FOUR PHASES IN SYSTEMS MODELING -

PHASE I: CONCEPTUAL-MODEL DEVELOPMENT

- ❖ Define the problem
- ❖ State the model objectives
- ❖ Determine the system boundary
- ❖ Categorize the components within the system-of-interest
- ❖ Identify the relationships among the components and construct causal diagrams
- ❖ Sketch the expected patterns of model behavior

1. Define the problem

- What is the problem to be solved?
- What is the phenomenon to be understood?
- What are the questions to be addressed?

2. State the model objectives

- What do you want to accomplish with a model specifically?
- Objectives provide:
  - the framework for model development
  - the standard for model evaluation
  - the context for interpretation of model results

3. Determine the system boundary

- To determine what to be included or what not to be included in the system-of-interest
- What are those important components for describing the phenomenon under consideration?
- What are the minimum set of components that must be included in the model in order to achieve the objectives?

4. Categorize the components within the system-of-interest

- To define distinctive classes of system components
- To classify components into the following types of variables:
  - State variables (accumulations, levels, or stocks)
  - Rate variables (flows)
  - Auxiliary variables (neither accumulations nor flows; intermediate variables for calculating rates and other variables)
  - Constants (coefficients and other unchanging numerical values)
  - Driving variables (that affect but are not affected by the rest of the system)
  - Sources and sinks (origination and termination points)

5. Identify the relationships among the components and construct causal diagrams

A. Two Ways That System Components Are Related:

1) Through material flow
2) Through information flow

B. Feedback, Causal-Loop Diagramming, And System Structure

(1) Causation and Causal Links

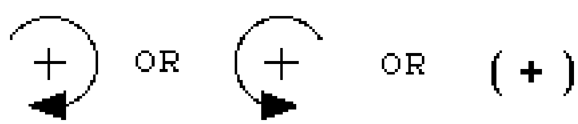
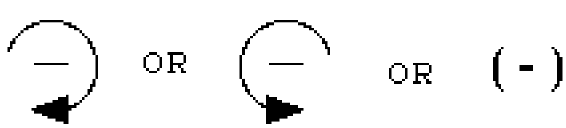
- Causal thinking is a powerful way of organizing ideas, generate hypotheses about mechanisms, and formulate theories.

- Positive influence (effect or relationship) versus negative influence (effect or relationship) for pairs of variables

    - Positive influence: All other things being equal, if a change in one variable generates a change in the same direction in the second variable relative to its prior value, then the relationship between the two variables is positive.
    - Negative influence: When a change in one variable produces a change in the opposite direction in the second variable, the relationship between the two variables is negative.

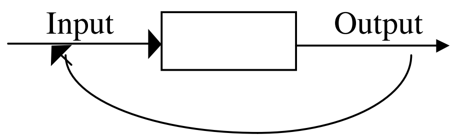
- Graphical representation of causal links (arrows, signs, and conventions).
- **Correlation is not equal to causation**, but the former can still be used to form (non-mechanistic) relationships between variables if the correlative relationship is consistent or robust.

Causal-loop Diagram Symbols

Symbol	Meaning
	The arrow is used to show causation or influence. The variable X at the tail of the arrow causes a change in (or influences) the variable Y at the head of the arrow.
	The "+" sign near the arrowhead indicates that the variable X at the tail of the arrow and the variable Y at the head of the arrow change in the *same* direction. That is, if X *increases*, Y *increases*; if X *decreases*, Y *decreases*.
	The "-" sign near the arrow head indicates that the variable X at the tail of the arrow and the variable Y at the head of the arrow change in the opposite direction. That is, if X *increases*, Y *decreases*; if X *decreases*, Y *increases*.
	This symbol, found in the middle of a closed loop, denotes a *positive feedback loop*. It indicates that the loop continues going in the same direction, often causing either systematic growth or decline, behavior that unstably moves away from an equilibrium point.
	This symbol, found in the middle of a closed loop, denotes a *negative feedback loop*. It indicates that the loop has an odd number of negative influences (or causal links), causing the system to fluctuate or to move toward equilibrium.

(2) Feedback (Loops)

- The process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself
- The process in which output affects input.



(i) Positive feedback (loop)
  - A feedback loop that amplifies changes of any variable in the loop
  - Response to a variable change **reinforces** the original perturbation
  - Synonyms: “snowball effect”, “vicious circles”, “virtuous circles”, “band wagon effect”
  - Generates “run-away” behavior; a special, yet common, example - exponential growth (or decay)

(ii) Negative feedback (loop)
  - Feedback loop that **counteracts** changes of any variable in the loop
  - Response to a variable change **opposes** the original perturbation
  - Synonyms: “Goal-seeking”, “self-governing”, “self-regulating”, “self-equilibrating”, “homeostatic”, “adaptive”
  - Characterized by goal-directed, goal-seeking, or “under-control” behavior
    Examples: Thermostat heating system and population regulation

- Determination of the loop polarity
  - Add up the number of negative signs around the loop
  - If even, the feedback loop is positive.
  - If odd, the loop is negative.

(3) Causal-loop diagramming

- Identification of the relationship between individual pairs of variables
- Draw causal links between variables [with signs: + or - by the arrow]
- Link variables together to form feedback loops [with signs: (-) or (+)]

(4) Feedback loop structure

- A key element in systems modeling is to identify closed, causal feedback loops because:
  - The most important causal influences usually are exactly those that are enclosed within feed back loops, and identifying them, thus, helps define the system’s boundary.
  - Identification of causal loops is a powerful tool to help understand the system structure and possible mechanisms.
- Most real systems have multiple and mixed (both positive and negative) feedback loops.

(5) Some General Principles of System Structure

- All state variables represent accumulations; they can be changed only by moving their contents between state variables, sources, or sinks.

- Information is not a conserved flow. Information from a single source can be transmitted to other variables in the system without diminishing the source.

- Rate and auxiliary variables represent information in the system, and are not conserved through time as state variables are.

- In any conserved flow subsystem, the rate and state variables must alternate.

- Levels are changed only by rates in most if not all cases.

- Rates depend, in principle, only on levels and constants.

- The only inputs to rates are information links. There can be, in principle, no rate-to-rate connections in a model because most rates are not instantaneously knowable by most variables in the system and because no rate can, in principle, control another rate without an intervening level.

- In practice a rate may be expressed directly in terms of another rate when the time constant of the intervening levels is very small relative to the other time constants.

- Every feedback loop in a model must contain at least one level.

- Without a level, rate-to-rate connections or simultaneous auxiliaries result.

- In every model equation, the units of measure must be consistent.

- Dimensional analysis can NOT prove an equation is correct, but it can certainly prove some equations to be incorrect!

- Levels (state variables) and rates can not be distinguished only by their units of measures.
  - E.g., A level could be an average flow rate over a period of time!

- Within any subsystem of conserved flows, all levels have the same units of measure and all rates are measured in those same units divided by time.

- Like every variable in a model, every parameter should have a meaningful interpretation or counterpart in the real system.

- An Example of Conceptual Model Using STELLA: A model of population dynamics (from Wu and Barlas 1989; a PDF of the paper is available at the class web site).

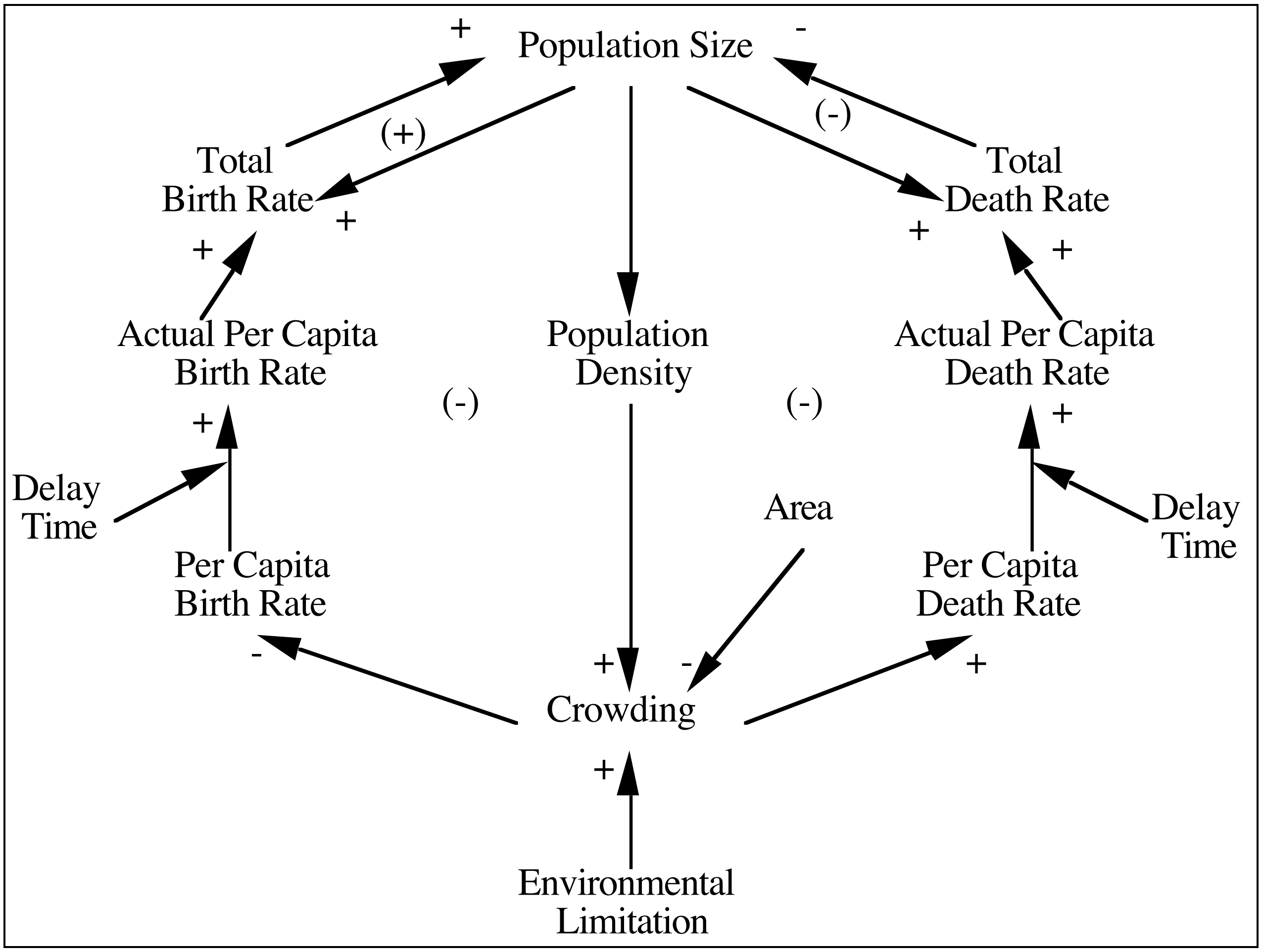


Fig. Causal-loop diagram of a generalized model of population dynamics, showing the basic feedback loops in natural population systems.

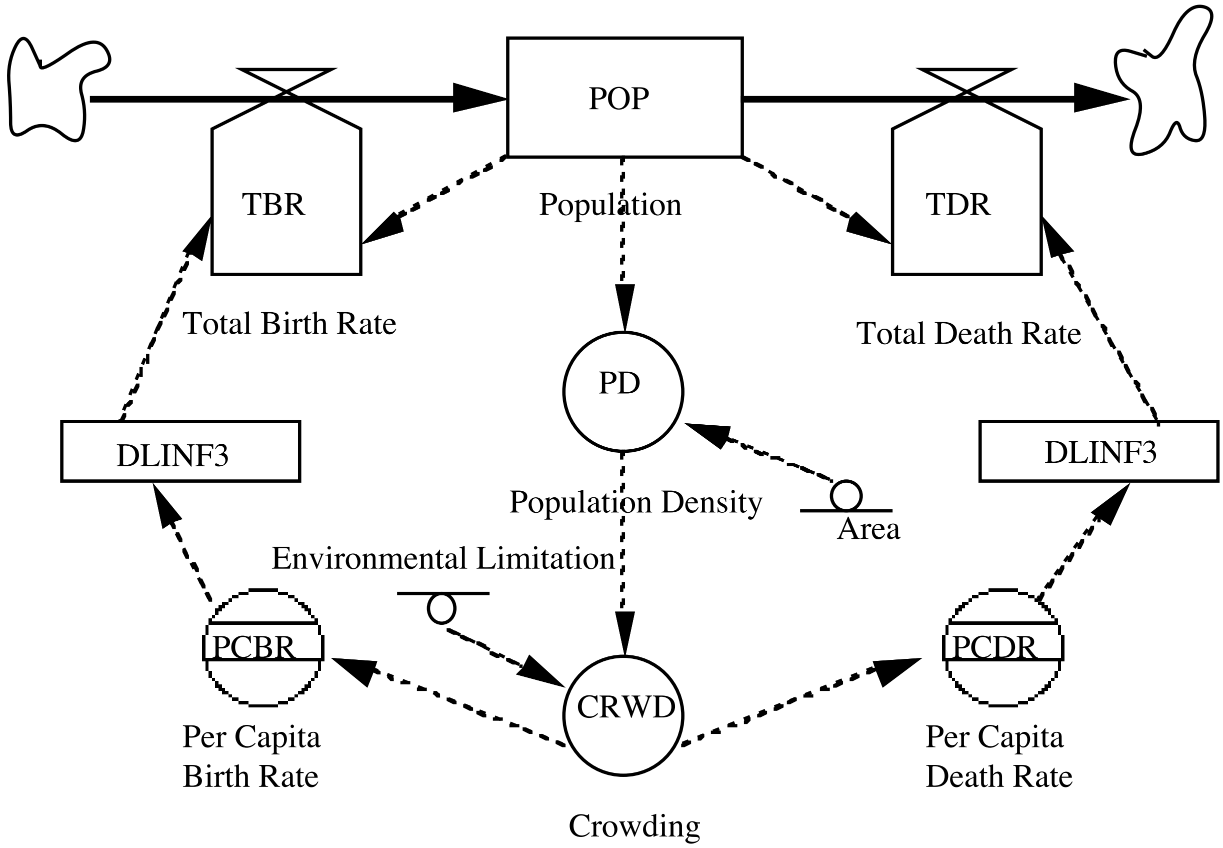


Fig. Flow diagram of the generalized System Dynamics population model.

6. Sketch the expected patterns of model behavior

- Sketch general patterns of the dynamics of the system based on:
    1) the feedback loop structure of the system
    2) your knowledge of the system (or phenomenon)
    3) information from other sources

- Consider them as preliminary hypotheses or speculations