VENTANA systems, inc.

Vensim® Software

Linking systems thinking to powerful dynamic models

Model Analysis with Vensim

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Setup

- **Download the course material folder and unzip to a convenient location**
  - Source: http://ventanasystems.com/conference
  - Choose a location you control, i.e. not locked by your operating system

- **Optional: if you don't already have Vensim DSS or Pro, install a copy**
  - Use the license key in the README file if you don't have an existing license
  - PLE or Plus is adequate for most of the material

Why Analyze?

- **Better decisions**

- via -

- **Quicker and deeper understanding**
- **Responsible model use (knowledge of limitations)**

- **Objection: it takes time!**
- **Response: it's time well spent.**
  - You will finish sooner because early bug discovery minimizes rework cycles.
  - You will live longer without the stress of discovering problems the night before a presentation.

Process

- **Problem identification**
  - What questions is the model trying to answer? For whom?
- **Replication**
  - Can you reconstruct and run the model and experiments from archived sources?
- **Structure Inspection**
  - Evaluate fitness to purpose
  - Reveal structural flaws
  - Develop analytical insights
- **Behavior Testing**
  - Explore robustness and realism
  - Diagnose problem behaviors
  - Evaluate policy conclusions

Learning Habits

- **Scientific method**
  - Use controls – vary one thing at a time
  - Confirm/reject hypotheses with appropriate tests
- **Learn from surprise**
  - Develop and record expectations before running experiments
  - Follow up on puzzling outcomes
- **Relate behavior to structure**
- **Look at every variable in the model at some point**
- **Think about the structural Big Picture**
- **Keep a lab notebook to record deficiencies and insights**
- **Share**

1. Model Inspection

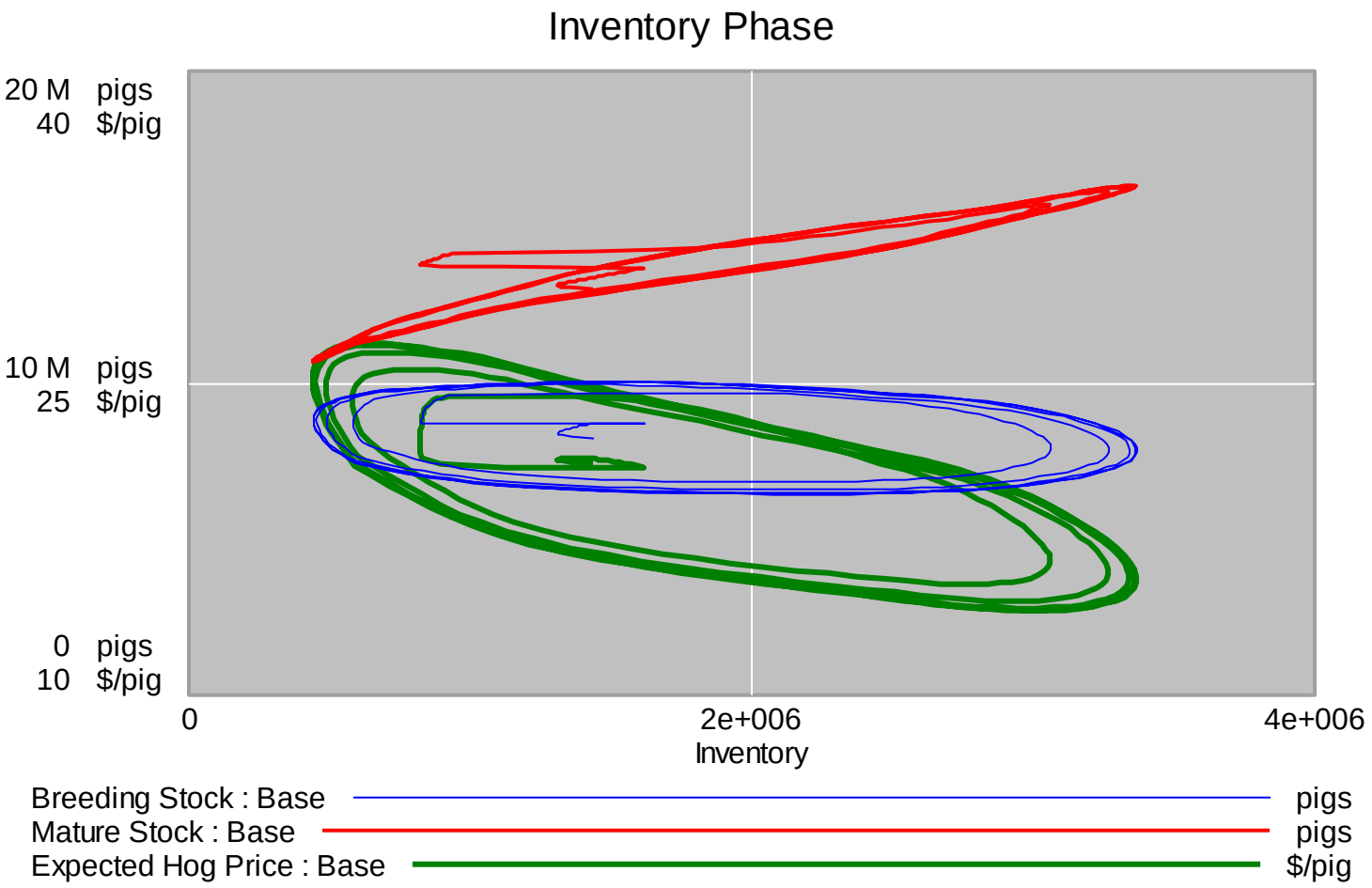
- **Browse through the model to familiarize yourself with its structure.**
  - How many feedback loops can you identify?
  - What are the key decisions?
  - What are the key stocks and flows? Do they contain physical quantities or information?
  - What common structures (or Molecules) are used?
  - Can you spot any potential problem areas?
- **Check the units of the model. Are there any errors? Are they important?**

2. Behavior

- **Make a "Base" run with no parameter changes, and explore the behavior.**
  - Are any runtime warnings generated? What do they indicate?
- **What does the model do?**
  - What behavior modes does the model exhibit? Exponential growth or decay? Overshoot? Oscillation?
  - What variables change the most? The least?
  - Does the behavior change qualitatively over time, or is it consistent?
- **What variables, stock-flow structures, or feedback loops are responsible for the behavior you see?**
- **Is the behavior driven by external disturbances, or is it due to inherent tendencies of the model?**

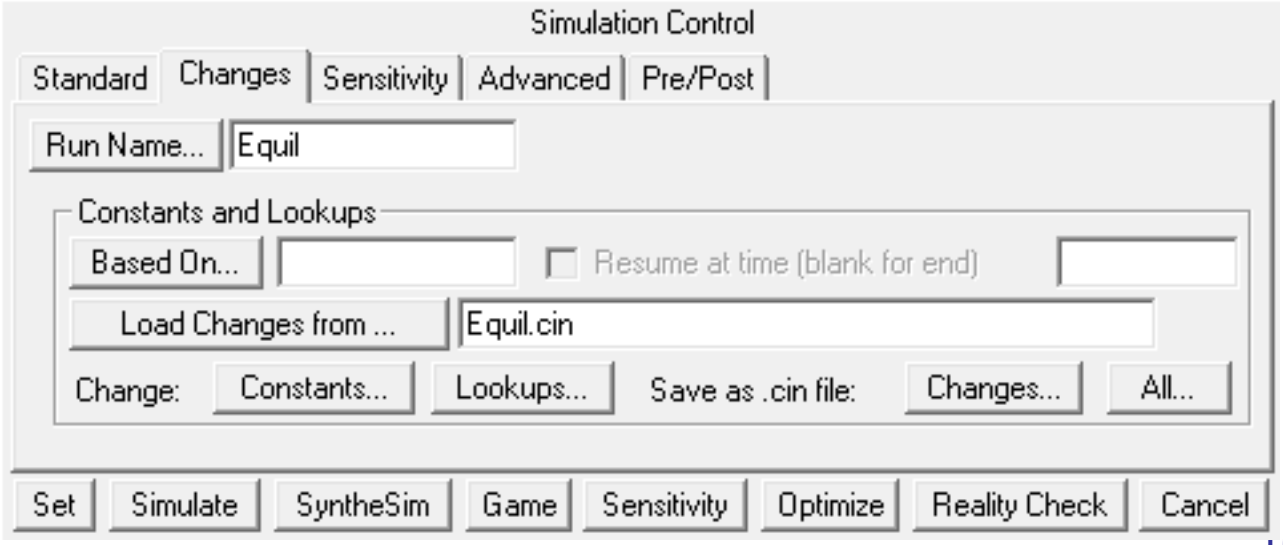
3. Equilibrium

- **If a model has equilibrium states, it is useful to identify them.**
  - Set the variable Step Size to 0, and run the model again. The variable Test Input should remain constant this time.
- **Is the model initially in equilibrium?**
- **Does it achieve an equilibrium state after some time?**
- **Can you identify an equilibrium state?**
  - Do you think there are other equilibria?
- **For each stock, what would have to be true for equilibrium to be achieved?**
- **You may find the second Control view in the model helpful for equilibrium testing.**



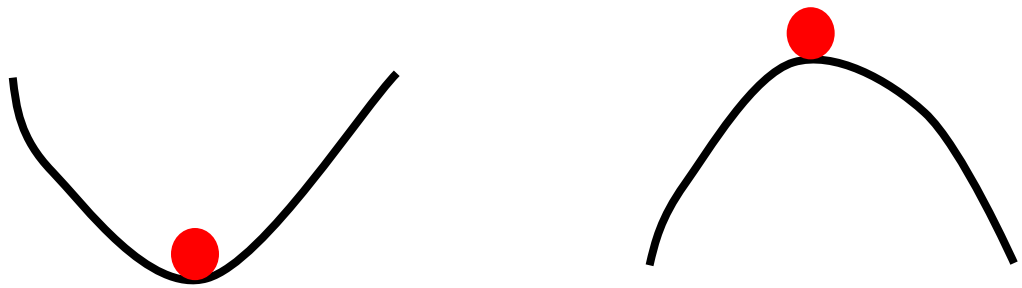
Putting the model in equilibrium

- **Option 1: manual experimentation**
- **Option 2: automate with optimizer**
- **Option 3: cheat – use equil.cin or**
  - Initial Breeding Stock = 8.33256e+006
  - Initial Expected Price = 20.0675
  - Initial Inventory = 1.64493e+006
  - Initial Mature Stock = 1.36044e+007
  - Step Size = 0



4. Stability of Equilibria

- **Set Step Size to .01 or some other small value.**
- **You may want to extend the FINAL TIME to 500 or 1000 months.**
- **Does the model return to its initial equilibrium after this small disturbance?**



5. Amplitude, Period, and Phase Shift

- **Set Step Size back to 0.15.**

- **Is the amplitude (the height from peaks to valleys) of the oscillations qualitatively similar or different?**
- **Is the period (the time between peaks) the same or different?**

- **Use the Custom Graph titled *Hogs* to compare the mature, breeding, and inventory stocks of hogs.**
- **Which variable peaks first following the step input?**
- **Can you explain why some variables lead or lag others?**

6. Simulation Method

- **Run the model with a new name, using a TIME STEP half the initial value (i.e. 0.25 months).**
  - What happens? Does the amplitude of the oscillations increase or decrease? Does the period change?
  - How many times do you need to halve the time step for further reductions to have no effect?
  - What happens if you quadruple the initial time step (i.e. 2 months)? Is this realistic?
- **Run the model with RK4 Auto integration, which adaptively varies the step size to achieve accurate integration.**
- **How does the behavior compare to the other cases? Do the oscillations still expand over time?**

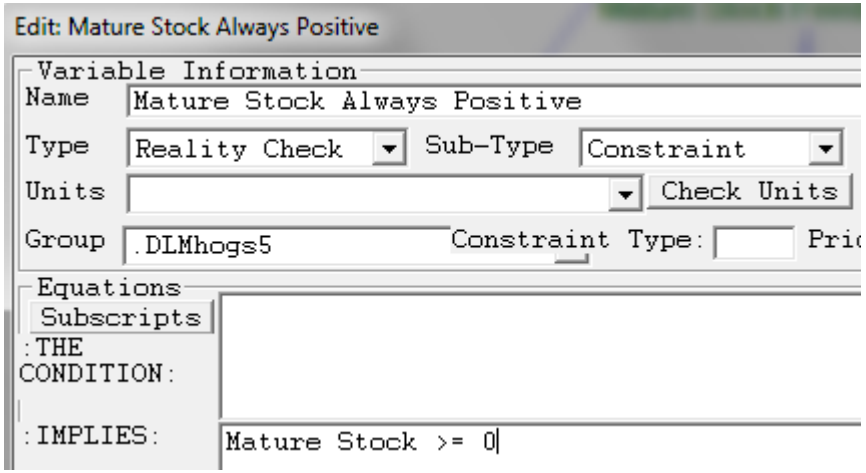
7. "Tire Kicking" – extreme conditions

- **Edit the equation for Weaning Survival Factor as follows:**
  - Weaning Survival Factor = 0.7 - STEP(0.7,10)

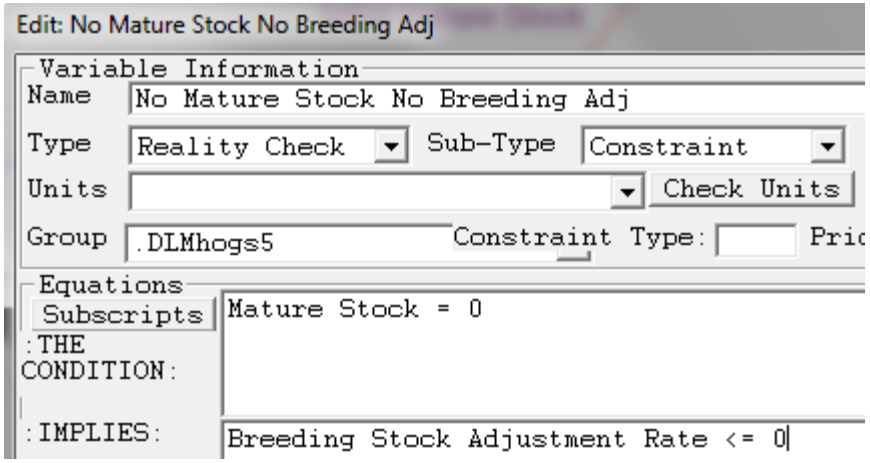
- **What happens to the Mature Stock under these circumstances? Is this possible in reality?**
- **What equations would you have to change to improve the behavior of Mature Stock?**
- **What happens to Inventory? Is this possible?**
- **What equations would you have to change to fix the behavior of inventory?**

8. Reality Check

- **Create a new variable near the Mature Stock, called Mature Stock Always Positive. Edit the equation, and change the type to Reality Check. Leave the condition blank, and specify that Mature Stock must be greater than or equal to zero:**



- **Create another new variable, called No Mature Stock No Breeding Adj, and define it as follows:**



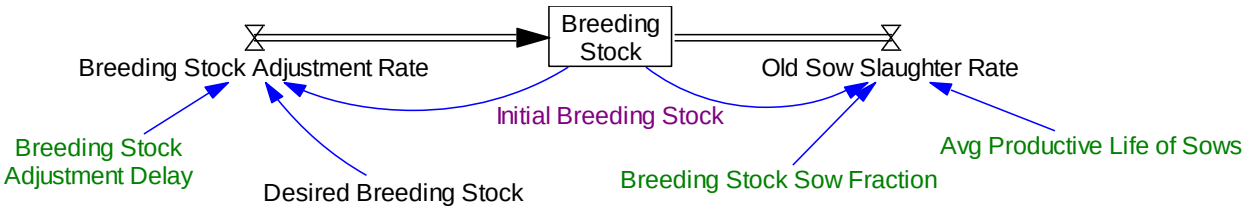
- **Use the Reality Check button to run these tests**

9. Partial Model Tests

- **Use a Custom Graph to plot Breeding Stock and Desired Breeding Stock on the same scale.**
  - Are the Breeding Stock and Desired Breeding Stock synchronized, or does one lead or lag the other? Why?
  - Do they have the same average value?
  - What is the source of the "flat spots" in the behavior of the Desired Breeding Stock? How might you fix them?

9. Copy & Paste

- **Copy & paste the following structure into a new model:**



- **Set the time bounds of the new model to the same values as the hog cycles model**
  - INITIAL TIME = 0
  - FINAL TIME = 150
  - TIME STEP = 0.5
- **Set the Desired Breeding Stock equal to the Initial Breeding Stock, with a STEP at month 50:**
  - Desired Breeding Stock = 8.2e+006 + STEP(4e+006,50)

9. Intended Rationality?

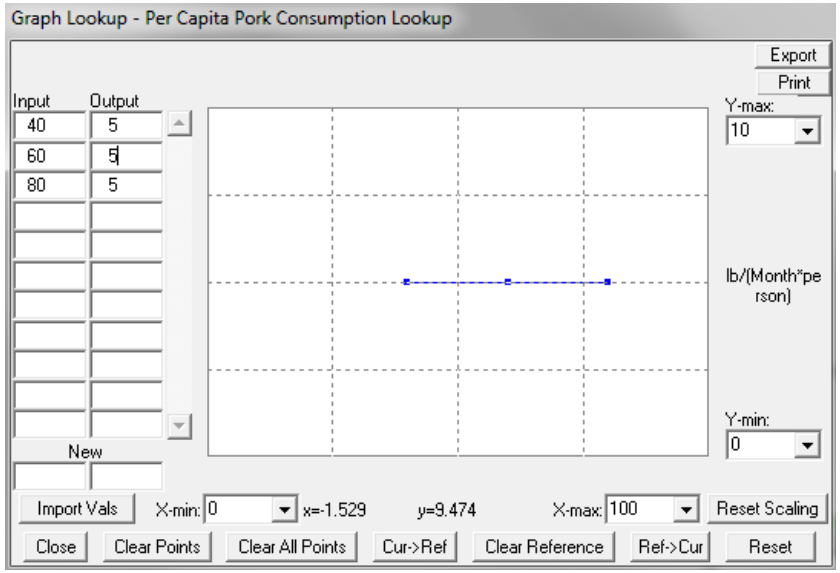
- **Plot Breeding Stock and Desired Breeding Stock on the same axes using a Custom Graph.**
- **How does the Breeding Stock respond to changes in the Desired Breeding Stock?**
- **Would a short or long Breeding Stock Adjustment Delay be more desirable?**
- **In equilibrium, does the Breeding Stock equal the Desired Breeding stock? Why or why not?**
- **What does this imply about the way farmers are making the Breeding Stock Adjustment Rate decision? Are farmers more or less rational than this?**
- **How could you improve the Breeding Stock Adjustment Rate formulation?**

10. Feedback Elimination

- **Edit the equation for Inventory, adding a 0 multiplying the old sow slaughter rate:**
  - Inventory= INTEG (+ Mature Stock Slaughter Rate + 0 * Old Sow Slaughter Rate - Consumption Rate, Initial Inventory)
- **What does this modification to the model mean in terms of the real system?**
- **How does the behavior change?**
- **Does the slaughter loop appear to play an important role in the system behavior?**

10. Feedback Elimination – Lookups

- **Flatten the Per Capita Pork Consumption Lookup in the Market Loop. Change all the output values to 5.**



- **What does this modification to the model mean in terms of the real system?**
- **How does the behavior change?**
- **Why is the market price response loop important to the behavior of inventory?**

11. Sensitivity Analysis

- **Experiment with different parameter and lookup changes in the model.**
  - Which feedback loops does the parameter change affect?
  - What influence does the parameter have? Does it change a loop's goal? Does it change the delay around a loop?
  - What characteristics of the output change? Are there slight numerical changes, or qualitative behavior changes?
- **One experiment you may want to try is the following.**
  - Change the slope of the Desired Breeding Stock Lookup, preserving its "normal" operating point (roughly the point where input = 20, output = 9e+6).
  - Shift the curve up or down, preserving the same slope.

Extra

Model Inspection

Model Inspection – Things to Consider

- **Basic Assumptions**
  - Scope
  - Simulation Method
  - Perspective
- **Variables**
- **Physics**
- **Functional forms**
- **Special cases**

Scope

- **Purpose – what are the questions it's designed to answer?**
- **Boundary – what's included, what's excluded, what's exogenous?**
- **Time Horizon and granularity – what are the fastest and slowest processes considered?**
- **Aggregation**
  - Are there arrays for detail?
  - Do aging chains or material flows have high or low order?
  - Are different kinds of accumulations recognized in distinct stocks, or with coflows?

Simulation Method

- **Continuous vs. discrete time or discrete event**
- **Continuous value vs. integer or discrete**
- **Equilibrium/simultaneous vs. disequilibrium**
- **Deterministic vs. stochastic**

Perspective

- **Behavior**
  - Bounded rationality
  - Optimization
  - Evolutionary learning
- **Feedback**
  - Causality vs. correlation
  - Sparse vs. rich causal structure

Variables

- **Operational correspondence with real system**
  - One variable <-> one concept
- **Names**
  - Are they quantities that can vary?
  - Nouns for stocks
  - "…ing," "… Rate," etc. for flows
  - Clear direction for positive and negative
  - No double negatives

"Physics"

- **Conservation of stocks and flows of material quantities**
  - Challenge sources & sinks – where does stuff go?
- **FONFOO**
  - "First Order Negative Feedback on Outflows"
  - Physical stocks always >= 0
  - Flows realistically constrained
- **Conformance to other physical laws (thermodynamics, gravity, …)**
- **Units balance**
  - Flow Units = Stock Units / Time
  - Dimensional analysis

Functional Forms & Lookup tables

- **Domain and range – comprehensive? Sensible?**
- **(Non)linearity**
- **Continuity**
- **Monotonicity**
- **Normalization**
- **Anchor points**
- **Reference lines**
- **Implicit time constants**

Functional Forms - Special Cases

- **Discrete Logic (overuse of IF THEN ELSE, binary switches)**
- **Discrete Events**
- **Simultaneity**
  - Time is what keeps everything from happening at once
  - Have arbitrary SMOOTHs or DELAYs been inserted to break conceptual simultaneities?
- **Noise**
- **Delays**
- **Exogenous inputs**
- **Data**

Testing

Testing

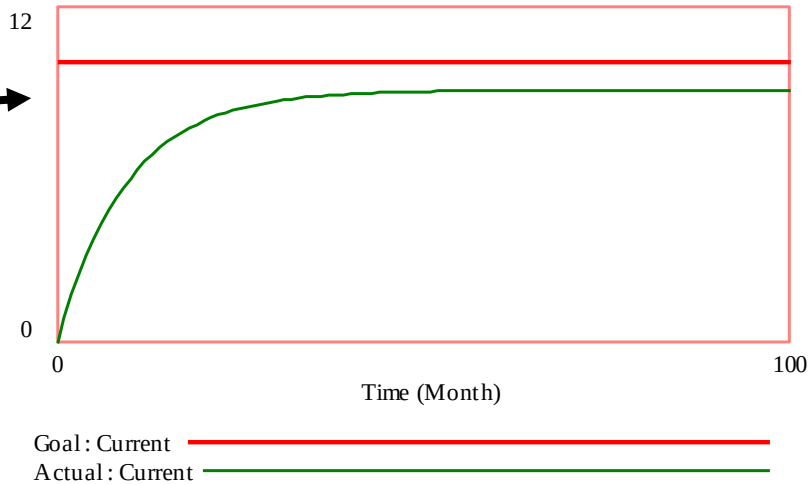
- **Behavior modes and performance**
- **Response to input changes**
- **Sensitivity to simulation technique**
- **Equilibrium**
- **Extreme conditions**
- **Reality Check**
- **Response to parametric and feedback changes**

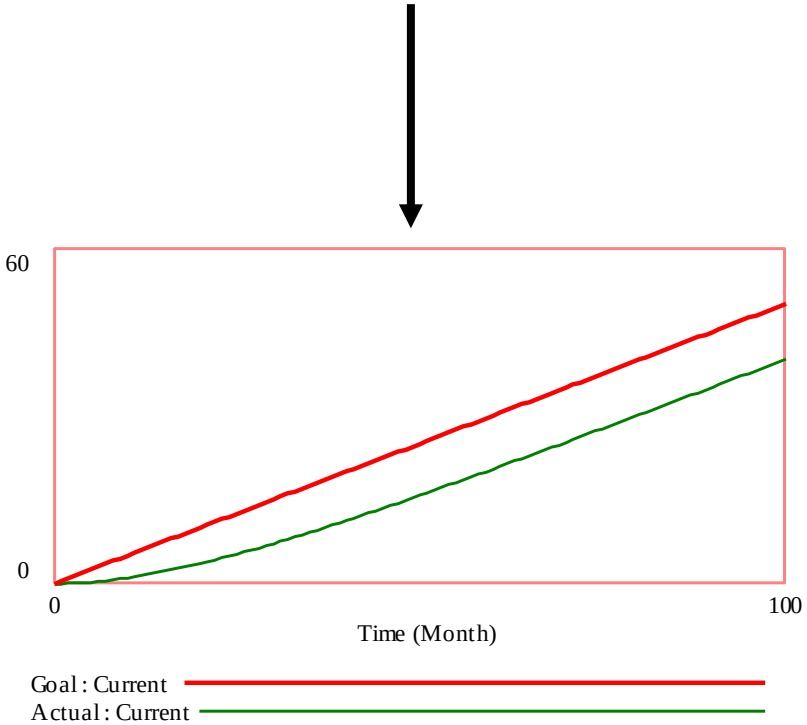
Behavior Modes

- Growth
- Decay
- S-shaped growth
- Overshoot
- Overshoot and collapse
- Oscillation
- Limit cycle
- Chaos

Performance Metrics for Steady State

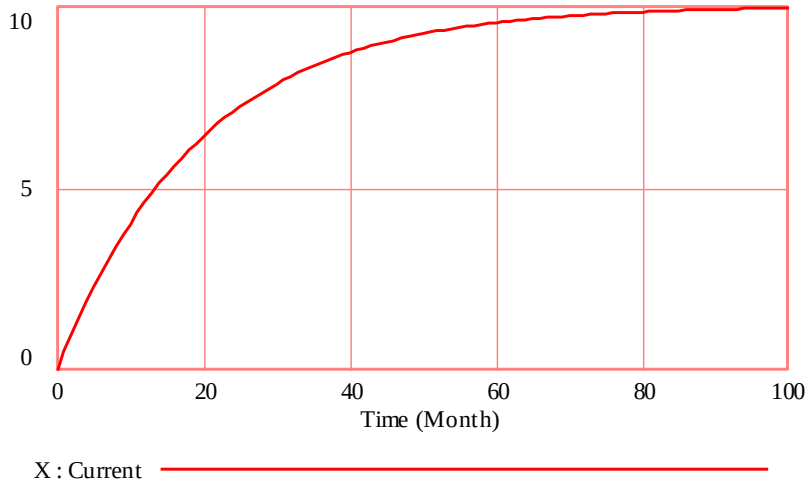
- **Mean value**
- **Equilibrium value**
- **Steady-state error**
- **Velocity error**

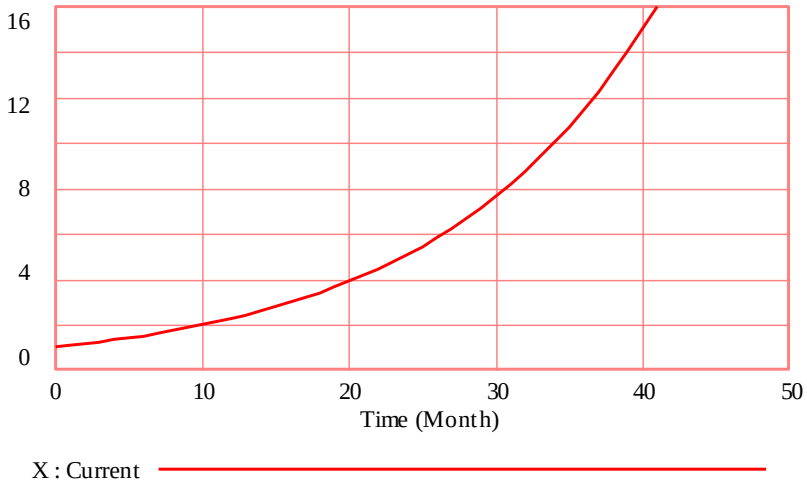




Performance Metrics for Growth and Decay

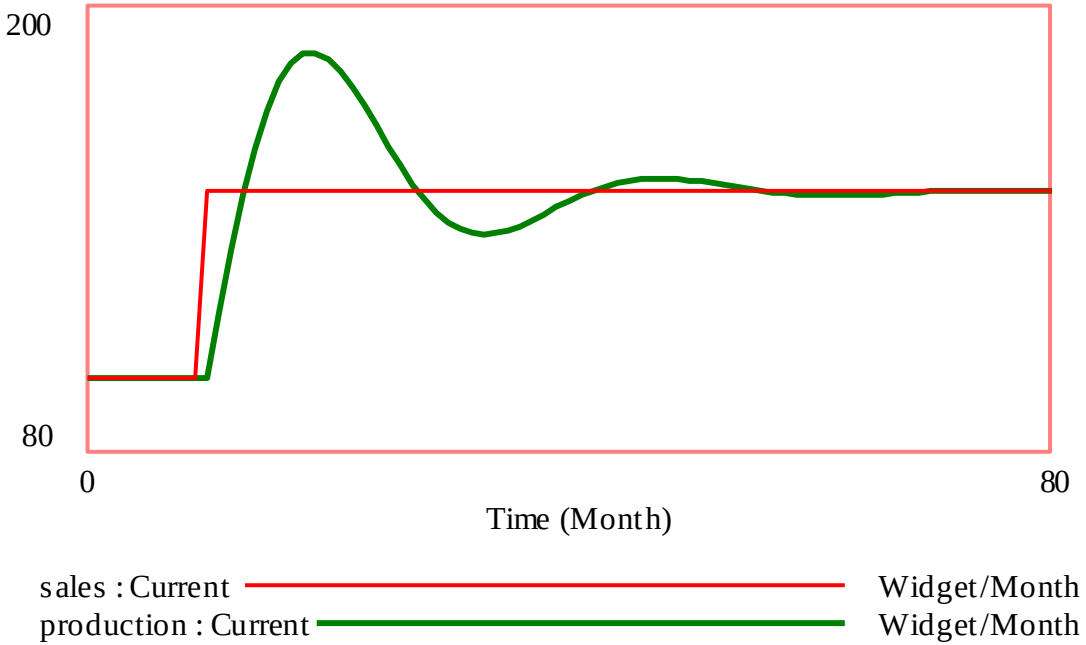
- **Time constant**
- **Half-life**
- **Growth rate**
- **Doubling time**





Performance Metrics for Overshoot

- **Rise time**
- **Maximum overshoot**
- **Time to peak**
- **Settling time**
- **Amplification**



Performance Metrics for Oscillation

- **Amplitude**
- **Period**
- **Phase lag**

Equilibrium and Stability

Equilibrium

- **Definition: the system is "at rest" with unchanging stocks**
  - Implies Inflows + Outflows = 0
- **Stability**
  - stable
  - unstable
  - metastable
- **Related: steady state growth, in which all stocks grow at the same rate, and therefore preserving constant ratios among them**

Simulation Method

- **Time step**
  - Rule of thumb: shorter than 1/2 to 1/4 of shortest time constant (delay)
  - Better: empirical test - halve TIME STEP until behavior is unchanging
  - Interesting: double TIME STEP as a test
- **Integration method**
  - Generally, Euler for models with discrete events
  - RK4 for models with oscillation
  - Test alternatives

Active Testing

Generating Surprises

- **Test for asymmetric responses to positive and negative disturbances**
- **Test small and large amplitude inputs**
- **Test policies at multiple points in system**
- **Test multiple patterns of behavior**

Dynamic Test Inputs

- **Purpose**
  - Reveal inherent behavior
  - Create extreme conditions
- **Examples**
  - Pulse
  - Step
  - Ramp
  - Exponential growth
  - Noise

- **Easy to implement in Synthesim™ and Reality Check™!**

Extreme Conditions

- **Purpose**
  - Reveal weaknesses
  - Generate insight
- **Methods**
  - Remove contents of stock with PULSE
  - Cut off inflows or outflows
  - Artificially force variables to 0 or ~infinity

Reality Check™

- **Purpose**
  - Automate model quality checks
- **Format**
  - Test input
    - :THE CONDITION: Staff = 0
  - Constraint (expected consequence)
    - :IMPLIES: Production = 0

Structure Testing

Partial Model Testing

- **Purpose**
  - Divide and conquer
  - Develop understanding of subsystems
  - Test response of subsystems to driving data
- **Methods**
  - Cut & paste structures into a new model
  - Use data variables or test inputs to drive behavior

Feedback Elimination

- **Purpose**
  - Identify feedback loops that are causing behavior
- **Methods**
  - Sever flow connections
  - Replace variables with constants or test inputs
  - Insert 0*… or (…)^0 in equations
  - Flatten lookups

Sensitivity Analysis

Examples of Sensitivity

- **Numerical**
  - Numerical values change, but behavior is qualitatively the same
- **Behavior mode**
  - Shift from s-shaped growth to oscillation
- **Policy**
  - Policy conclusions change
- **Chaotic**
  - Small initial deviations grow exponentially
- **Insensitive**
  - Pendulum always comes to rest at bottom

Parameter Sensitivity Analysis

- **Purpose**
  - Link behavior to feedback loop structure
  - Identify leverage points
  - Search for equilibria
- **Methods**
  - Vary parameters and initial conditions
  - Stretch and shift lookup table shapes

Policy Evaluation

- **Purpose**
  - Develop effective policies
  - Identify conditions for effectiveness
  - Identify weaknesses in formulation of existing policies
- **Tools**
  - Sensitivity Analysis
  - Optimization
  - Gaming

Some Rules of Thumb

Negative feedback (goal seeking, exponential decay)

- **Decay**
  - Stock = INTEG(- Outflow)
  - Outflow = Stock*Decay Rate
- **Smoothing**
  - Stock = INTEG(Change)
  - Change = (Goal – Stock)/Time Constant
- **Time constant = 1/decay rate**
- **Half life = 0.7 * time constant (because Log(2) ~ 0.7)**
- **~2/3 of adjustment at 1 time constant**
- **~95% at 3 time constants**

- **Example: my perception of the price of gasoline adjusts 20% of the way toward reality per day. After a step change in prices, my expectations have adjusted 95% of the way to reality after 3*(1/.2)=15 days or about two weeks.**

Positive feedback (exponential growth)

- **Stock = INTEG(Inflow); Inflow = Stock*Growth Rate**
- **Time constant = 1/growth rate**
- **Doubling time = (70%)/(% growth rate)**

- **Example: a city's population grows at 5% per year. It will double in 70/5 = 14 years, and quadruple in 28 years.**

Initializing in Equilibrium

- **Definition of equilibrium: stocks aren't changing; ∑(flows) = 0**
- **Little's Law:**
  (average value of a stock)
  = (average inflow) * (average residence time)
- **Typical strategy:**
  - Initial stock = Initial inflow * residence time, where residence time = mean time constant of outflows, which is a harmonic mean, e.g., $\tau_{mean} = 1/(\frac{1}{\tau_1} + \frac{1}{\tau_2})$