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## Road Maps Glossary<sup>1</sup>

- accumulation:** The collection of some quantity over time. Examples of accumulation include water in a bathtub, savings in a bank account, *inventory*. In the *STELLA* modeling software, the accumulator is also referred to as a *Stock* or *Level*.
- aggregation:** The incorporation of numerous distinct system components into one variable. Aggregation is done for simplicity when combination generates the same behavior of interest as representing the components separately..
- amplification:** A system response that is greater than is seemingly implied by input causes. Amplification occurs in information-feedback systems when policies adjust levels to values that change with varying *flow* rates. It is associated with *delays*, order/inventory processes, forecasting, etc.
- asymptotic growth/decay:** *Goal-seeking behavior* produced by *negative feedback*. The *stock* of the system moves towards the goal, slowing down as it approaches the goal.
- auxiliary equation/variable:** An equation that takes the present value of variables (levels, constants, or other auxiliary variables) to compute the present value of an auxiliary variable. Auxiliary variables are part of a rate equation connecting a level to a rate. Auxiliary equations embody unit consistency and are symbolized by a circle in a *flow equation*.
- balancing loop:** A loop that seeks *equilibrium* — it tries to bring stocks to a desired state and keep them there. It limits and constrains, and is also called a *negative loop*. When a balancing process has a long *delay*, the response may overcorrect, often leading to instability, the opposite of what is intended.
- The Beer Game:** A “laboratory replica” of a real organization that involves a production/distribution system. The players at each position make decisions about placing orders, and find from practice the problems that originate from traditional ways of thinking and interaction.
- behavior over time diagram:** A *system dynamics* tool that shows how certain variables change over time. Several variables can appear on the same graph for comparison. and Time is shown on the horizontal axis.
- boom and bust cycle:** See *overshoot and collapse*
- boundary:** Border enclosing only the parts of system structure needed to generate the behavior of interest. In other words, the system boundary excludes all components not relevant to the problem behavior of the system. Also called *system boundary*.
- business cycle:** See *boom and bust cycle, oscillation*

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<sup>1</sup> Italicized words represent terms that are defined in this glossary

**causal loop diagram:** Diagram representing a closed loop of cause-effect linkages (causal links) which is intended to capture how the variables interrelate. The five steps of constructing a causal loop diagram are: 1. Choose variables; 2. Link variables with arrows pointing from cause to effect; 3. Assign a direction of effect (same or opposite) to each link; 4. Indicate delays; 5. Assign *polarity* to overall loop.

**closed system:** A system that functions without any *exogenous variables* generated outside the model. The system internally generates the values of all the variables through time by their interactions.

**cloud:** An origin or ending place of a flow that is outside the *boundary* of the system. In other words, the cloud represents an input or output of the system that is inconsequential to its behavior of interest. In a population system, clouds might represent origin of the inflow “birth rate” and destination of death rate that determine a “population” *stock*.. Where babies come from and where dead bodies go may not be dynamically important and thus represented by clouds.

**compounding:** Phenomenon that occurs when the *stock* serves as the basis for generating its own inflow, producing *exponential growth*. The behavior is also said to be self-reinforcing.

**computation interval:** See *solution interval*

**computer model:** A set of descriptions that tell the computer how each part of the system acts. A good computer model captures the dynamic essence of the system it represents. It explicitly contains the assumptions being made about the system.

**connector:** The building blocks that carry information from one element in a model to another element. "Information" may be a constant, an algebraic relationship, a graphical relationship (contained by *converters* or table functions), or a quantity (e.g. how many dollars in your savings account). “Information” flows through connectors to converters (*auxiliary variable*) or *flows* (rates), but not to *stocks*.

**conserved flow :** A flow that moves a quantity of material between two distinct stocks so that the total amount of material in that part of the system is unchanged. There is only so much material and it is divided between the two stocks. Non-conserved flows, on the other hand, flow from or to a cloud that has no limit in the quantity it can supply or absorb.

**converter:** A term used in the *STELLA* software. More generally, known as *auxiliary variables*. They are usually represented in diagrams by circles. Converters do not accumulate flows and do not have memory, but rather are recalculated from scratch each time calculations are performed. Three types of converters define constants, algebra, or graphs.

**conveyor:** A type of stock that represents a space into which material flows and stays for a fixed amount of time, then exits. Its associated parameters determine transit time which represents how long material stays in the conveyor. Material that flows in at a given time is not mixed with material that had flowed in earlier — whatever entered first will also leave first.

**counterintuitive behavior:** A surprising result of policies devised to remedy a problem. Often the presumed “solutions” result in counter-productivity. Thus as troubles

increase, efforts are intensified which actually worsen the problem. See *policy resistance, fixes that fail*.

**cyclical behavior:** See *oscillation, overshoot and collapse*

**decision function:** Also known as a rate equation. It is a policy statement that determines how the levels are related to the decisions (rates).

**delay:** A phenomenon where the effect of one variable on another does not occur immediately. Delays result from decisions often require a long period of time to be effective. Delays can result in *overshoot* or *oscillation*.

**dimensional analysis:** A process that checks for unit consistency in equations. The saying “one can’t add apples and oranges” shows why dimensional analysis is necessary. Dimensional inconsistency is a sign of an incorrect equation.

**disaggregation:** The opposite of *aggregation*. Disaggregation is done to separate variables that do not have similar effects on system behavior.

**doubling time:** Length of time it takes an exponentially growing quantity to double in size. If a rate flowing into a level equals a multiplier times the level, then doubling time equals approximately 0.7 divided by the multiplier. Associated with *exponential growth*.

**dynamic model:** A model that deals with relationships that vary with time.

**DYNAMO:** An equation-based simulation language for system dynamics modeling on MS Windows computers.

**endogenous variable/view:** Opposite of *exogenous*, meaning internal. An endogenous view approaches a problem searching for its causes and cures within some *boundary*. Endogenous variables affect and are affected by the rest of the system.

**equilibrium:** A situation in a dynamic system where the inflows and corresponding outflows balance, and the levels cease to change.

**exogenous variable/view:** The opposite of *endogenous*. An exogenous view considers systems under the influence of outside events that are not part of the internal dynamics of the system. An exogenous variable is an outside variable that affects but is not affected by the behavior of the system.

**exponential growth/decay:** Behavior that occurs when the rate of growth depends on the size of the *stock* at that point in time. As the stock gets larger, its growth gets progressively faster. Or, for decay, as the stock gets smaller, the decay gets progressively slower. Exponential growth/decay has a *doubling time*. Associated with *positive feedback*, or a *half-life* associated with decay.

**feedback system:** A closed system influenced by its past behavior. Feedback systems have feedback loop structure that consist of closed paths of cause and effect. They are self-regulating and can be either a *positive feedback* system or a *negative feedback* system.

**first order system:** See *order*

**Fish Banks Game:** A management flight simulator. The Fish Banks Game consists of a group of players acting as competing fishermen trying to maximize profits. The game passes on to its participants the lessons of *tragedy of commons*, *S-shaped growth*, and *limits to growth*.

**fixes that fail:** A situation where a “fix” has immediate positive results but eventually makes the problem worse. The underlying structure of the system that caused the problem in the first place does not change. Similar to *policy resistance* and *counterintuitive behavior*.

**flow:** Movement of a quantity from one level to another.

**generic structure:** A structure that can be applied across different settings due to fundamentally same underlying structures and relationships.

**goal-seeking behavior:** Behavior that results from a *balancing loop* which drives a system toward a specified goal. The farther the system from the goal, the quicker it changes towards that goal, the equilibrium *homeostasis* point, and as it approaches the goal, the growth/decay slows down. Associated with *negative feedback*.

**graphical function diagram:** A diagram that relates movement in one variable to movement in another. The input and output variables are placed on the axes of a graph, and the relation plotted.

**half-life:** The amount of time it takes for a stock to go halfway towards its goal. It is the converse of *doubling time* in *positive feedback*. Half-life is approximated by 0.7 times the time constant, or 0.7 divided by the decay fraction. Associated with *goal-seeking behavior*.

**homeostasis:** Control through the operation of *negative feedback* loops — homeostasis is reached when the goal is attained and stable *equilibrium* achieved.

**impulse:** Theoretically, a signal of zero width but finite area. Practically, in models, a signal (rate of flow) of specified area lasting for one solution interval and occurring at a specified time.

**integration:** See *accumulation*, *stock*, *level*

**inventory:** A frequently-used stock in modeling economic systems. When production is greater than consumption, the excess production goes into inventory.

**ithink:** The business-oriented application version of *STELLA*, by High Performance Systems.

**learner-centered learning:** Innovative learning style in which the teacher is no longer a dispenser of knowledge but rather a colleague. The teacher is a facilitating participant who sets directions and introduces opportunities. Students working in small groups acquire their own knowledge without having it spoon-fed to them. Such classrooms make acquisition of facts and information a consequence of needing inputs to reach an objective.

**level:** An *accumulation* in a system. It represents the accumulated difference between inflow and outflow rates, illustrating the results of action within the system over time. Levels are conserved quantities that can be changed only by moving contents in and out.

**leverage point:** A policy which can yield large changes in a system.

**limits to growth:** A resource constraint, an external or internal response to growth. A growth caused by reinforcing feedback processes begins to slow and eventually come to a halt at the limit, and may even reverse itself and collapse. For instance, population growth is limited by space, water and resources essential for survival.

**linear system:** A system in which different behavior models can be superimposed without interacting with one another.

**loop dominance:** A system in which one loop is stronger. In a system with multiple loops, magnitudes and algebraic signs of variables determine what kind of behavior, positive or negative feedback, is dominant at any given time. If the system exhibits *exponential growth*, then the positive loop is dominant. If *asymptotic behavior* is evidenced, the negative loop has dominance. *S-shaped growth* is a common behavior of a system in which loop dominance shifts with time.

**mental model:** A model representing the relationships and assumptions about a system held in a person's mind. Mental models are often correct in system structure, but frequently draw wrong conclusions about system behavior.

**negative feedback:** Feedback that works to cancel deviations from a goal. It exhibits *goal-seeking behavior*. The control decision attempts to adjust a system level to a value given by a goal introduced from outside the loop.

**non-linearity:** See *linear behavior*

**open-loop thinking:** Approaching a problem without applying the concept of feedback.

**order:** The number of *levels* a system has. For instance, a "second-order" system has two level variables.

**oscillation:** Behavior exhibited by a second-order or higher-order system in which the stock value moves sinusoidally over time. Three types of oscillation include sustained, where the amplitude is always constant; expanding, where the amplitude increases over time; and dampened, where the amplitude decreases over time.

**overshoot and collapse:** A system that grows beyond a sustainable condition, reduces the basis for sustained existence, then collapses below the level that might have been sustained. Example: fishing rates that exceed the replenishment rate resulting in a collapse of the fishing population.

**parameters:** Numerical values that describe relationships in a system and are considered constant, at least during the computation span of one model run. Parameters are shown by a circular *converter* in *STELLA* and by other symbols in other software.

**period of oscillation:** The time duration of each cycle in oscillatory behavior from the analogous part of one wave to another.

**polarity:** Positive or negative sign of a *causal loop*. Positive loops are called reinforcing, and negative loops are called balancing.

**policy analysis:** Analysis employed to evaluate the causes of undesirable behavior in a system. It allows the model-builder to compare how a system would react to different policies through simulation.

**policy resistance:** See *fixes that fail*

**positive feedback:** Feedback that contains *reinforcing loops* which produce *exponential change*. Change in one direction results in more and more change in the same direction. Positive feedback produces growth that would be out of control if it weren't for *limits to growth*.

**POWERSIM:** MS Windows-based modeling software package for system dynamics models. POWERSIM is equipped with advanced functions such as interactive simulation, On-Line Help, expandable function library, and data exporting.

**queue:** Waiting lines, an explicit line build-up as opposed to a pile-up implied by a *reservoir*. In the *STELLA* software, they are used in conjunction with a *conveyor* to represent batches of material waiting to enter a process or activity.

**ramp function:** A way to designate the value of a variable to change linearly over time.

**rate:** Definition of the present, instantaneous *flow* to and from a *level* in a system. Rates represent activity, while levels represent the state to which the system has been brought by the activity. Rates are determined by the levels of a system according to rules defined by the *decision functions*. In turn, rates cause levels to change.

**reinforcing loop:** Loop that occurs when an action causes change that accelerates that action, reinforcing the effect of the original action. Associated with *positive feedback*.

**reservoir:** The type of stock that is analogous to a tub with water flowing in and draining out. In many ways it is the simplest of stocks. When something flows into a tub, it is mixed into any "stuff" that is already in the tub so that it can not be distinguished from earlier or later inflows.

**sensitivity analysis:** Analysis used to determine how "sensitive" a model is to changes in specific parameters, or policies, or structures. If the behavior of a model changes drastically, that suggests a critically important factor, or high sensitivity. Conversely, if a large change results in little change in behavior, that factor is not likely to be central to the dynamics in question, that is, it shows low sensitivity.

**shifting the burden to the intervenor:** A system behavior where an intervenor acts to improve a system and the effort fails because the system lacks incentive to continue its own effort to take the action.

**simulation:** Conducting dynamic experiments on a model instead of on the real system.

**smoothing:** Filtering out the superimposed short-term fluctuations in order to detect underlying, significant changes in data. There is formal (numerical processing of data into averages) and intuitive smoothing.

**solution interval:** The amount of time elapsed between successive computer calculations of *flows* accumulating into *stocks*. Also known as *computation interval* or *DT* (for Delta Time). It is measured in units of time and must be short enough so that its value does not affect the computed results, but also long enough to avoid unnecessary waste of computation time.

**S-shaped growth:** Growth that exhibits behavior in the shape of the letter “S.” It expands rapidly at first, then slows down as stock approaches its maximum value. S-shaped growth is caused by a shift in *loop dominance* from positive to negative feedback.

**stability:** Behavior exhibited by a system that returns to its initial condition after being disturbed. In an unstable system, a disturbance is amplified, leading increased growth or *oscillation*. A stable oscillation is one at a constant amplitude, as in a clock pendulum.

**state variable:** See *stock, level*

**steady-state:** A behavior pattern that is repetitive with time and in which the behavior in one time period is of the same nature as any other period.

**STELLA:** Visual diagram-based simulation software for system dynamics models. It is the education-gearred version of the *ithink* software.

**step input:** An input (usually for testing purposes) that suddenly changes and then remains at the new value.

**stock:** An element of a system that is accumulating or draining over time. Stocks are the memory of a system and are only affected by flows. Also known as *levels*, they are signified by rectangles in system dynamics diagrams.

**structural diagram:** Diagram that gives an overview of the structural elements that produce system behavior by showing the *stocks* and *flows*. Also known as *flow diagrams*.

**structure:** The building blocks and interval connections of a system. It is the way in which system elements are organized or interrelated.

**system:** A collection of parts that interact to function as a whole. A system is almost always defined with respect to a specific purpose. Systems often contain circular patterns of cause and effect called *feedback loops*.

**system boundary:** See *boundary*

**system dynamics:** A field for understanding how things change through time. System dynamics deals with how the internal *feedback-loops* within the structure of a system create behavior. Computer simulation models are used to achieve better understanding of system behavior over time. With a better comprehension of systems, one can redesign structure or policies to improve the behavior. The field of system dynamics was created by Jay Forrester beginning in 1956.

**systems archetypes:** A *system dynamics* structure that is common to many systems. See also *generic structures*.

**systems thinking:** Thought process that involves 1) seeing interrelationships (*feedback loops*) instead of linear cause-effect chains, and 2) seeking processes of change over time rather than snapshots. Systems thinking involves understanding many concepts of *system dynamics*, most notably, *feedback*. It helps thinkers see things on three levels: events, patterns of behavior, and system *structure*.

**table function:** Feature used to formulate a non-linear relationship when it is necessary to use an *auxiliary variable* that is not a simple algebraic function of other variables. The function is a graph that can be sketched to capture the relationship at hand. A table function can be represented with a *graphical function diagram*.

**tragedy of commons:** The structure in which each person pursues action beneficial only to oneself, then eventually the system cannot support all the activity and everyone experiences diminishing results. The commons is the resources everyone calls upon, but does not take care to replenish. It is a *systems archetype* that surfaces in many socioeconomic systems. The *Fish Banks Game* is an excellent example of tragedy of commons behavior.

**transferable structure:** See *generic structure*

**transient:** A dynamic response that does not persist.

**unit-conversion:** A modeling function that allows for units of a certain variable to change as that variable is altered. Example: cloth (square meters) is made into clothing (articles).

**validity:** Judgment of a model's suitability for a particular purpose. A model is valid when it accomplishes what is expected of it.

**VENSIM:** Modeling software for system dynamics. VENSIM offers a "Workbench" featuring simulation tools for tracing sources of behavior in a model.

**vicious cycle:** Reinforcing, amplifying process that yields undesirable results.

**virtuous cycle:** Process that reinforces in desired directions.