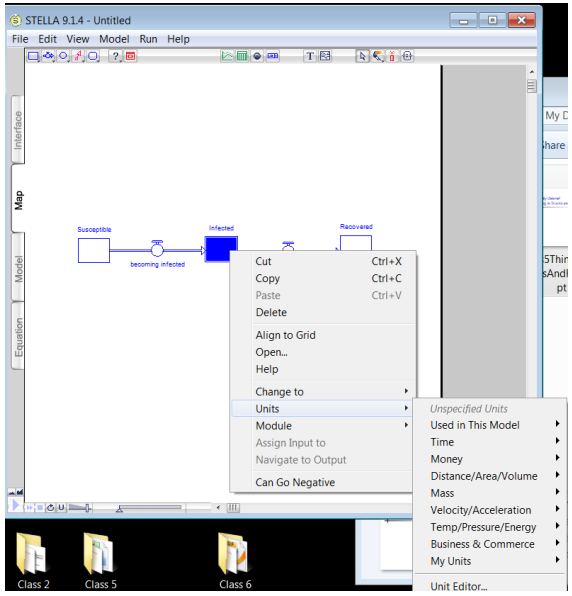
Using Unit Checking in Stella : Basic Approach

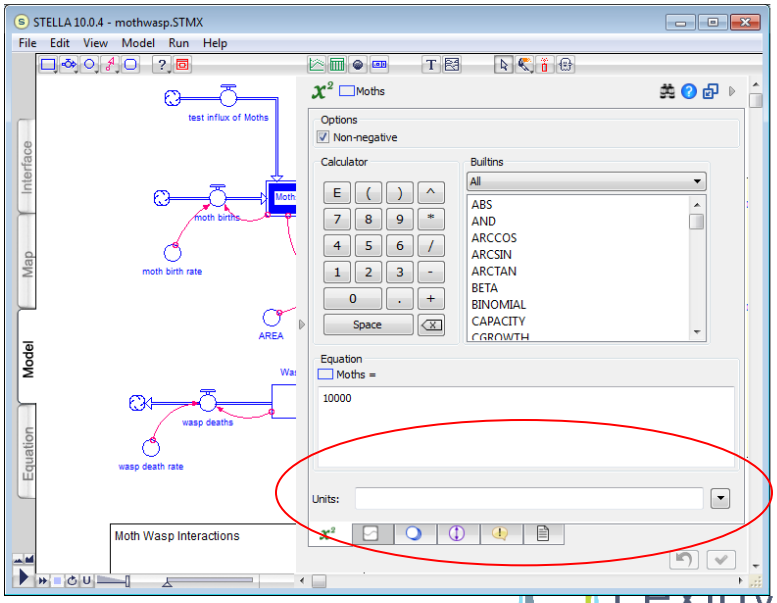
1. Set the base unit of time.
   - Enter Run Specs
   - The unit you choose will be applied to flows in your model.



Using Unit Checking in Stella : Basic Approach

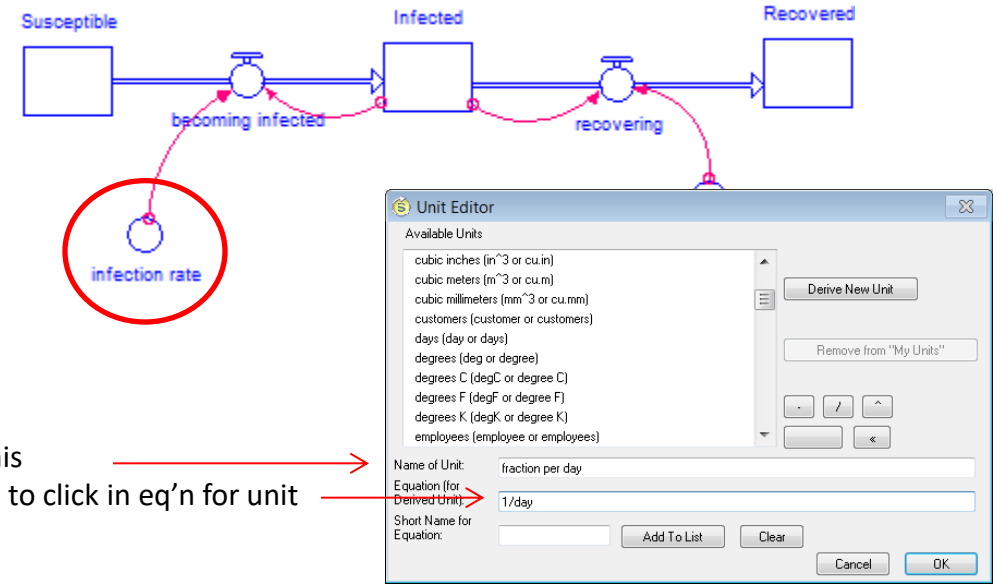
2. Apply units to stocks
   - Select a stock
   - Right click on stock, or enter its eq'n space and click the units drop-down at the bottom of the space.
   - Pick a unit from the list of default units, or enter the unit editor and define your own. Note that units are grouped ("people" lives in business & commerce. So does "unitless")
   - The unit you select or define will be applied to all stocks in the main chain. Unit-per-time will be applied to all flows in the main chain

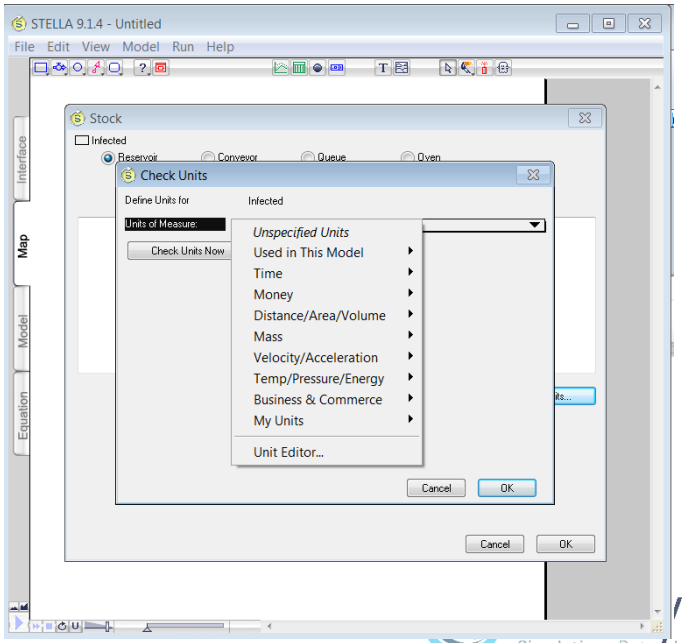




Using Unit Checking in Stella : Basic Approach

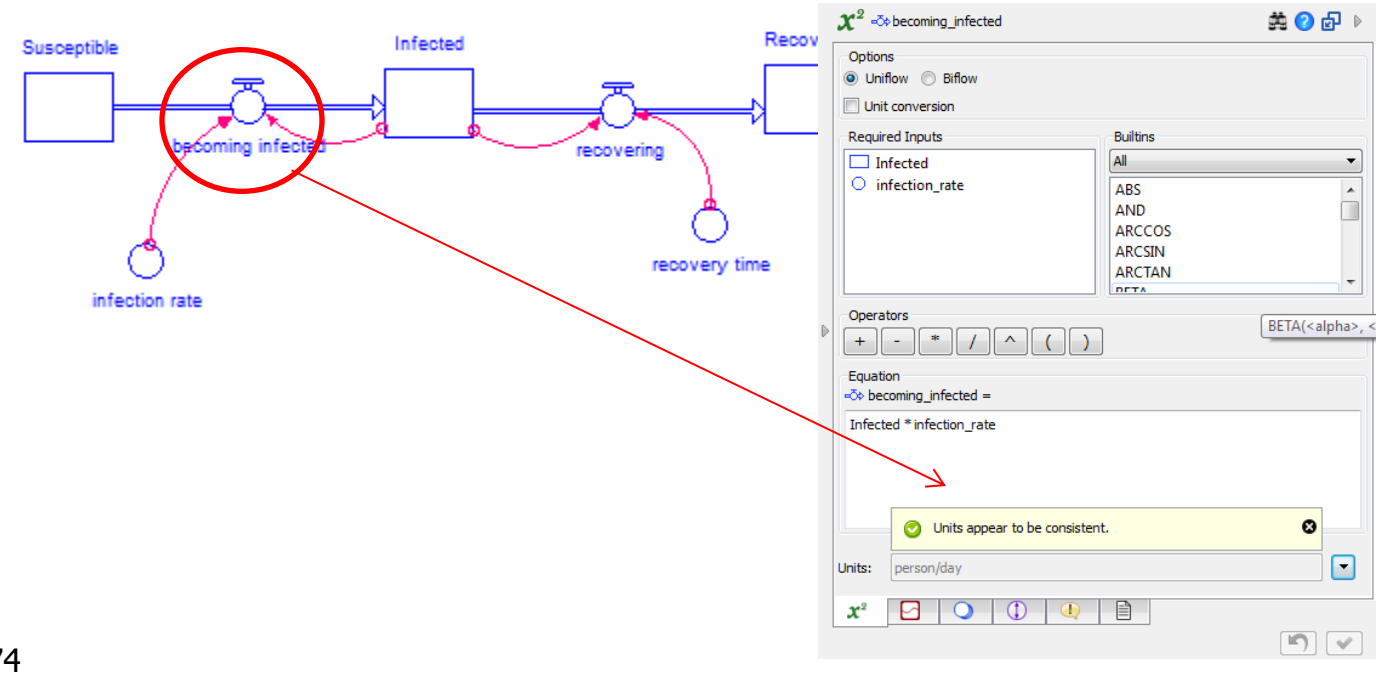
3. Apply units to converters
   - Select converter. Right click, or enter enter units through its dialog
   - Pick a unit from the list, or derive a unit using the unit editor (shown below)
   - Add the new unit to the list and/or OK your way out of the dialog





Using Unit Checking in Stella : Basic Approach

4. Check for unit consistency
   - Method 1: Check entire model : Run Menu→Check Units. Useful to double check after model is completed
   - Method 2: Check as you go. From within dialog, click on the drop-down next to the units field. You'll get an alert if you have problems.



Hints and Tips:

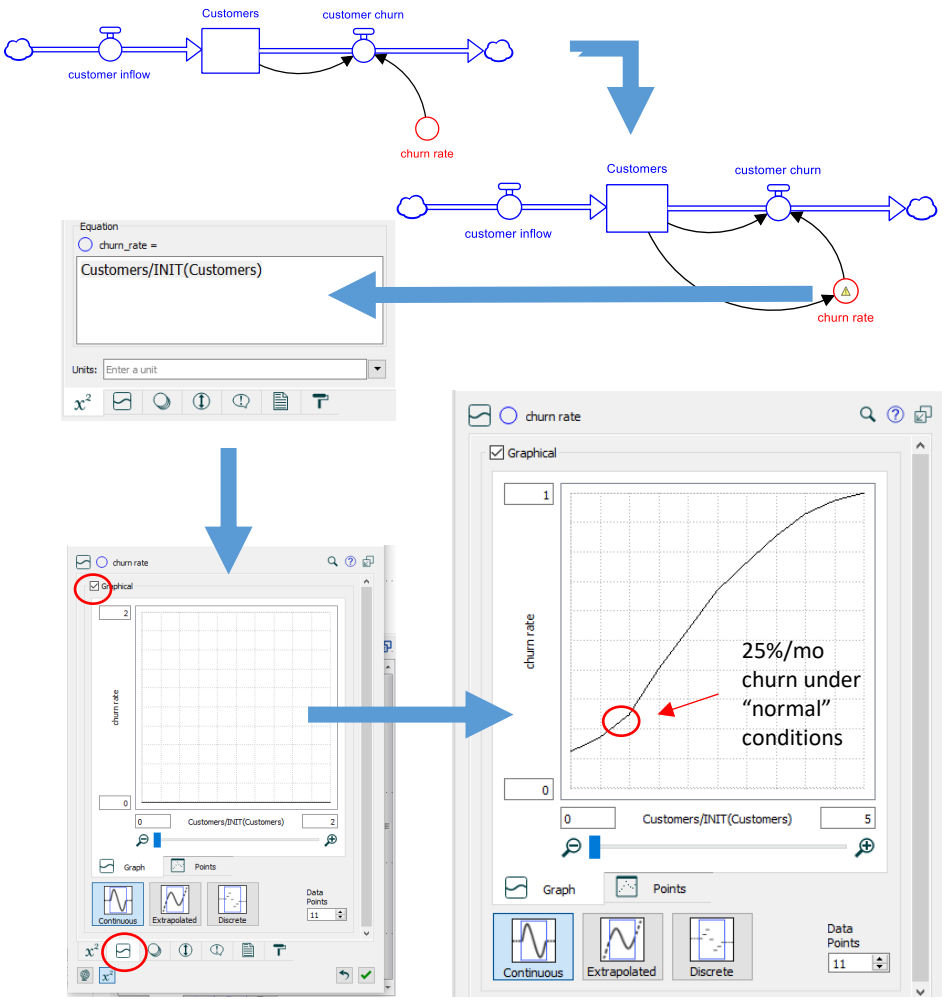
- In defining units , you have limited algebraic options
  - NOT OK: widgets/person/week
  - OK: widgets/person-week
- Some built-ins will choke on units (e.g., Ramp)
- Run → check units fails to correctly check units for conveyor transit time
- Good to keep names of units short/terse.
- *Lexidyne (prompted by Steve!) often uses CamelCase to define units (less ambiguity around spaces).*

Creating graphical functions

SIMPLE WAY TO REPRESENT NONLINEAR RELATIONSHIPS

You can use graphical functions to represent input-output relationships as a lookup table or as a picture. Graphical functions can also be used to represent time-dependent input scenarios.

1. Begin by drawing connector(s) to represent the interdependency relationship(s)
2. Open the converter (here, "churn rate") and define the input to the graphical function. Often helpful to "normalize" the input as shown here.
3. Click the graphical function tab, and then check the box in the graphical function panel
4. Create the graphical function
   - Think only of the relationship between the input and the output variable, holding constant all other variables that might impact the output variable (Ceteris Paribus Principle).
   - Define ranges for the input and output variables. Be sure to define a range that incorporates the full possible movement, not just the historically-observed range.
   - Determine the direction of slope; the slope should, in almost all cases, be either positive or negative (or zero) over the whole range. If the slope changes direction, be certain you are not inadvertently including another influence in your thinking.
   - Identify extreme points on either end of the range (possible to extrapolate beyond extrema). In some cases, you'll also be able to identify a so-called "normal" points.
   - Sketch a smooth curve through the points.
5. Also possible to create a graphical function by typing or pasting points directly



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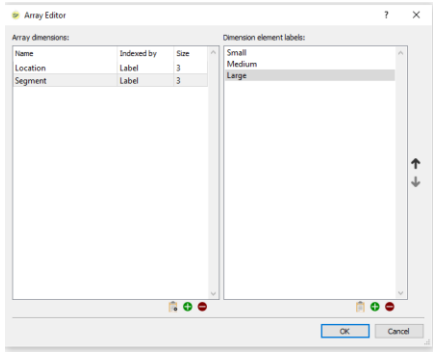
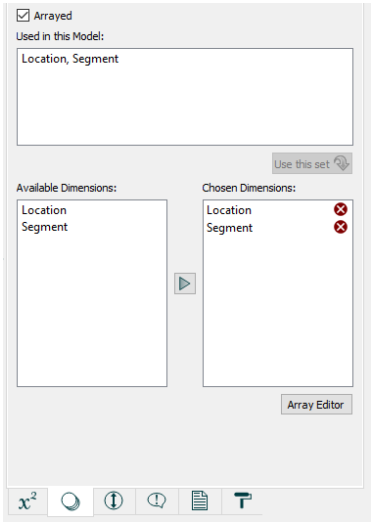
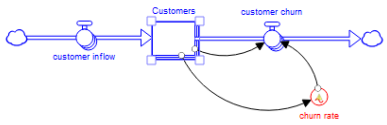
Working with arrayed variables

MODEL SEGMENTATION AND DISAGGREGATION

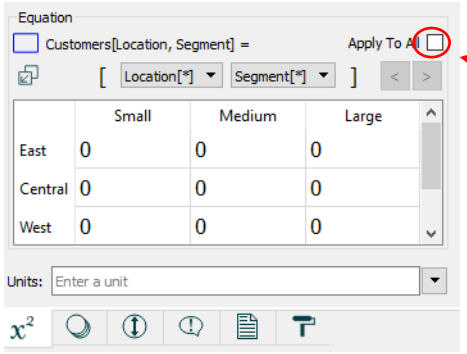
Arrays are helpful whenever a common model structure is repeated in parallel multiple times. Copy/paste can become very unwieldy!







- The software supports n-dimensional arrays. (4-D arrays represent an upper limit in most practical applications.)
- Steps to using arrays:
  1. Use the array editor (model menu→ array editor) to define one or more dimensions
  2. Transform scalar variables into arrayed variables. When you change a stock, attached flows will change as well.
  3. Define the equation logic for arrayed variables
- See Help system (Building models → working with arrays section) for more than you'd ever want to know!



Can use element-specific eq'ns (shown here) or a generic eq'n that is applied to all

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Sensitivity Analysis

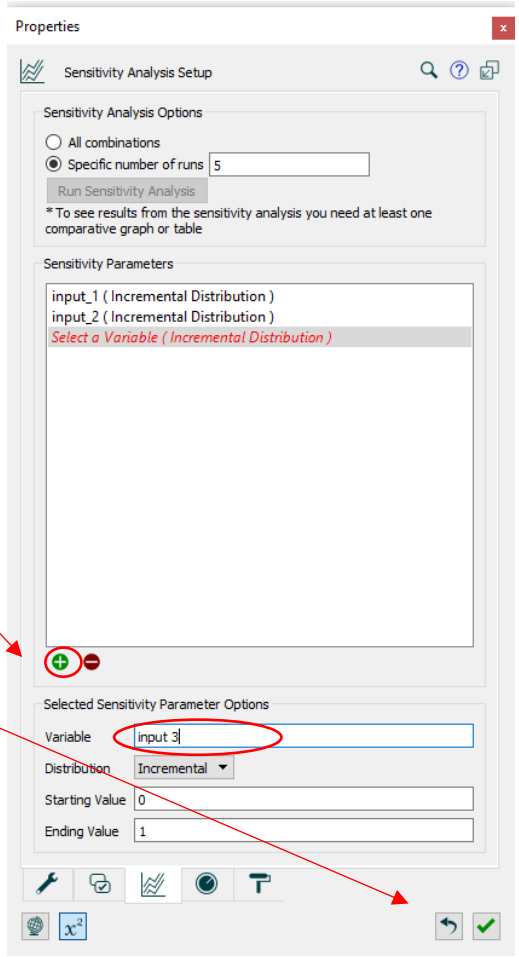
FOR EXPLORATION OF PARAMETER SPACE

Useful for understanding responsiveness of system to changes in one or more parameters. Provides mechanism for exploring risks and uncertainties.

Steps to working with sensi analysis:

1. Enter the setup dialog(model menu→ Run specs → tab)
2. Hit the green button and then load each sensi input to the parameters list. Can set variation type as incremental, as a distribution, or as ad-hoc sequence of numbers
3. Set up the analysis to reflect all combinations or a specific number of runs
4. Hit the check box to confirm your setup
5. Create one or more comparative graphs/tables to collect results.
6. Run the analysis

See Help system (Running models → Sensitivity analysis section) for more than you'd ever want to know!



Lexidyne Simulation Data Analytics

Case Studies

CAPSTONE, NEW PRODUCT DIFFUSION, PREDATOR/PREY

Lexidyne
Simulation Data Analytics

SD Case Study 1

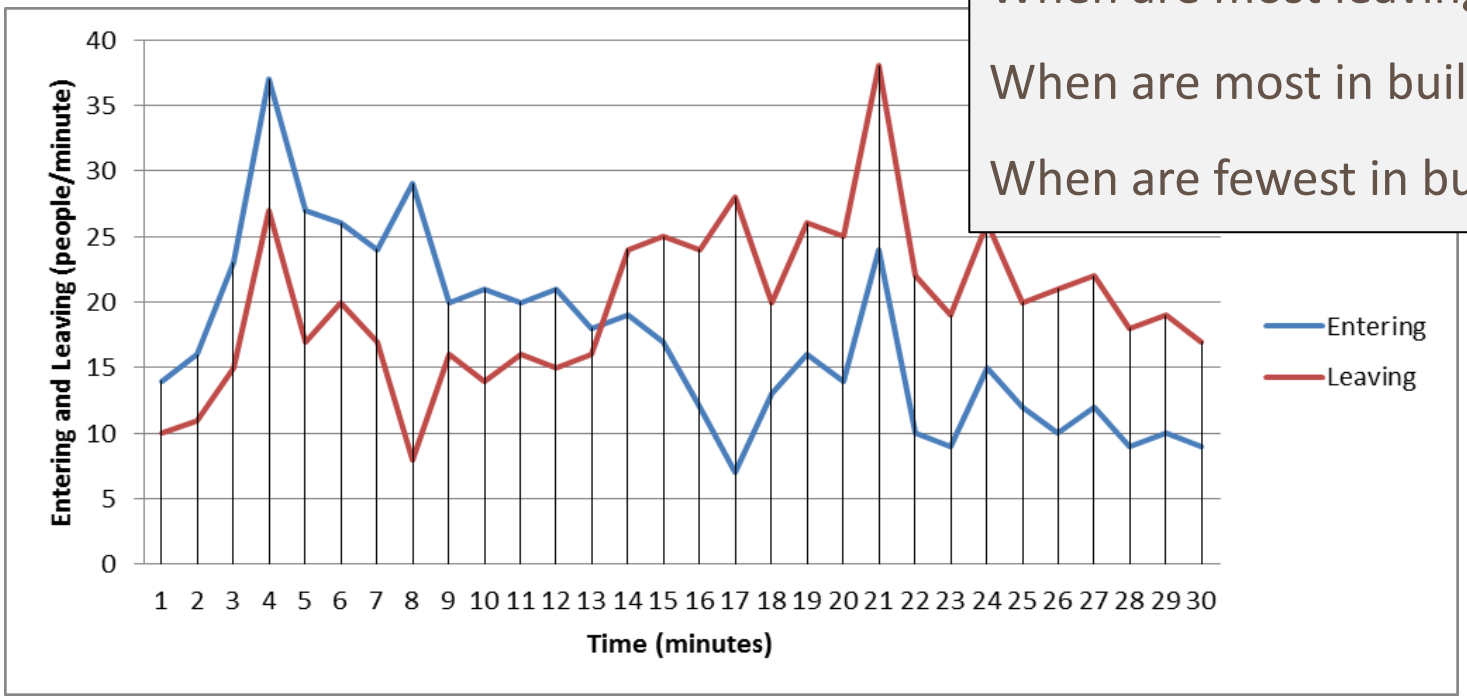
CONSIDER THIS DATA FROM NREL SECURITY DESK

When are most entering?

When are most leaving?

When are most in building?

When are fewest in building?



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SD Case Study 2

Work by yourself to think through this scenario:

How it's put together:

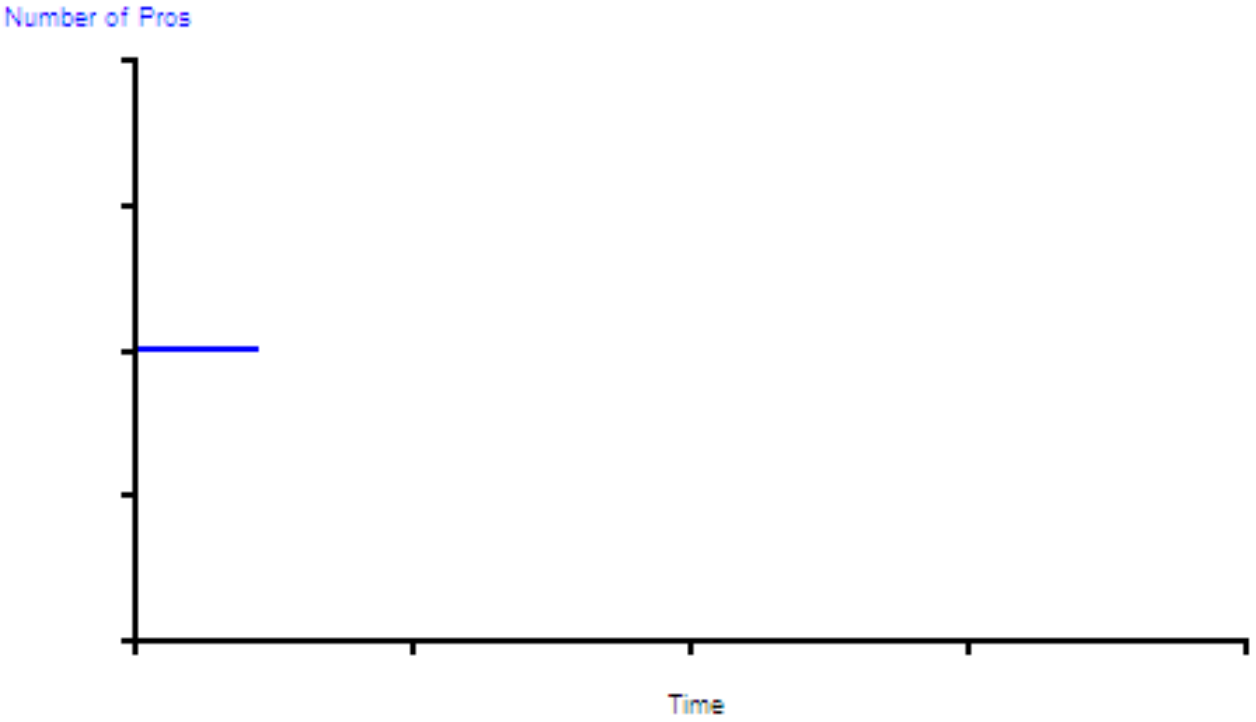
A service organization has two classifications for its professional staff, Rookies and Pros, based on experience levels. When Pros leave the organization, Rookies are immediately hired in exact number to replace them. After being hired, Rookies immediately enter an intensive 6-month training program. They emerge as full-fledged Pros after 6 months. The program is so good that no Rookies drop out or quit along the way. All Rookies are able to "graduate" to become Pros in exactly 6 months! Because of its position and reputation, the organization never has difficulty in its recruiting efforts. No matter how many Pros leave the firm in a given month, it is able to instantly hire that number of replacements in the form of high-quality Rookies.

This organization has been operating in a balanced headcount situation for several years. Hiring of Rookies has been constant, exactly equal to the loss of Pros from the organization (which also has remained constant for years). Now, all of a sudden (and for reasons that we're not concerned about right now), the rate at which Pros are exiting steps up to a new, higher constant number of people per month. It then remains at this new value forever.

A question about the dynamics:

If the organization continues with its current hiring policy (i.e., immediately replace departing Pros by hiring Rookies), and the external environment continues to enable the organization to execute this hiring policy, what pattern over time will be traced by the number of Pros following the step-increase in the Pro quitting rate? Sketch your guess on the axis provided on the next page, or on a blank sheet of paper.

SD Case Study 2



Generic Activity Templates Exercise - A

In today's data-rich environment, modeling projects often begin by taking a look "at the numbers." Suppose you want to model the dynamics of the HIV/AIDS epidemic in the US. A quick Internet search has revealed the following data:

HIV/AIDS in US																	
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Prevalence																	
Undiagnosed		33,621	38,048	41,613	46,114	51,504	56,213	60,708	62,206	66,447	70,923	75,645	80,955	84,273	88,176	91,919	95,974
Diagnosed		168,107	190,240	208,067	230,569	257,521	281,063	303,538	311,031	332,233	354,615	378,226	404,774	421,363	440,880	459,594	479,868
Incidence																	
true incidence		123,874	93,751	85,288	80,179	69,719	55,573	53,718	46,028	45,619	47,033	48,877	49,838	44,797	43,381	42,521	41,706
diagnosed incidence		103,228	78,126	71,073	66,816	58,099	46,311	44,765	38,357	38,016	39,194	40,731	41,532	37,331	36,151	35,434	34,755
Deaths																	
from undiagnosed		8,786	9,683	9,838	7,290	4,220	3,488	3,216	2,962	3,396	3,328	3,481	3,491	3,263	3,404	3,245	3,218
from diagnosed		43,928	48,416	49,190	36,451	21,098	17,442	16,081	14,809	16,980	16,641	17,404	17,453	16,316	17,018	16,226	16,088

Use a basic stock/flow map to describe this system.

Questions to consider:

- What is accumulating? What's flowing?
- What is the simplest possible representation of the operational nature of this dynamic?

Generic Activity Templates Exercise - B

With the “main chain” map laid out, now specify the flows using GATs.

Question to consider:

- How does your representation compare to the basic GAT templates?

Generic Activity Templates Exercise - C

Treatment for HIV/AIDS patients is extremely expensive, averaging about $20,000 per diagnosed patient per year in 1994. Expand your model to include both the yearly and cumulative cost of treatment.

Question to consider:

- What if average annual cost of treatment is not static, but instead increases at 6% per year?

Generic Activity Templates Exercise - D

The AIDS Quilt Project was designed to commemorate and honor lives lost to this disease. In 1994 there were approximately 10,000 “panels” on this enormous quilt. If 50% of HIV/AIDS deaths result in a new panel being added, how large (in terms of panels) has the quilt become?

Questions to consider:

- What is the units of measure of the AIDS Quilt?
- How might you calculate the size of the quilt in other units (square feet, pounds, etc.)?

Generic Activity Templates Exercise - E

The introduction of powerful new treatment “cocktails” in the mid-1990s significantly altered the dynamics of HIV/AIDS epidemiology. Specifically, mortality rates plunged. Suppose that beginning in 1994, the death rate for patients treated with these novel regimens was expected to fall by 5% per year.

Questions to consider:

- What is the RBP for the mortality rate variable?

Capstone Exercise 1

You are planning to go on-line with a subscription-based internet service. This service aims to be a cutting-edge information and resource portal for pharmaceuticals researchers. Several people have told you that the key to your success involves attracting and retaining a sufficient number of subscribers to enable you to sustain profitability. Hard to argue with that!

a) Develop the simplest possible stock/flow map around subscribers
   - Consider the pool of subscribers for your service
   - Consider the activity of gaining subscribers
   - Consider the activity of losing subscribers

   Sketch your map in the space below. Then, we'll work as a group to implement the map in the software.

Questions to consider:
- What assumptions are you making about the total potential amount number of subscribers in this system?
- If you replaced clouds with stocks, what would those stocks be?
- What other stocks are in this system?

Capstone Exercise 1

b) Transform the map into a running simulation model, using the following information.
   - Initially you have 2 subscribers
   - Assume you gain subscribers at a rate of 5 per month
   - Assume you lose subscribers at a rate of 1 per month

c) Set up a graph to collect model results for subscriber dynamics. Test.

d) Create sliders to control the flows. We'll then do some simple tests.

e) Enter the Run specs… dialog under the Run menu. There, we'll make a few changes.

Capstone Exercise 2

We'll extend the model to more accurately capture the connection between subscribers and cash flow….

a) Modify the model so that it incorporates basic cash-flow dynamics.
   - Cash accumulates revenue net of expenses.
   - You plan to charge each of your subscribers a subscription fee of $50/subscriber/month.
   - There are two sources of expenses: Fixed expenses and variable expenses
     - Fixed expenses are $1000/month
     - Variable expenses are $25/subscriber/month
   - You've been seeded with $5,000 in start-up cash.
   - Monthly profit/loss is simply the algebraic difference between total revenue and total spending.

b) Using values of 5 for gaining subscribers, and 1 for losing subscribers, conduct a simulation. How close do you come to running out of cash over a 12 month period? What's the maximum profit? Loss?

c) Explore different values for gaining and losing subscribers. Can you make yourself profitable "out of the gate?"

d) Explore different values for subscription fee. Implications?

e) Set up navigation buttons to move from the model to the interface view. Use text boxes to give your model a title.

Capstone Exercise 3

Colleagues have pointed out to you that internet-based businesses such as the one you are contemplating tend to grow via word of mouth. They also have noted that membership losses tend to be proportional to the size of the population. Let's incorporate these concepts. Working from the Model view…

a) Add feedback from the stock of subscribers to its inflow.
   - Draw a connector from subscribers to its inflow. Note that a ? appears in the flow equation.
   - Re-define the inflow as a compounding process. Use a converter to represent the growth rate resulting from word of mouth. Your best estimate is that each 4 existing subscribers will generate one new subscriber each month.
   - On the interface level, use the dynamite to blow up the slider that you had assigned to the gaining flow.

b) Add feedback from the stock of subscribers to its outflow.
   - Draw a connector from subscribers to its outflow. Note that a ? appears in the flow equation.
   - Re-define the outflow as a draining process. Use a converter to represent the churn rate associated with the loss of customers. Your best estimate is you'll lose customers at a rate of 10% per year.
   - On the interface level, use the dynamite to blow up the slider that you had assigned to the losing flow.

c) Run a simulation or two (you may find it helpful to set up a Run button to facilitate your experiments). What does the growth potential look like for this business? What sort of seed $ will you realistically need in order to capture this potential?

Capstone Exercise 4

Take a close look at the subscriber sector of your model. One difficulty with this structure is that it assumes an infinite number of potential subscribers. A second potential problem is that it doesn't track drop-outs. Let's fix these problems!

a) Add potential subscribers to the system.
   - Create a new stock. Call it Potential Subscribers.
   - Connect the stock to the *inflow to* subscribers, by dragging it over the cloud until the cloud is hi-lighted. Then release your click.
   - Initialize the stock of potential subscribers at 200

b) Add drop-outs to the system.
   - Create a new stock. Call it Drop Outs
   - Connect the stock to the *outflow from* subscribers, by dragging it over the cloud until the cloud is hi-lighted. Then release your click.
   - Initialize the stock at 0

c) Test your model. Do you see any "strange" behavior in the stocks?

Capstone Exercise 5

In your tests of the previous model, you likely found that the model "slammed against the wall" when it ran out of potential subscribers. This is because you're missing a feedback loop here. We'll fix this, now!

a) Add two converters to the screen. Call one, "base wom multiplier." Call the second, "impact of potential subscribers on wom." [note that wom stands for word of mouth!]

b) Draw connectors…
   - from the stock of potential customers to the impact variable
   - From the impact variable to your word of mouth multiplier
   - From base wom multiplier to your word of mouth multiplier

c) Re-define the three variables, using the next two pages for guidance.

d) Test your model. Does it perform more reasonably?.

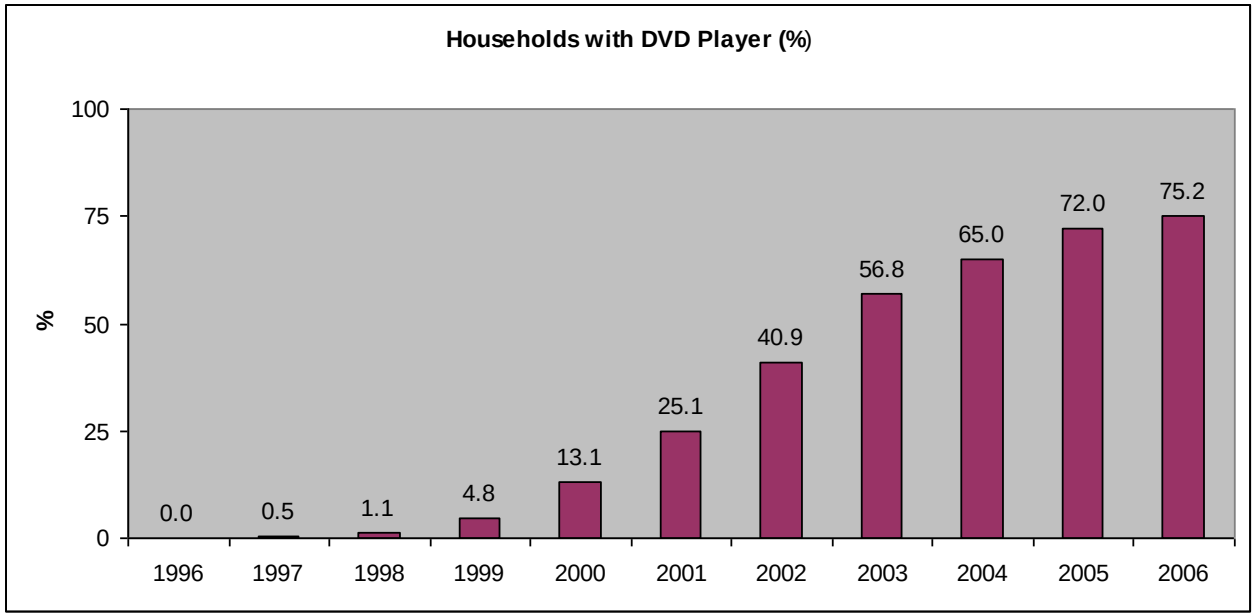
e) Explore the response to changes in the word of mouth multiplier relationship. You may find it helpful to use a graphical input device on the interface layer to accomplish this.

f) Question to consider: Let's say that you wanted to experiment with different "baseline" rates for those flows with feedback. How might you accomplish this?

g) Question to consider: Are there any strategies suggested by the stock of "drop-outs?"

Exercise 1 – New Product Introductions

Case Study: Since their release in 1997, digital video disk (DVD) players have had a very rapid adoption by US households. Data from the Digital Entertainment Group shows that these devices now exist in 75% of US households.



Sales for hot technology products such as DVDs are often driven by strong word of mouth, as excited enthusiasts tell their friends about the latest new gadget. You have been asked to analyze the uptake of DVD players to understand how big of an impact such word of mouth dynamics played, and how much was driven by the marketing efforts of various DVD manufacturers.

Exercise 1 – New Product Introductions

A Google search for “product diffusion” has brought up a list of references to something called the Bass Diffusion Model. Further investigation reveals this to be a well-established approach in the area of economic research. The model reads as follows:

$$q_t = p*R_t + w*N_t* (R_t/(R_t + N_t))$$

where

- q_t = number of adopters at time t
- R_t = total number of potential adopters who have not yet adopted at time t
- N_t = cumulative number of adopters at time t
- w = effect of each adopter on each remaining potential adopter
- p = effect of external factors (such as marketing) on adoption propensity

Clear as mud, huh?

In fact, this somewhat “inaccessible” formula can often be converted into a simple SD framework for the purposes of analysis and extension.

Exercise 1 – New Product Introductions

Let's take this equation and see if we can identify any stocks and flows in it. Think about what's accumulating and what activities fill/drain those "buckets."

$$q_t = p*R_t + w*N_t*(R_t/(R_t + N_t))$$

where

- q_t = number of adopters at time t
- R_t = total number of potential adopters who have not yet adopted at time t
- N_t = cumulative number of adopters at time t
- w = effect of each adopter on each remaining potential adopter
- p = effect of external factors (such as marketing) on adoption propensity

Exercise 1 – New Product Introductions

That's more like it!

Now let's if we can plug in some values that would allow us to replicate the historical behavior of the DVD player market.

Assume that:

- Research indicates that penetration is basically maxed out. (For simplicity, let's ignore the growth in the number of US households and instead keep the model in % terms.)
- Marketing efforts throughout the past 10 years have been relatively constant in dollar terms. Your colleague, an expert in the effect of advertising, has indicated that such spending levels typical result in an external coefficient (variable *p*) of about 0.008.
- Further research shows that values for internal coefficients (variable *w*) are never more than 1.0.
- DVD players were launched in 1997, and the data for the adoption of this product relates to end of year (EOY) numbers.

Using the STELLA software, create the structure for a Bass Diffusion model and experiment with different parameters of *w.* Can you find a value of *w* such that the simulation results closely approximate the historical data?

Exercise 1 – New Product Introductions

Wrap Up

- Product/service diffusion curves often display behavior that can be characterized using the Bass formulation.
- Consider the actual iPod data shown here and how such a dynamic could be modeled.

Lexidyne Simulation Data Analytics

Exercise 2 – Feedback and Modules

Case Study: The Colorado Parks and Wildlife (CPW) division has asked you to build a model of deer and cougar populations in the Routt National Forest to assess the impact of allowing hunting in this region. The CPW is interested in the natural predator/prey dynamics of the area, as well as having a tool to assess possible outcomes given different intervention strategies. A Google search has produced an incomplete model (circa 1984 by Newes and Inman) that might serve as a starting point for the project. Open the model called Predator Prey.stmx.

As a good dynamic modeler, walk through the following steps:

- Understand the existing model structure.
- Eliminate the "?s" by finalizing undefined model variables.
  - Analytic initialization for the starting population of Deer
  - Parameter values for constants that will result in Steady-State
- Run a simulation.
- Question the validity of model structure. Are there places where feedback exists?
- Close feedback loops, one at a time using graphical functions, retaining Steady-State.
- Change an initial condition, then see the results of a subsequent simulation.
- Assess reasonability of the outputs. What is causing the simulation behavior?

Exercise 2 – Feedback and Modules

Conversations with officials from the Forest Service indicate that the deer population also affects (and is affected by) the natural resources in the region; specifically, the amount of vegetation available. A web search reveals an un-copyrighted model by Peck (2018) that relates to the dynamics of vegetation.

- Use a Module to import the model called Vegetation.stmx.
- Establish links between the main Predatory Prey model and the Vegetation model residing in the Module.
- Re-establish a Steady-State condition for the linked models/Modules.
- Close any remaining feedback loops using graphical functions.
- Extend the model by including a Hunter Module and assessing its impact on the system.