NOTES AND INSIGHTS

A system dynamics glossary

David N. Ford*

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Introduction

As a narrowly focused dictionary, this glossary defines commonly used terms that are central to traditional system dynamics and some more general terms that have special meanings or particular importance within system dynamics. General terms that have no special meanings in system dynamics, application-specific terms, and software-specific terms are not included. The reader is referred to the relevant literature for those definitions, as well as detailed descriptions, explanations, and examples of the terms included here.

accumulation (integration): a gradual, non-instantaneous increase or decrease of a quantity over time. An accumulator is also referred to as a stock or *level* and represents the state of a system. To accumulate is the act of increasing and decreasing the size of a state variable (a stock) over time.

aggregation: the grouping of numerous distinct system components into one variable. Aggregation is done for simplicity when the grouping generates the same behavior of interest as those generated by the components separately.

aggregation level: the extent to which the system components are aggregated or disaggregated.

aging chain: a sequence of stocks connected by conserved flows in which the stocks depict the contents of the chain in different stages, conditions or locations, and the contents move in one direction along the aging chain.

amplification: an increase in the magnitude of movements from an average value of a dynamic behavior, typically as in oscillations. Often implies a system response that is greater than is seemingly implied by input variables. Amplification can occur in information feedback systems when policies try to adjust levels to desired values in complex settings. It is associated with delays, order/inventory processes and forecasting.

archetype: see *system archetype*.

asymptotic growth/decay: goal-seeking behavior produced by negative feedback. The control stock moves towards the goal, slowing down as it approaches the goal.

* Correspondence to: David N. Ford, Beavers Charitable Trust / William F. Urban ′41 Professor in Construction Engineering and Management Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, TX 77843, U.S.A. E-mail: davidford@tamu.edu

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auxiliary (convertor) variable: an intermediate, conventional variable to facilitate the expression of functional dependency of a flow to system stocks. A convertor is capable of changing its value instantaneously.

balancing feedback loop: a feedback loop in which the resultant effect of the causal links over time limits or constrains the movement of variables. Balancing loops seek equilibrium, trying to bring stocks to a desired state and keep them there. Also called a negative, compensating, goal-seeking or controlling feedback loop.

behavior mode: a shape or pattern over time of the values of a system variable. Behavior modes are typically displayed graphically using behavior-over-time graphs (BOTG), where time is represented on the *x*-axis and values of the variables are represented on the *y*-axis.

boundary (system boundary): a border enclosing the parts of system structure needed to generate the behavior of interest. The system boundary excludes all components not relevant to the problem behavior of concern.

bounded rationality: the theory developed by Herbert Simon that human decision making is rational only insofar as the rational solution does not require calculations or mental efforts that exceed cognitive limitations and available information. Bounded rationality is a characteristic of human decision making that often impacts system performance.

calibration: the process of setting model parameter values to reflect an actual case (or specific hypothetical conditions of interest).

causal: a driving or influencing relationship between two variables; in contrast to correlations, when two variables change together in time and/or space, but one does not necessarily drive or influence the other.

causal link: an arrow in a causal loop diagram or system structure diagram that describes a relationship between two variables with the direction of causality (from cause variable to impacted variable) and the nature of impact (same direction of change or opposite direction of change). If there is a significant delay in the influence of the driving variable on the driven variable, it can be represented by a link "broken" by parallel lines.

causal link polarity: a positive (+) or negative (−) sign that indicates the direction of impact of the driving variable on the driven variable. Positive polarity indicates that the impacted variable moves in the same direction (increase or decrease) as the driving variable. Negative polarity indicates that the impacted variable moves in the opposite direction (increase or decrease) to the driving variable. Alternatively, positive link polarity is sometimes indicated by the letter "S" (causing to move in the *same* direction) and negative link polarity by the letter "O" (causing to move in the *opposite* direction).

causal loop diagram: a tool that represents closed loops of cause–effect linkages (causal links) as a diagram intended to capture how the system variables interrelate and how external variables impact them. Causal loop

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diagrams identify and label feedback loops to facilitate understanding, dynamic reasoning and formal modeling.

closed-loop thinking: approaching a problem with an endogenous perspective, focusing on the role of feedback loops.

closed system: a system that functions without the influence of exogenous variables. The system internally generates the values of the variables through time by their interactions. A completely closed system does not exist in reality, but many systems do primarily determine their behaviors internally.

cloud: a symbol in a structure diagram that represents an infinite source or sink. An origin or ending place of a flow that is outside the boundary of the system as modeled. A cloud represents an unrepresented input or output stock of the system that is inconsequential to the behavior of interest.

co-flow: a parallel stock-and-flow structure that mimics a primary stock-and-flow structure in which the co-flow structure models an attribute or characteristic of the contents of the primary structure.

compensating feedback: a negative feedback structure typically used to denote one or more negative feedback loops that undercut the intended effects of a policy. See *policy resistance*.

computation interval: see *solution interval*.

connector: the directed links in a model that carry information or influence from one element to another element. The information may take the form of an algebraic relationship or a graphical relationship. The connectors can directly influence/determine auxiliary variables or flows (rates), but never stocks.

conserved flow: a flow that moves a quantity of material between two or more stocks so that the total amount of material in the related part of the system is unchanged. The total amount of material is divided among the stocks. In contrast, non-conserved flows flow across the model boundary from or to a source or sink, where the quantity is "created" or "lost" (non-conserved).

controlling feedback loop: see *balancing feedback loop*.

conveyor: a type of stock that represents a space into which material flows and stays for a fixed period of time, then exits. Its parameter determines transit time—how long material stays in the conveyor. Material that flows in at a given time is not mixed with material that flowed in earlier—a quantity that enters at t will flow out exactly at t + transit time. Also called a pipeline delay.

counterintuitive behavior: when policies assuming a particular solution yield unexpected, surprising or paradoxical results that are very different from those intended or expected. Often, as troubles increase, well-intentioned but flawed efforts are intensified, which reduce improvement or worsen the problem instead of improving the situation. See also *policy resistance*.

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cyclical behavior: see *oscillation*.

dampening: a decrease in the magnitude of movements from an average value, typically in oscillations. Also a system response that is less than is seemingly implied by input variables.

decision function: a policy statement that determines how information is used to generate actions for managing the system. Also the algorithm used to transform incoming information into a stream of decisions over time.

delay: a phenomenon in which the effect of one variable on another does not occur immediately. A process by which the output lags behind its input in time.

delta time: see *solution interval*.

diffusion structure/behavior: a structure/behavior that describes the spread of products, ideas or beliefs, typically based on a model of new product adoption developed by Frank Bass.

dimensional analysis: a procedure that checks for unit consistency in equations.

disaggregation: the opposite of aggregation. Disaggregation is done to separate variables into components that do not have close enough effects on system behavior to be modeled with a single variable.

doubling time: the length of time it takes a quantity to double in size. Normally associated with exponential growth.

dynamic: changing over time. The opposite of static.

dynamic hypothesis: a structure that the modeler advances to explain a dynamic behavior of interest.

endogenous variable/view: internal, the opposite of exogenous. An endogenous view approaches a problem searching for its causes and solutions within the system boundary. Endogenous variables are affected by other system variables.

equilibrium: conditions in a dynamic system where the inflows and outflows of each stock balance each other, and the sizes of the stocks do not change.

equilibrium behavior: a behavior mode in which all stocks are at equilibrium conditions. Static equilibrium behavior occurs if all flows are zero (so the contents of stocks do not change over time). Dynamic equilibrium behavior occurs if flows are non-zero but they balance (so the contents of stocks change, but their values stay constant) over time. Asymptotic equilibrium behavior means the system approaches equilibrium values, but does not reach these values in finite time.

equilibrium conditions: a system structure and set of numeric conditions that generate equilibrium behavior.

exogenous variable/view: external, the opposite of endogenous. An exogenous view assumes that a system's behavior is dominated by the influence of outside forces or factors. An exogenous variable is an external (input) variable that affects but is not affected by the system.

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exponential behavior: a nonlinear behavior mode generated by a relationship in which the change in a stock variable is proportional to the size of the variable itself.

exponential decay: a behavior mode that occurs when the rate of increase or decrease in a variable (usually a stock) is proportional to how far the stock is from its equilibrium, so as to slow down its rate of change. As the stock gets larger (smaller), its increase (decrease) occurs progressively more slowly. The speed of increase or decrease can be described by half-life. The corresponding structure is associated with negative feedback and tends to generate goal-seeking behavior.

exponential delay: a model structure in which a value moves towards the input or target value gradually, in a goal-seeking exponential fashion.

exponential growth (or collapse): a behavior mode that occurs when the rate of increase or decrease in a stock variable is proportional to the size of the stock at that point in time, so as to accelerate its change. As the stock gets larger (smaller), its increase (decrease) occurs progressively more quickly. The speed of increase or decrease can be described by doubling time. The corresponding structure is associated with positive feedback.

feedback: when the effect of a causal impact comes back to influence the original cause of that effect. A feedback loop is a sequence of variables and causal links that creates a closed ring of causal influences. See *reinforcing feedback loop* and *balancing feedback loop*.

feedback loop polarity: a characteristic of feedback loops represented by a positive (+) or negative (−) sign that indicates whether a loop is a reinforcing (positive) or balancing (negative) one. Loop polarity is found by the algebraic product of all signs around a loop.

flow (rate): the movement of quantities between stocks within a system boundary or across the model boundary and thereby into or out of the system (sinks and sources); changes in stocks over time. Flows represent activity, in contrast to stocks, which represent the state of the system.

formalization (specification): the creation of a model from a conceptual model that can be mathematically analyzed, solved or simulated.

frequency of oscillation: a descriptive measure of oscillatory behavior. The number of cycles a system generates in a time unit. The inverse of the period of oscillation.

generic structure: a structure that can be applied across different settings due to having the same fundamental underlying components and relationships. See *system archetype*.

goal-seeking behavior: a behavior mode in which the system moves towards an equilibrium or target condition. The flow that changes the stock value is typically modeled as a fraction of the difference between the equilibrium condition (or target) and the current condition. Therefore, the further the system is from the goal, the more it changes towards that goal and as it approaches the goal the increase or decrease slows. The

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corresponding structure is associated with negative feedback. See *exponential behavior*.

graphical differentiation: the process of using graphs to determine and describe the net flows that impact a stock, based on the given values of the stock over time; the complement of graphical integration.

graphical function: a graph that relates the values of one variable to the values of another. The relation between input and output variables is plotted on a graph. Often used to describe nonlinear relationships.

graphical integration: the process of using graphs to determine and describe how a stock changes over time, based on the behavior of its flows.

group model building: a methodology for building models in which a group or team of people participate actively and simultaneously in building the model.

growth with overshoot: a behavior mode in which a system increases beyond its target or equilibrium condition and then decreases. See *overshoot and collapse*.

half-life: the time required for a stock to move halfway towards its goal. Associated with goal-seeking behavior. The half-life is the converse of doubling time in positive feedback.

high-leverage point (high-leverage parameter): part of a system where small changes can have a very large impact on system behavior and is therefore effective for focusing system design, management attention and resources.

homeostasis: the tendency of organisms to preserve their equilibrium conditions. 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 duration but non-zero finite height and area. Practically, in simulation models, a signal (flow) of specified area lasting for one solution interval and occurring at a specified time.

information delay: a delay that represents the gradual adjustment of information, perceptions or beliefs, or a gradually delayed impact of some variable on a flow or auxiliary variable. Used to model non-conserved variables.

integration: see *accumulation*.

integration error: error generated in computer simulations due to the mathematical method used to approximately compute variable values.

limits to growth: a resource constraint, an external or internal limiting response to growth. An initial growth begins to slow and eventually comes to a halt at the limit, and may even reverse itself and collapse.

linear system: a system in which all relations between variables are mathematically linear. In such systems, the complete behavior can be found by superimposing different behavior modes without interacting with one another.

link polarity: see *causal link polarity*.

Little's law: the relationship among the size of a stock, the net flow into or out of the stock, and the average time material stays in the stock under

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conditions of perfect mixing and when the system is in equilibrium. At equilibrium, the size of the stock is the product of the net flow and the delay.

look-up function: see *table function*.

loop dominance: a characteristic of feedback systems in which a loop is strong enough to determine the behavior mode of a part of the system. In a system with multiple loops, the mathematical relations, magnitudes and algebraic signs of variables determine what kind of behavior is dominant in any time period.

loop polarity: see *feedback loop polarity*.

material delay: a continuous delay that captures the time delay in the flow of conserved material through a process.

mental model: a relatively enduring and accessible, but limited, internal conceptual representation of a system (historical, existing, or projected) whose structure is analogous to the perceived structure of that system. Mental models represent the relationships and assumptions about a system held in a person's mind.

model boundary: see *boundary*.

model credibility (validity): how well a model represents a given problem; a model's suitability for a particular purpose. A model is credible/valid if it can accomplish what is expected of it, as demonstrated by structure and behavior tests.

model justification (validation): the process of developing confidence in a model's credibility and usefulness, performed with tests of model structure similarity to actual structures, simulated behaviors that reflect the behaviors of the system modeled, and ultimately impacts of the model suggestions on actual systems and problems.

negative feedback: feedback that works against deviations from a goal. In isolation or if dominant, negative feedback generates goal-seeking behavior.

nonlinear relationship: a causal relationship between two variables in which the change in the impacted variable is not directly proportional to the change in the impacting variable.

open-loop thinking: approaching a problem with an exogenous perspective, without applying the importance of feedback (endogenous structure).

oscillation: behavior exhibited by a second-order or a higher-order system in which the stock value increases and decreases cyclically over time. Three types of oscillation are: sustained, where the amplitude stays constant; expanding, where the amplitude increases; and dampened, where the amplitude decreases.

overshoot and collapse: a behavior mode in which a system variable increases beyond the equilibrium condition, often destroying its ability to sustain itself, and then collapses to lower equilibrium conditions. See *growth with overshoot*.

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parameters: constant factors in relationships in a model.
period of oscillation: the time duration in which the oscillatory behavior repeats itself. The inverse of the frequency of oscillation.
phase plot: a plot of the behavior of one endogenous variable in relation to another endogenous variable.
pipeline delay: a fixed or discrete-time delay. See *conveyor*.
polarity: see *causal link polarity* or *feedback loop polarity*.
policy: a decision rule or structure that uses information streams to generate decisions.
policy analysis: analysis employed to evaluate policies to alleviate undesirable behaviors of a system. It allows the model builder to compare how a system would react to different policies through simulation.
policy resistance: circumstances in which policies are delayed, diluted or defeated by the unforeseen reactions of various factors and (usually negative) feedbacks in the system.
positive feedback: a structure that produces exponential growth or collapse. Change in one direction results in more and faster change in the same direction.
positive feedback loop: see *reinforcing feedback loop*.
pulse function: see *impulse*.
ramp function: a common input variable that changes linearly over time.
rate: see *flow*.
reference mode: a behavior-over-time graph that depicts how one or more system variables change over time, often used in problem articulation to describe the dynamic hypothesis, and in model validation to test a model's ability to reproduce realistic behavior patterns.
reinforcing feedback loop: a feedback loop in which the sum effect of the causal links tends to strengthen (reinforce) the movement of variable values in a given direction due to positive feedback.
sensitivity analysis: analysis used to determine how responsive model outputs are to changes in specific parameters, or policies or structures. Behavior that changes drastically suggests a critically important factor or high sensitivity. Conversely, if a large change in a parameter value or a structure results in small changes in behavior, that factor is not likely to be central to the dynamics in question; that is, the behavior shows low sensitivity.
simulation: the generation of the behavior of a system with a formal computer model.
sink: see *cloud*.
smoothing: filtering out short-term noise-like fluctuations in a time series to detect or reveal underlying, significant patterns.
solution interval (computation interval, delta time (dt), time step): the interval of time between successive computer calculations used to simulate behavior in a formal model.

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source: see *cloud*.

S-shaped growth: growth that exhibits a behavior like a flat "S" shape. Values initially grow exponentially, then slow down and approach a maximum value. Endogenously caused S-shaped growth is typically generated by a shift in loop dominance from a positive feedback structure to a negative feedback structure.

stability (stable behavior): behavior in which the system moves toward equilibrium conditions after being disturbed or remains within specified limits. In an unstable system or region a disturbance is amplified, leading to increased growth, collapse or oscillation away from equilibrium.

stable equilibrium: a system structure and set of parameter values in which, if the system is moved away from the equilibrium conditions, the system tends to return to those conditions. See also *unstable equilibrium*.

stasis: see *equilibrium behavior*.

state variable: see *stock*.

static: not changing over time; constant. The opposite of dynamic.

steady-state behavior: a behavior pattern that is repetitive or constant over time and in which the behavior in one time period is of the same nature as any other period.

step function (step input): an input (usually for testing purposes) that suddenly changes by a fixed amount and then remains at the new value.

stock (level): an accumulation of quantities in specific locations or conditions in a system. A component of a system that accumulates or drains over time. Stocks are the memory of a system and can only be changed by flows.

stock-and-flow diagram: a visual depiction of the stock, flow and auxiliary (converter) variables in a system and how they are connected.

structure diagram: A diagram that displays the system feedback and accumulation structure.

structure: see *system structure*.

system: a collection of parts that interact in a meaningful, inseparable way to function as a whole.

system archetype: an integrated feedback structure, the resulting behavior mode or modes, and a story of how the structure can create the behavior modes, so as to describe a common problem and potential solutions. A type of generic structure.

system boundary: see *boundary*.

system structure: the way in which system elements are organized or interrelated. The totality of feedback loops, stocks, flows and time delays in the system. The building blocks and connections of a system.

systems thinking: the use of conceptual system models and other tools to improve the understanding of how the feedback, delays and decision-making policies in a system's structure generate the system's behavior over

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time. Systems thinking does not use computer simulation. Systems thinking involves (i) seeing interrelationships and feedback loops instead of linear cause–effect chains, and (ii) seeking processes of change over time rather than events/snapshots. Systems thinking helps people see things on three levels: events, patterns of behavior and system structure.

table function: a numeric table version of a graphical function.

time step: see *solution interval*.

transferable structure: see *generic structure*.

transient behavior: a dynamic response that does not persist. Temporary, short-term behavior, typically between equilibrium conditions.

unintended consequence: an unplanned and typically undesirable side effect of well-meaning intentions and actions, often occurring after a time delay and across an organizational boundary from the intended action.

unstable behavior: behavior over time that does not converge to an equilibrium or remain within specified limits.

unstable equilibrium: a system structure and set of parameter values in which, if the system is moved away from the equilibrium condition, the system tends to move further away from it. Also see *stable equilibrium*.

vicious cycle: a reinforcing loop or amplifying structure that yields undesirable results.

virtuous cycle: a reinforcing loop or amplifying structure that yields desirable results.

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