SAND2006-6640P

Enabling a Methodology

System Dynamics and Modeling with Studio

Jordan International Water Resources Modeling Workshop, 5-9 November, 2006

Enabling a Methodology

- Industrial Dynamics
- Operationalizing the Methodology
- MIT's Standard Method
- Examples
  - Illegal Mexican Migration
- Exploring the methodology
- Resources

Industrial Dynamics

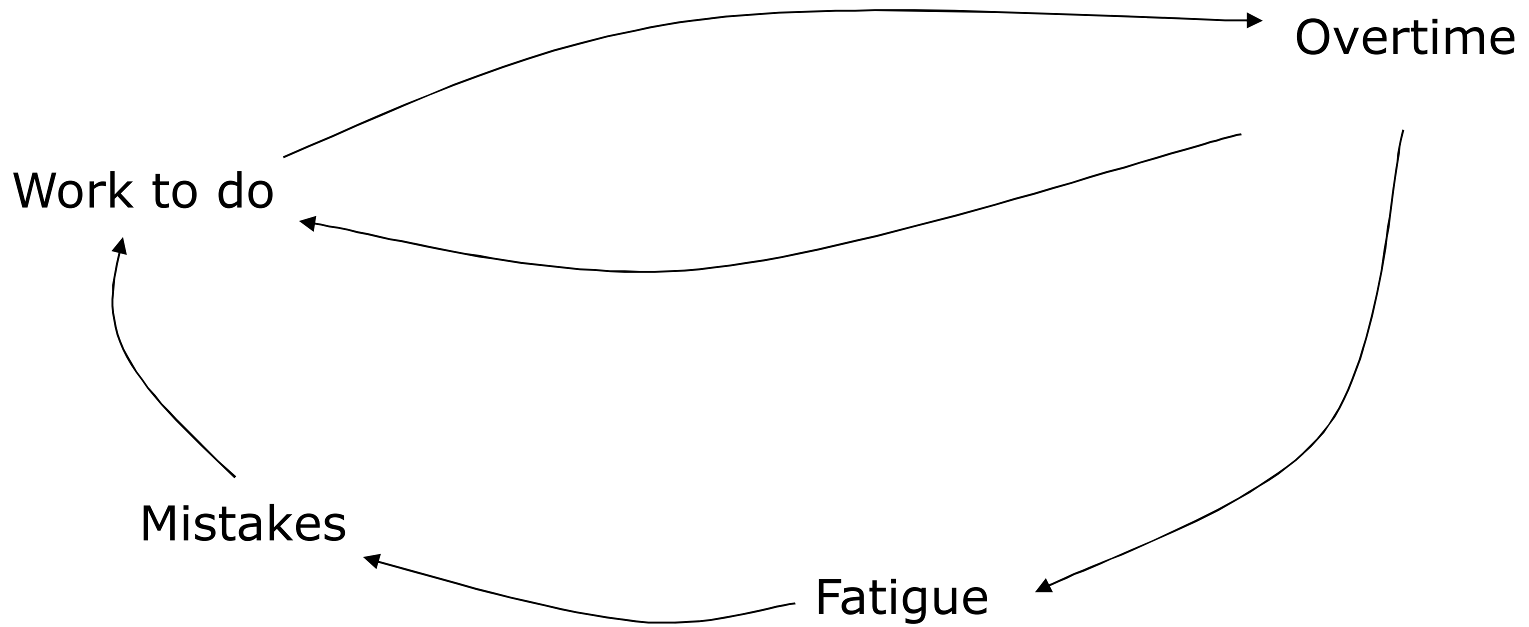
- In Industrial Dynamics[1], Jay Forrester (1961) presents a type of model structure. He indicated that a model should have the following characteristics:
  - Be able to describe any statement of cause-effect relationships that we may wish to include.
  - Be simple in mathematical nature.
  - Be closely synonymous in nomenclature to industrial, economic and social terminology.
  - Be extendable to large numbers of variables (thousands) without exceeding the practical limits of digital computers, and
  - Be able to handle "continuous" interactions in the sense that any artificial discontinuities introduced by solution-time intervals will not affect the results. It should, however, be able to generate discontinuous changes in decisions when these are needed.

•[1] Now commonly termed System Dynamics.

Operationalizing the methodology

- "an alternating structure of reservoirs or levels interconnected by controlled flows."
  - They are made operational by stocks, flow rates, decision functions and information channels.
  - Forrester's proposal has often been metaphorically described as "bathtub dynamics."
  - Stocks are the bathtubs themselves, decision functions are the automated or humanly controlled valves on the flows to and from bathtubs, and the information channels serve as pipes between stocks
  - Feedback is an important feature of these systems

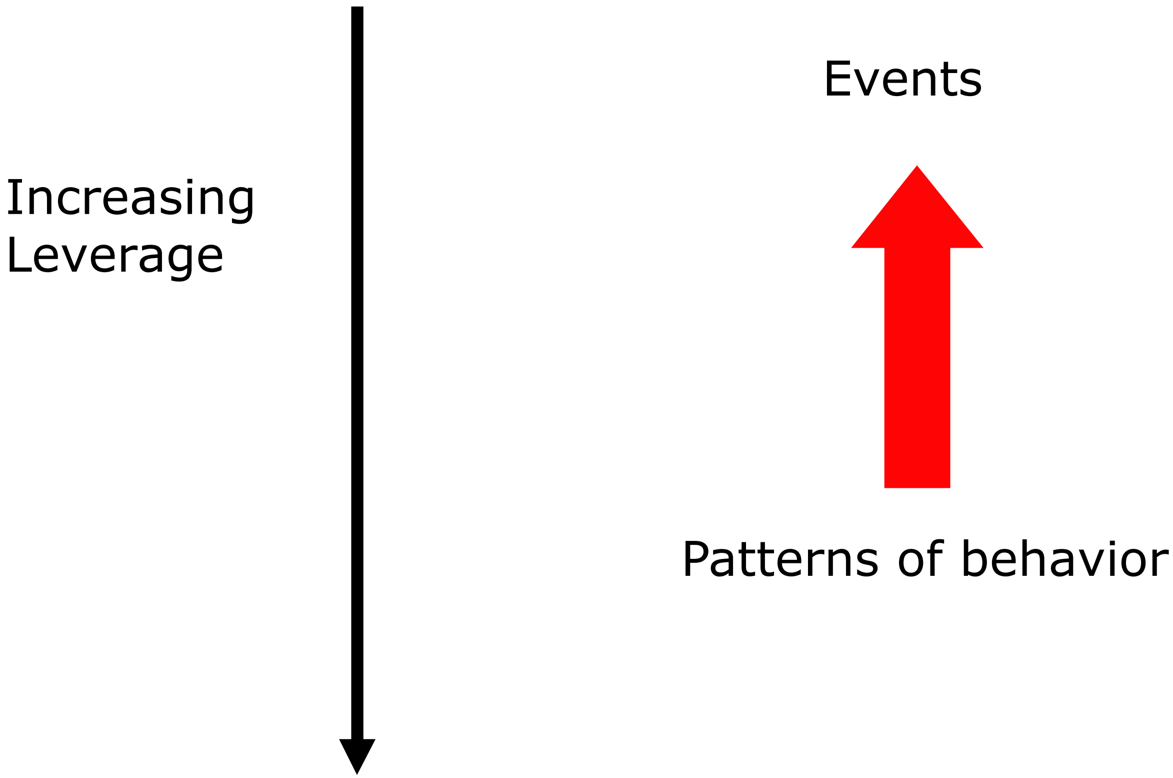
Policy Resistance Example: Overtime



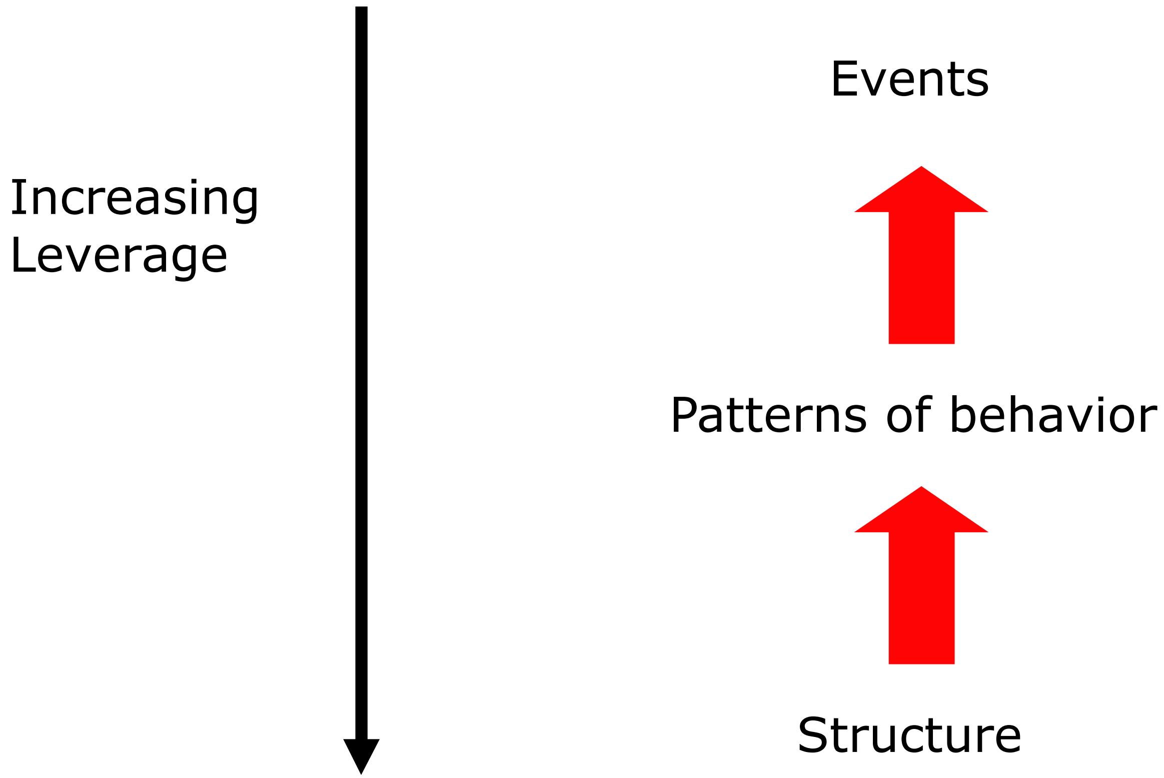
Most of us deal with systems at the event level

- Events happen
- We have little or no power over events
- The next event has probably already happened

Events are the visible manifestation of patterns



The Ultimate Cause is Structure



System Dynamics

- System Dynamics is an approach to assessing the long term system wide consequences of your policies.
- Ultimately, we are interested in designing better behaved systems

MIT's Standard Method

- Develop the problem statement
- Enumerate variables of interest
- Prepare "reference modes" or behavior over time graphs
- Develop dynamic hypothesis with causal loop diagramming
- Build computer model

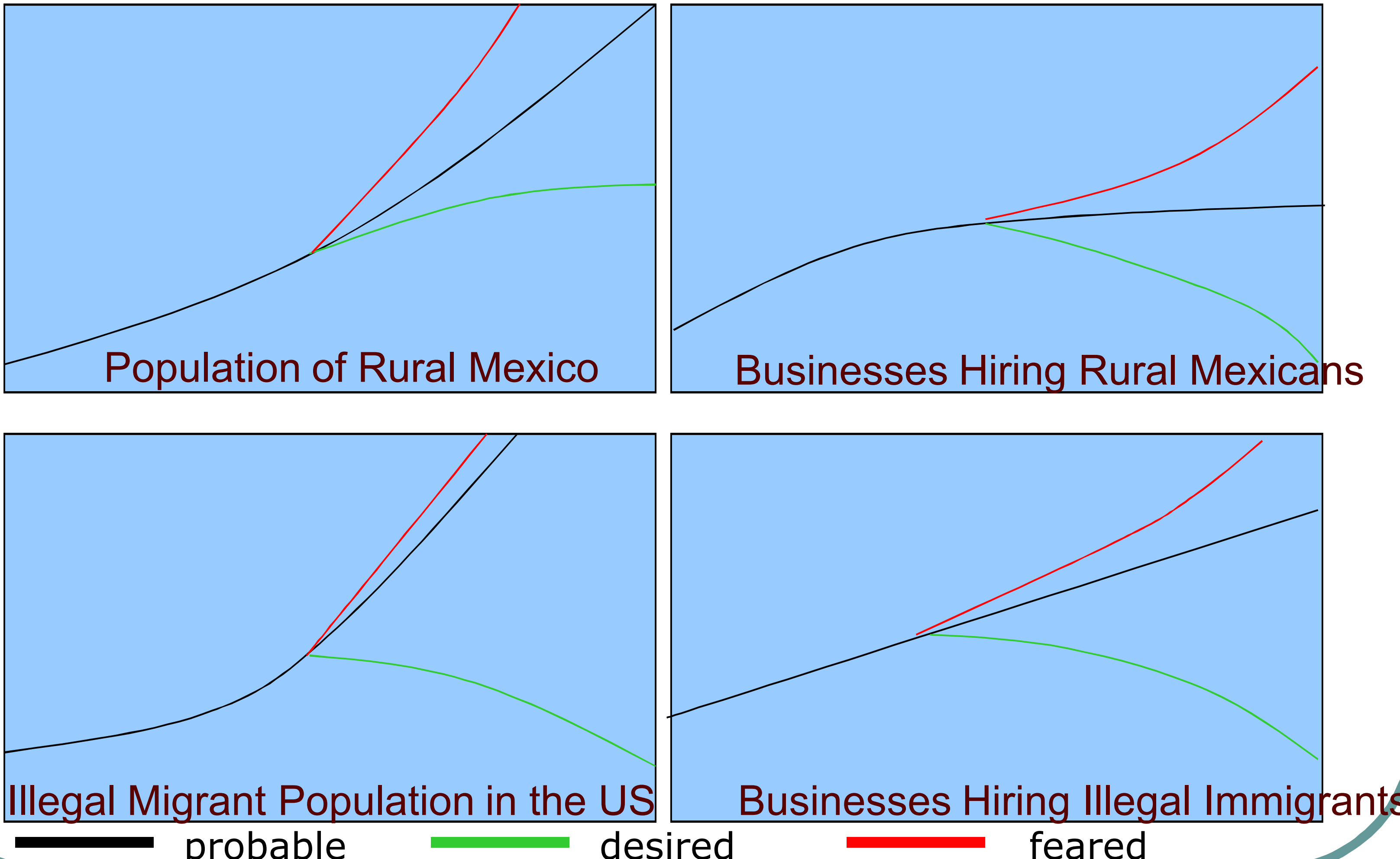
Illegal Migration: Develop the problem statement

- Illegal migration: there is a concern that over the long run illegal Mexican migration will continue to rise. The only way to stop this is to increase enforcement at the border and/or tax illegal wage earners.

Illegal Migration: Enumerate variables of interest

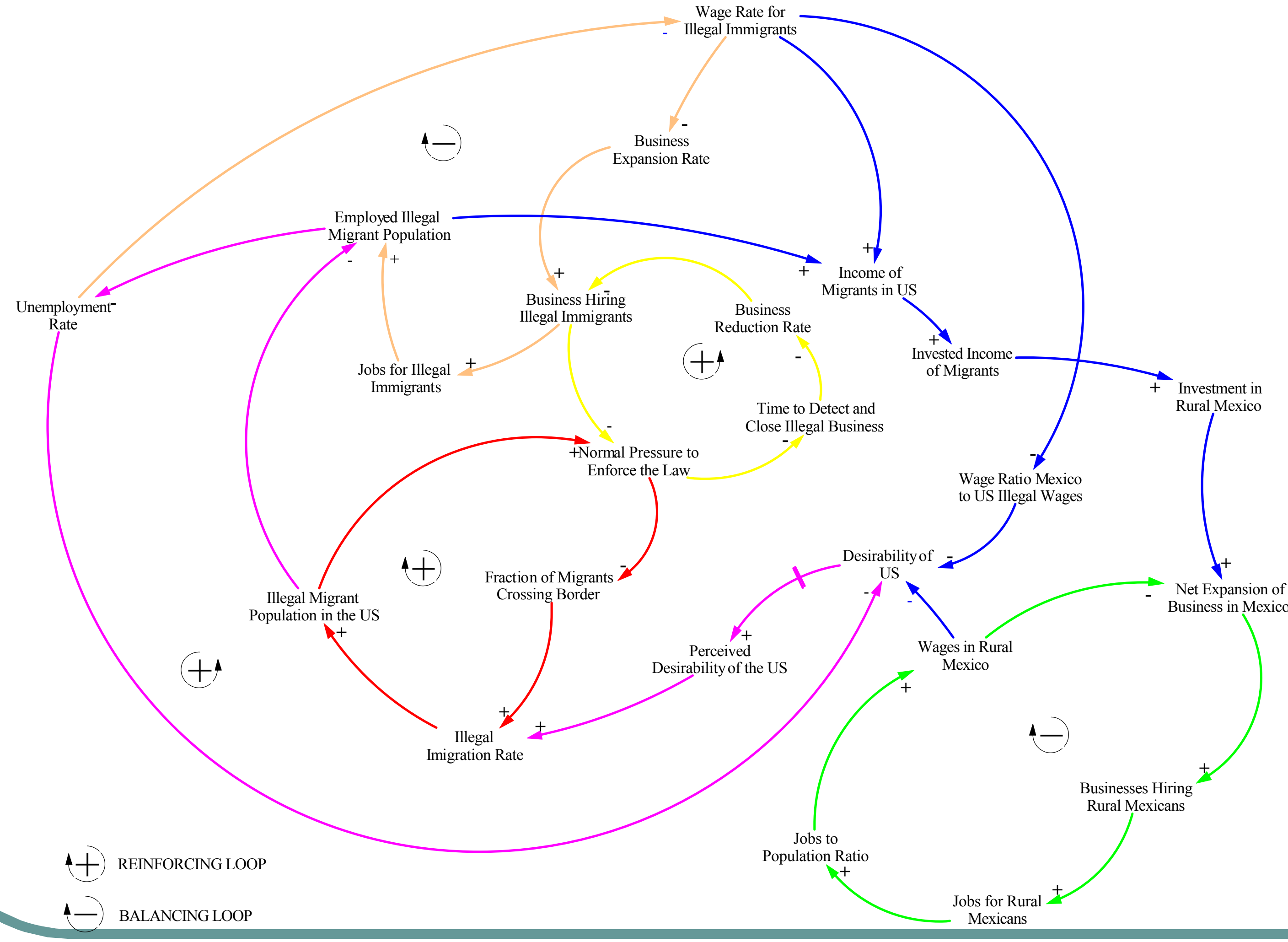
- Population of Rural Mexico
- Businesses Hiring Rural Mexicans
- Potential Migrant Population in Mexico
- Illegal Migrant Population in the US
- Business Hiring Illegal Immigrants

Illegal Migration: Prepare "reference modes"

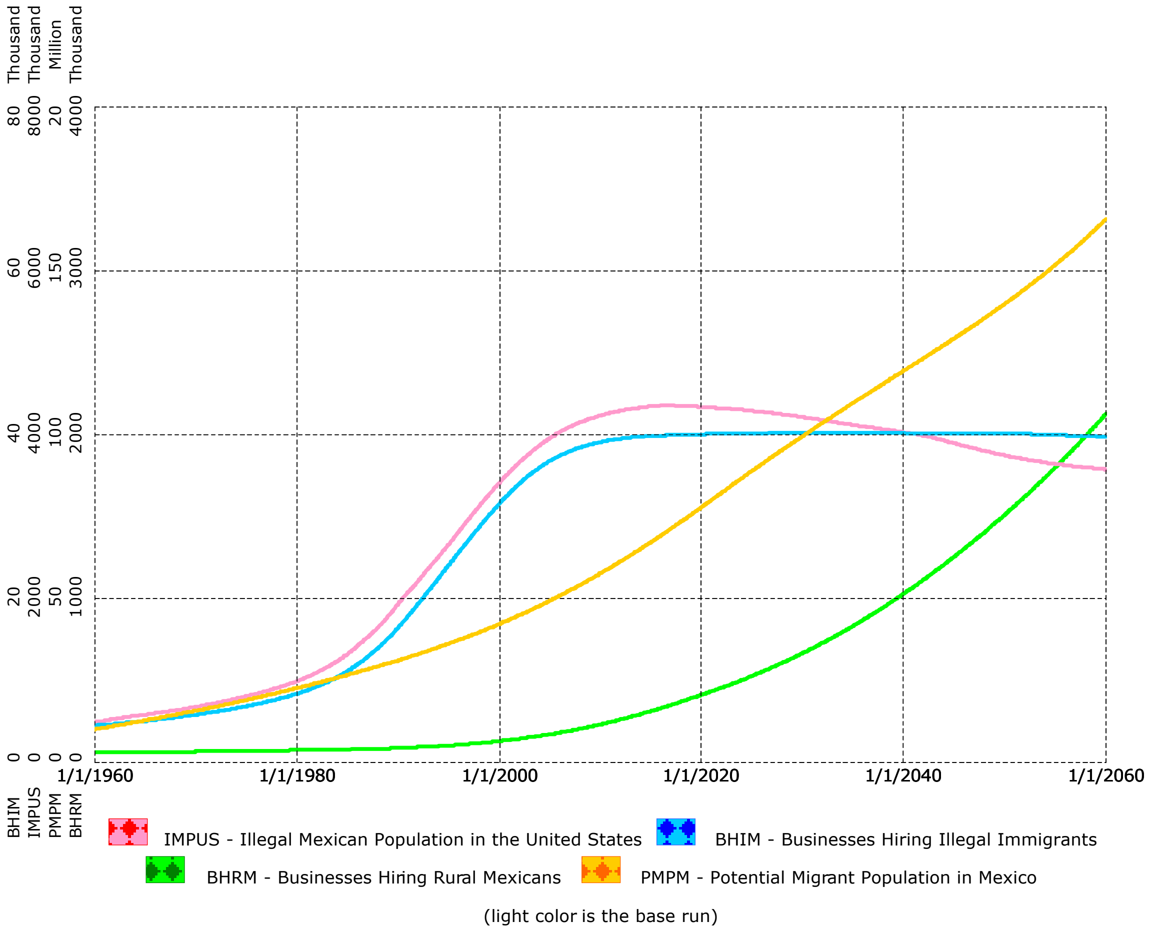


For illustration only, does not represent instructor's opinion

Illegal Migration: Develop dynamic hypothesis



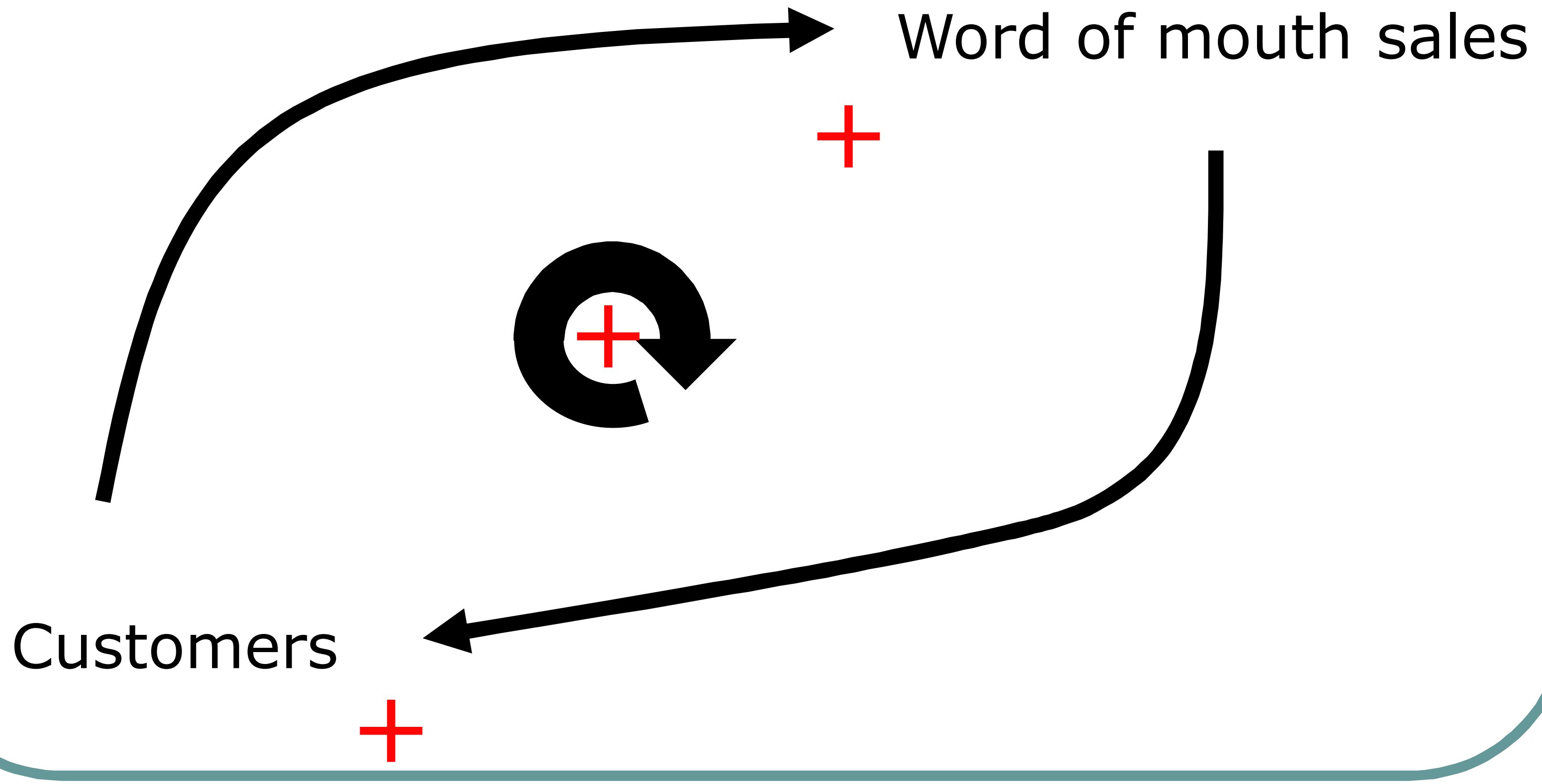
Illegal Migration: Build computer model



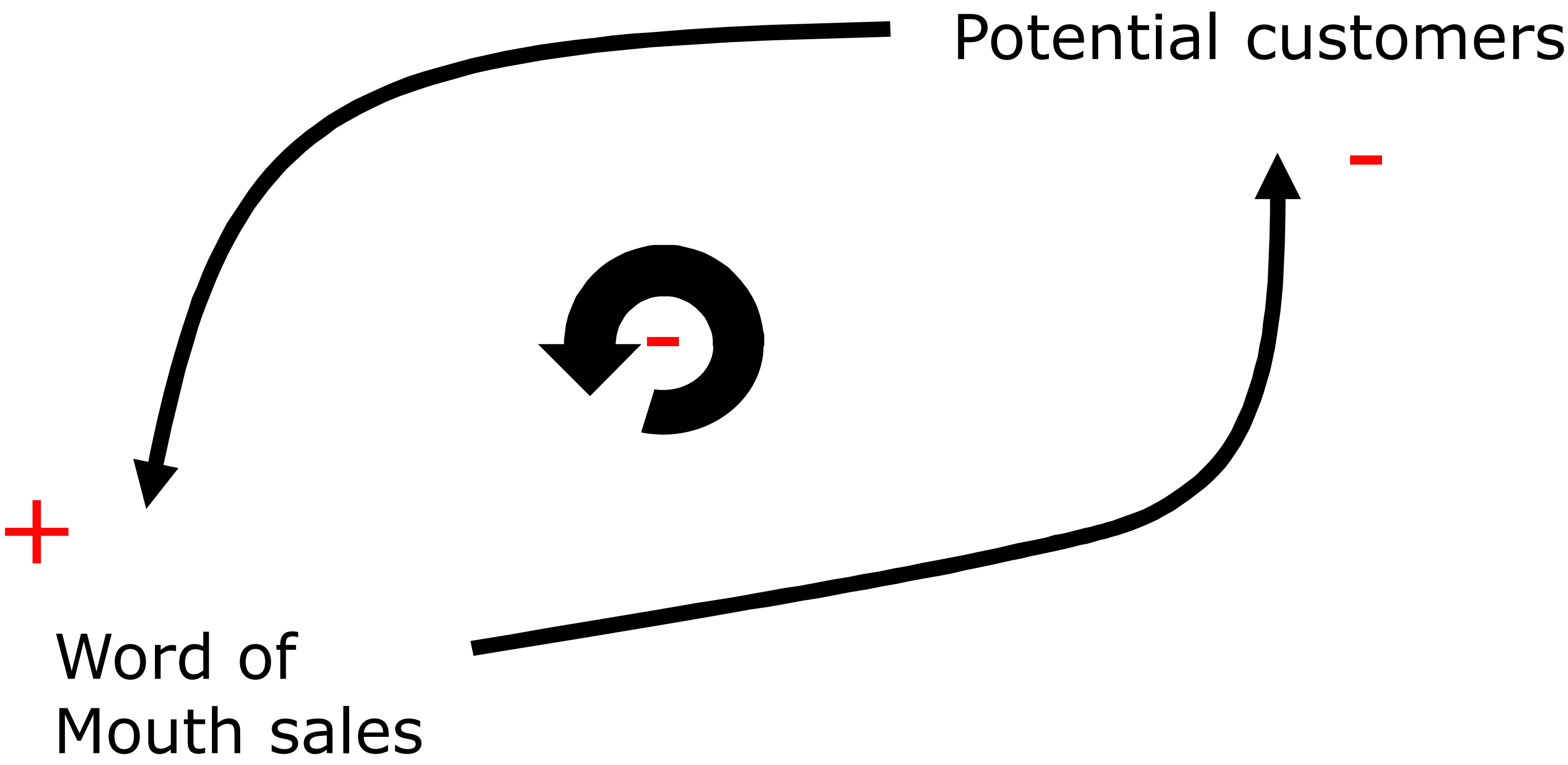
Exploring the Methodology

- Structure determines behavior
- Causal loop diagramming
- Appropriateness of SD
- Resources

Structure: Reinforcing loop



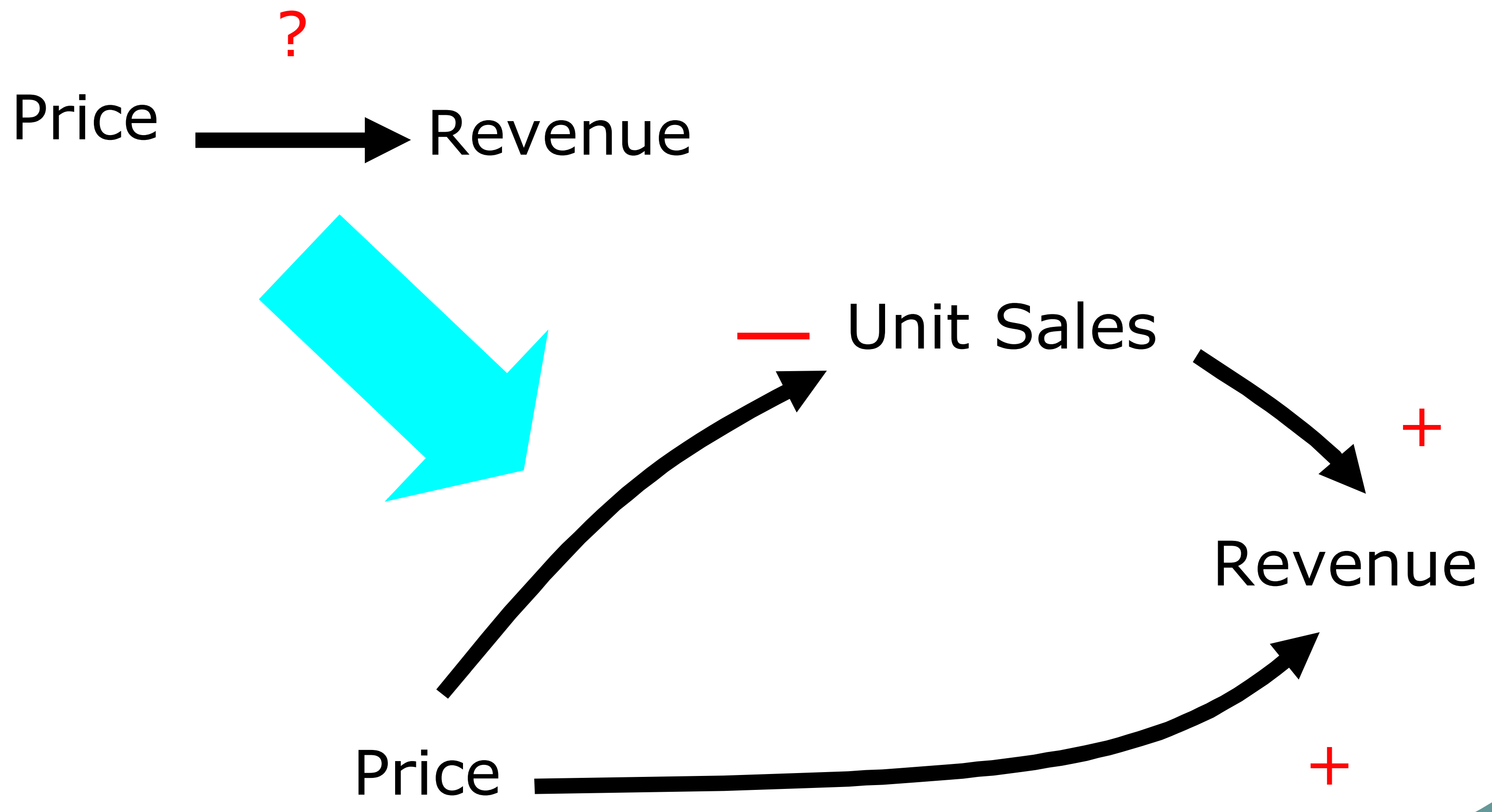
Structure: Balancing loop



Causal Links

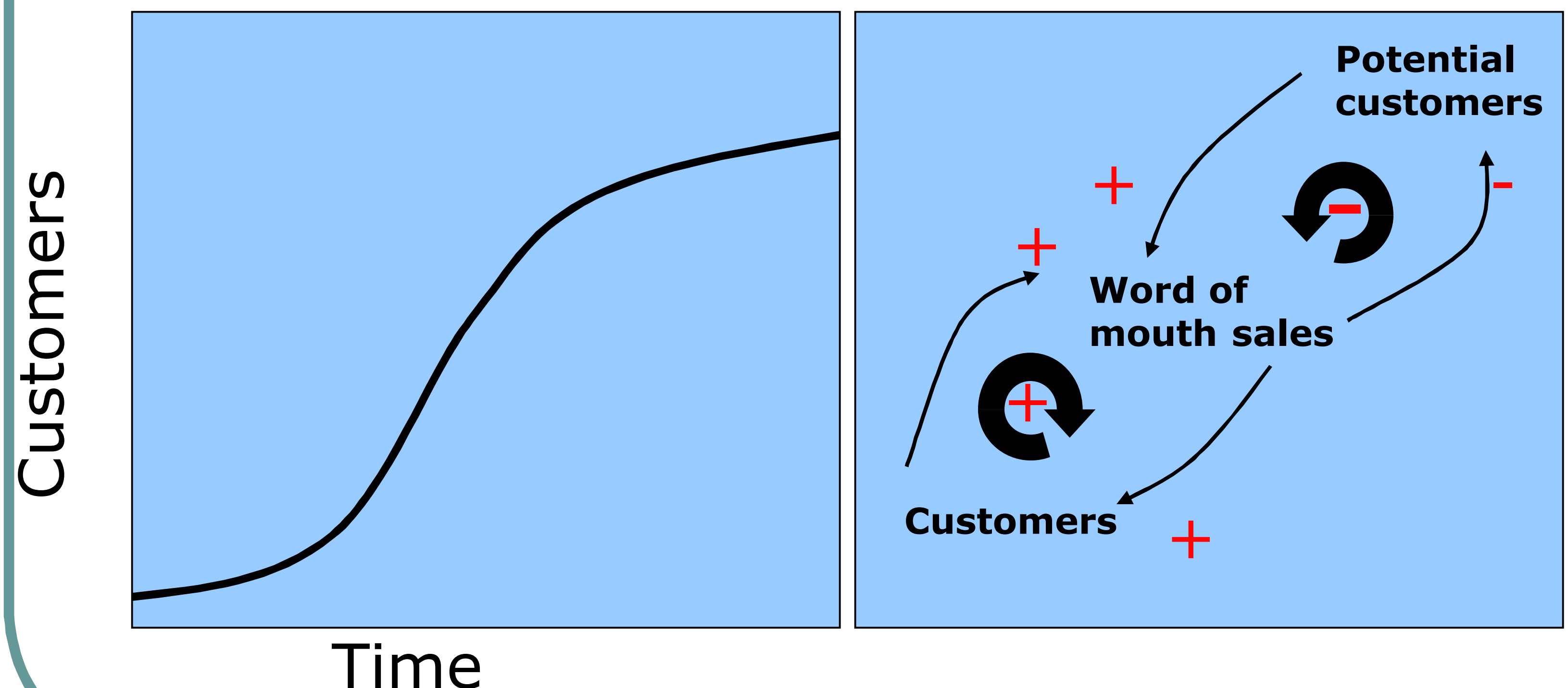
$A \xrightarrow{+} B$	A change in A produces a change in B in the SAME Direction	If A increases, B will increase If A decreases, B will decrease
$A \xrightarrow{-} B$	A change in A produces a change in B in the OPPOSITE Direction	If A increases, B will decrease If A decreases, B will increase

Ambiguous Link Polarity Means Multiple Pathways between the Variables



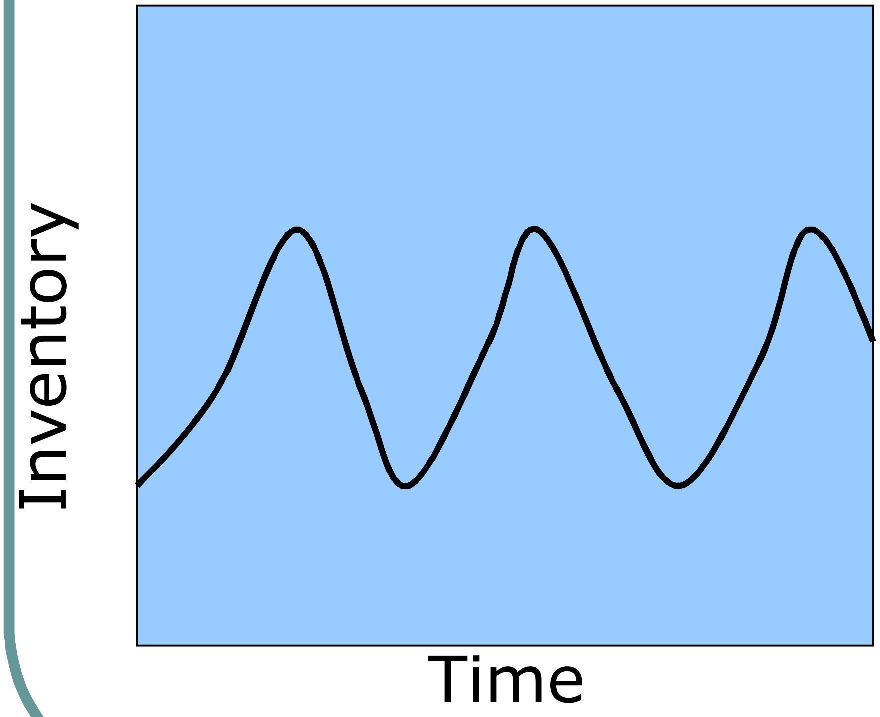
S-Shaped Growth

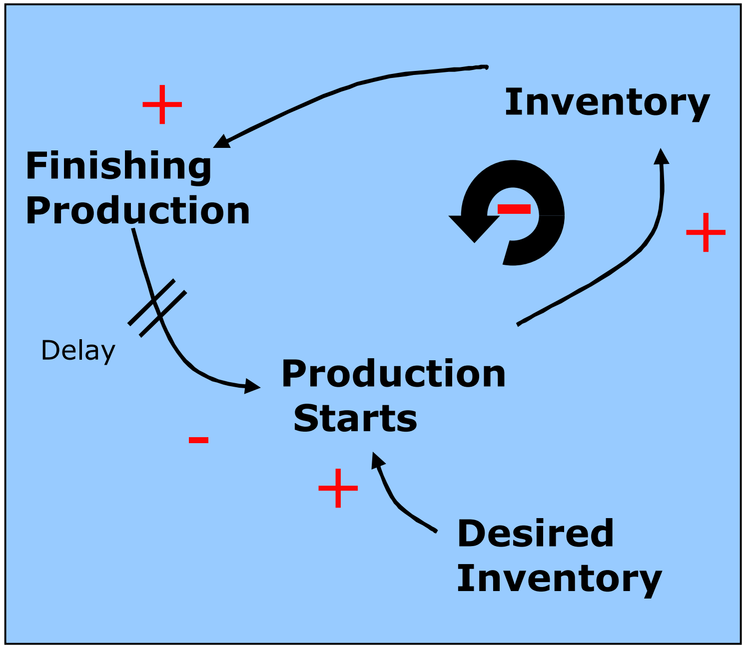
Behavior



Oscillation: Example

Behavior





2-Loop Archetypes

Undesired Loop \ Desired Loop		
	Success to the successful	Fixes that fail
	Limits to growth	Shifting the burden Escalation

Dynamic Modeling Styles

- Systems Thinking & Archetypes
- Small, Policy-Based Models
- Detailed, Calibrated Models
- Management Flight Simulators (Applications = Model + Interface)
- Hybrid, extra-methodological, and dynamic simulation

The Approaches Share a Common Philosophy

- Emphasis on understanding behavior over time
- Internal rather than external causes
- Structure creates behavior
  - High level viewpoint
    - whole rather than parts
    - interactions

Outcomes Needed For Success

- An effective understanding, structuring and analysis of the problem
- Education of clients
- Convincing others within the organization

Purposes of Large, Calibrated Models

- Assure model contains all of the structure necessary to create problem
- Accurately price cost-benefits of alternatives
- Facilitate strategy development and implementation
- Sell results to those not on project team
- At least 3 different approaches to calibration used to date at SNL (Energy, NISAC, Water Models)

Conclusions

- Each of the dynamic modeling styles has its appropriate uses
- Detailed, calibrated models are most effective for achieving implementation of specific decisions/investments
- Detailed, calibrated models can form the basis of effective learning and early warning systems
- *Effective use of such models requires a staged approach to development with the client team*

System Dynamics vs. Dynamic Simulation

- System dynamics software does not a system dynamics model make!
  - Does time have units?
  - Both stocks and flows
  - Feedback
  - Delay

The System Dynamics - Dynamic Simulation Debate

- Why doesn’t SD suffice?
  - It may be fundamentally non-SD problem => but SD interface tools add value
  - Customers demand extra-methodological features => builds confidence
  - Customers demand more granularity => more and more data and micro-processes

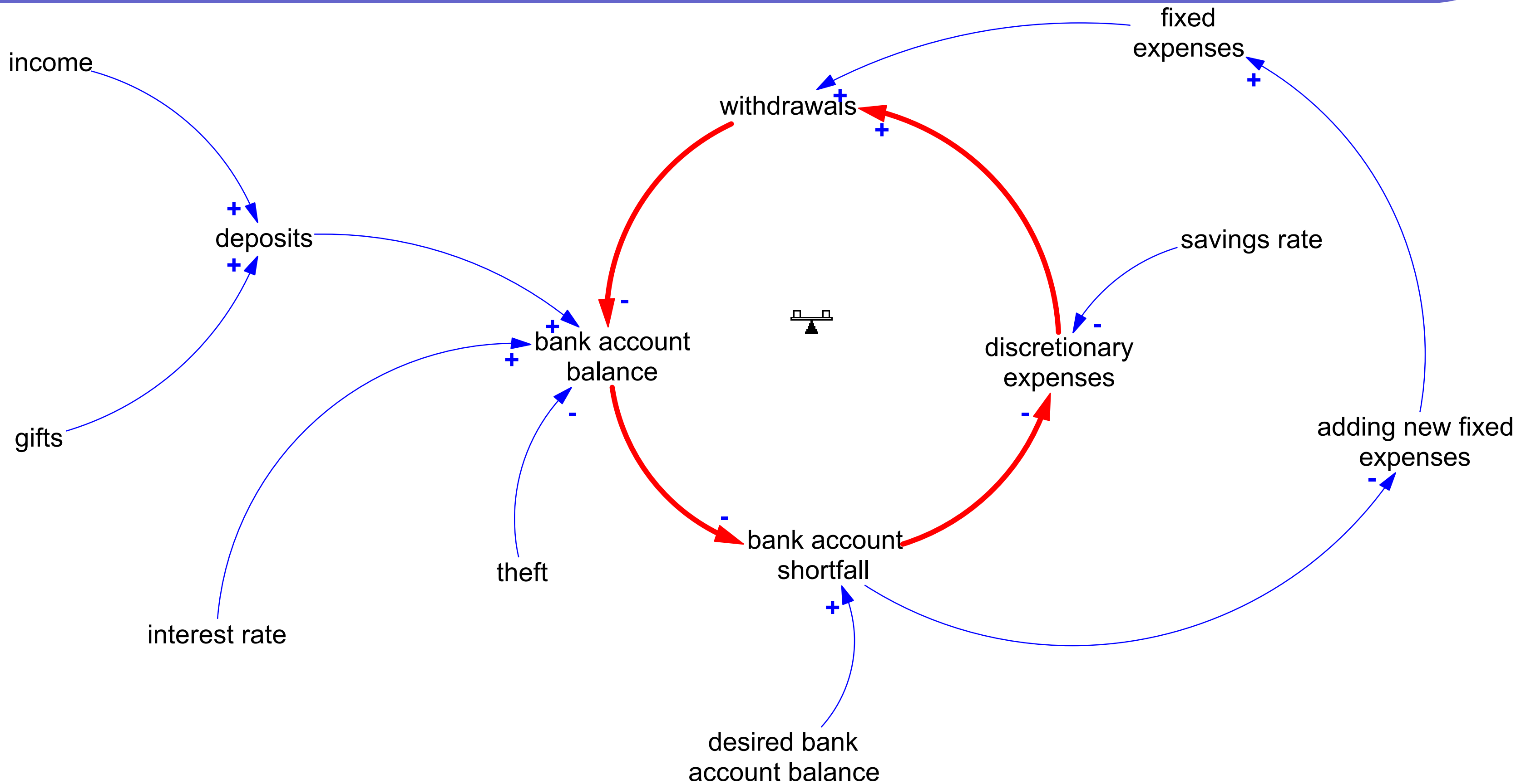
Software Landscape

- Began with DYNAMO in the 1960s
- Dominated now by Vensim, iThink/Stella, and Studio. Essentially integration engines with an IDE and varying capabilities for interface design and function libraries

Powersim Studio

- Market dominated by: isee systems, Powersim, and Ventana
- Historically commercial versions were released as follows: Stella - 1985, Vensim - 1991 and SimTek – 1988 (Studio's original product name).

Causal loop diagram

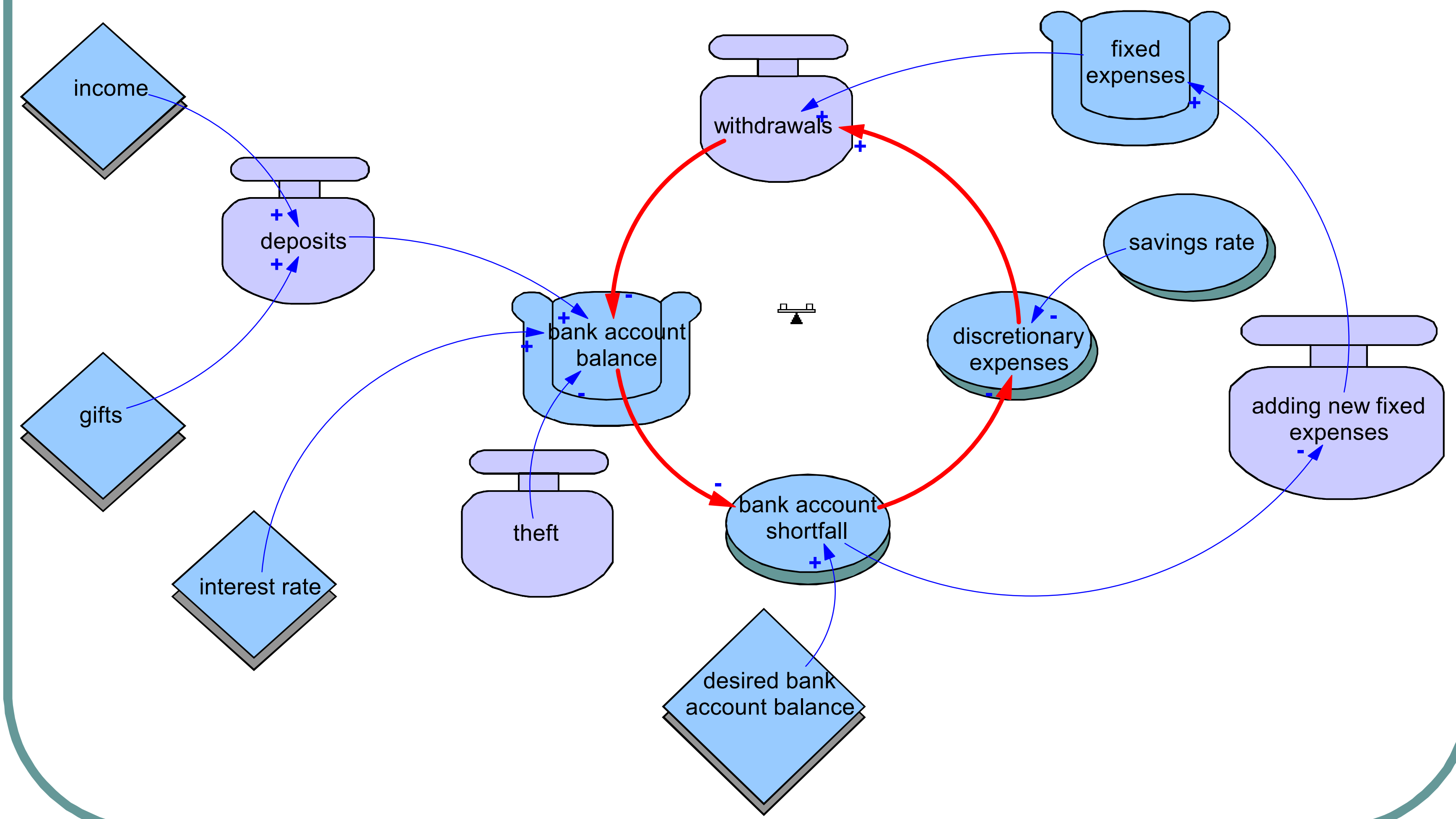


Read the diagram by picking any two variables connected by an arrow and asking,
"If the variable at the arrow base increases, what happens to the variable at the arrow head?
A + means it too increases, a – means it decreases.

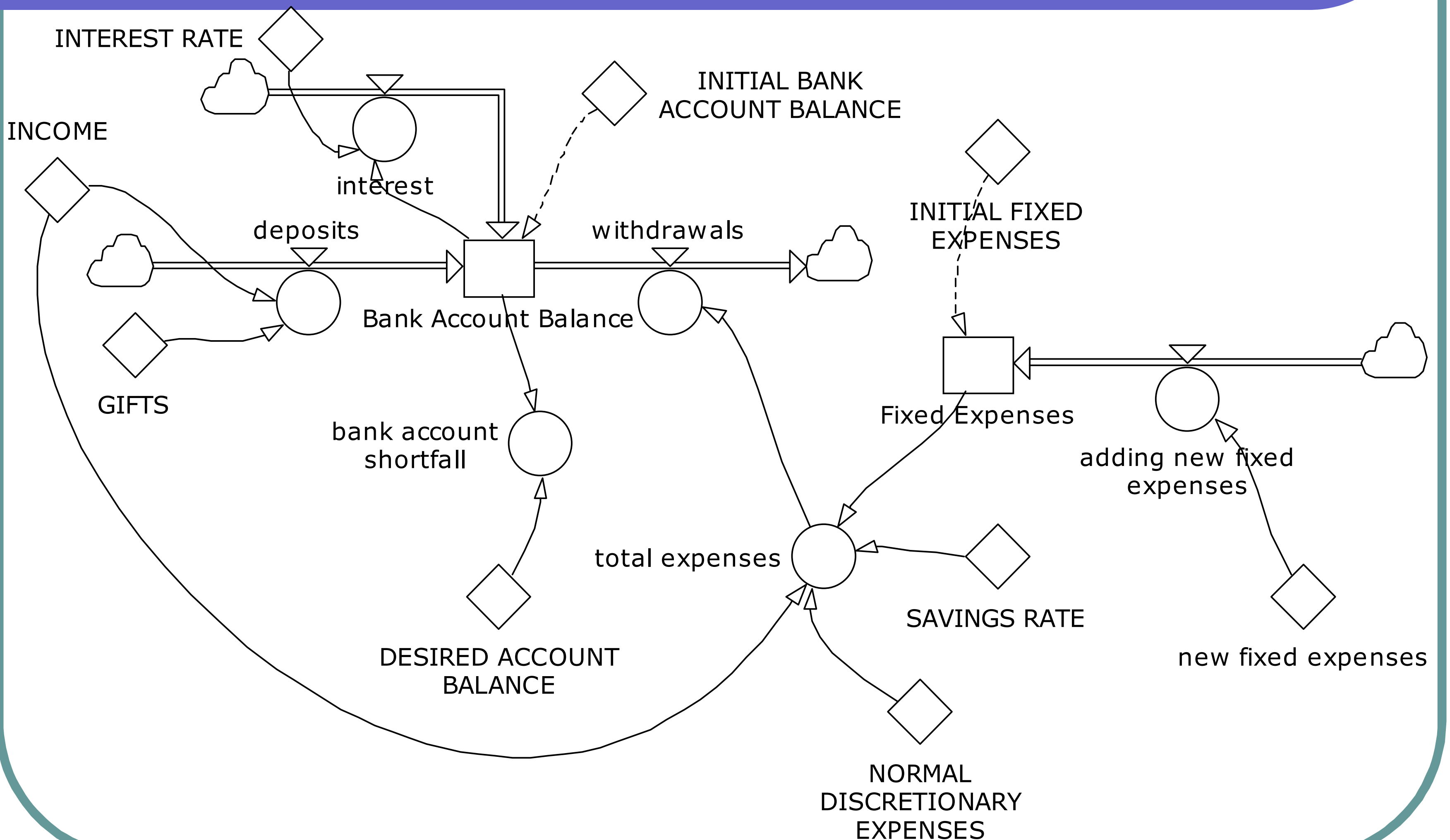
Stocks, flows, variables

- Stocks - A stock is a generic symbol for anything that accumulates or drains. For example, water accumulates in your bathtub. At any point in time, the amount of water in the bathtub reflects the accumulation of what has flowed in from the faucet, minus what has flowed out down the drain. The amount of water in the bathtub is the stock of water.
- Flows – A flow is the rate of change of a stock. In the bathtub example, the flows are the water coming into the bathtub through the faucet and the water leaving the bathtub through the drain.
- Variables – Constants or auxiliaries are used to: calculate, make a model readable, prepare an interface

Possible stocks and flows



Powersim Studio Model



Coyle's SD software criteria (1996)

- its basis in fundamental system dynamics theory;
- the ease with which it can be used;
- the support it gives to model building;
- the extent to which models can be documented and explained to a customer;
- the facilities it has for debugging a model;
- the ease of making experiments and producing output; and
- the scope of its facilities for policy design.

External Resources

- www.albany.edu/cpr/sds/ System Dynamics Society
- www.albany.edu.cpr/sds/DL-IntroSysDyn/inside.htm SD Tutorial done for DOE
- www.csdnet.aem.cornell.edu/index.html Cornell SD sources
- www.powersim.com Powersim Corporation (Studio)
- www.vensim.com Vensim
- www.iseesystems.com iThink and Stella
- www2.umass.edu/systemdynamics/papers.html Papers on SD and software engineering
- Len Malczynski
  - Geohydrology, 6313
  - lamalcz@sandia.gov

Text resources

- Business Dynamics: Systems Thinking and Modeling for a Complex World – John Sterman
- Modeling the Environment – Andrew Ford
- Dynamic Modeling of Environmental Systems – Michael Deaton and James Winebrake
- Systems Thinking and Modeling – Kambiz Maani and Robert Cavana
- McLucas – System Dynamics Applications
- Alvarez – Theory and Practical Exercises of System Dynamics