Glossary

**Action rate** “g(Y/X)” Indicates the variation of Y for each unit of variation of X.

**Active variable,** *X*<sub>t</sub> In the general model of the control system, any variable *X* capable of modifying Y. See Levers.

**Apparatuses** See *Chain of control*.

**Archetypes** Models or patterns that occur continuously, also known as generic structures. “One of the most important, and potentially most empowering, insights to come from the young field of systems thinking is that certain patterns of structure recur again and again. These "systems archetypes" or "generic structures" embody the key to learning to see structures in our personal and organizational lives” (Senge 2006, p. 93).

**Causal loop diagram (CLD)** Model of a system built following systems thinking using arrows to indicate the direction of the causal relationships among the variables. A CLD consists of a system of loops in which all variables are linked by arrows, without there being an initial and a final variable. All the variables are connected. By connecting a number of variables and determining the direction of variation we can build models of every dynamic system, keeping in mind that we must zoom in order to analyze the processes in more detail, in order to identify and connect other important variables.

**Chain of control** The fundamental “machines” or “apparatuses” that represent physical control systems and whose functioning produces the dynamics in the active and passive variables and determines the variance.

- **EFFECTOR**: produces a variation in *X*<sub>t</sub> into the corresponding variation in *Y*<sub>t</sub>.
- **DETECTOR** (sensor or comparator): measures the value of *Y*, compares this with the objective *Y*<sup>*</sup> (or the constraint *Y*<sup>/C_1</sup>), and determines the deviation *E(Y)*.
- **REGULATOR** (or compensator): “activates” the lever *X* taking account of *E(Y)*.
- **INFORMATION TRANSMISSION**: represents the “real” chain of control that produces the “formal” control system.

**Control apparatuses** See *Chain of control*.

**Control discipline** This is based on the hypothesis that control systems occupy a preeminent place among all types of systems. Even though we are not
accustomed to “seeing them,” they are all around us, and only their presence makes our world, life, society, and our very same existence possible, producing an ordered and livable world, erecting barriers against disorder, and guiding the dynamics of the system toward equilibrium states. The control discipline teaches us how to recognize control systems, build models, simulate their behavior, and use these to improve our knowledge and our behavior. I would propose naming the control discipline as the Sixth Discipline, or the control discipline of the individual, the collectivity and the organizations in the ecosystem; this is the discipline of the present and future of our world.

**Control objective** Each specific value, $Y^*$, or each trajectory of values, $Y^*_t$, however formed, which are set as values that the objective variable, $Y_t$, must achieve or maintain. The control objective can also mean the constraint which is not to be exceeded or the limit to be respected. If $Y^*$ is a vector of values, $[Y^*]$, then the control system is multi-objective and the system manager must establish a control policy. The objectives can be both quantitative and qualitative.

**Control process** See control system (concept).

**Control system (concept)** Any set of apparatuses, logical or technical (algorithm or machine, rule or structure, etc.), which, for a set of instants, perceives $E(Y)_t$, calculates and assigns the values $X_t$, and produces the appropriate $Y_t$ to gradually eliminate, when possible, the error $E(Y)_t = Y^* - Y^*_t$ at instant $t^*$. The control system is repetitive and functions by means of action ($X$ acts on $Y$) and reaction ($E$ ($Y$) acts on $X$ through $Y$), activating a closed-loop or feedback control. With a certain number of iterations on the control lever, it tries to achieve the objective (goal-seeking systems) or to respect the constraints or limits (constraint-keeping systems) by gradually eliminating the deviation $E(Y)$. Control systems have a logical structure and a technical structure. The former consists of the logical relationships between variables, always arranged in one or more balancing loops in order to develop feedbacks between $[X]$ and $[Y]$; the latter is formed by the chain of control.

**Control system (logical structure)** The general model of a control system is a balancing loop, which consists of the elements shown in the model.
Control system (technical structure) The set of apparatuses that constitute the physical control systems. See Chain of control.

Control variable Synonym for lever.

Cybernetic control system An automatic control system guided toward a fixed (or even variable) objective determined by an outside governor, but guided by a manager within the chain of control.

Delay Abnormal or unexpected length of action of $X$ on $Y$. There are three types of delay:

- **Action delay** (or response delay), which slows the response of $Y$ to an impulse from $X$; this depends on the effector.
- **Detection delay** (or informational delay), which acts on our perception and on the measurement of the error.
- **Regulation (decisional) delay**, which occurs when the regulator does not respond promptly to the error.

Deviation See Error, $E$.

Direction of the causal link The arrow that indicates which variable is the cause and which the effect in a causal relation typical of systems thinking. The cause variable ($X = \text{input}$) is written at the tail of the arrow; the effect variable ($Y = \text{output}$) at the head (first arrow). If the causal link shows the opposite direction (second arrow), then $X$ is the effect and $Y$ the cause.

\[ X \rightarrow Y \quad X \leftarrow Y \]

Direction of the variations This indicates the concordance in the signs of the variations between two variables, $X$ and $Y$, which are linked in the same direction. Variations of $X$ are linked to those of $Y$ in the same direction ($\rightarrow$) if $Y$ increases/diminishes when $X$ increases/diminishes (first arrow). Variations of $X$ are linked to $Y$’s variations in the opposite direction ($\leftarrow$) if $Y$ diminishes/increases when $X$ increases/diminishes, thus presenting the opposite sign of variation (second arrow).

\[ X \quad \rightarrow \quad Y \quad \leftarrow \quad X \quad \leftarrow \quad Y \]

Discipline Following Peter Senge: “A discipline is a developmental path for acquiring certain skills or competencies. [...] To practice a discipline is to be a lifelong learner. You “never arrive”; you spend your life mastering disciplines” (Senge 2006, p. 10).

Distance See Error, $E(Y)$.

Disturbances, $D$ In the general model of the control system, each variable, $D_t$, external to the system, that alters the values of $Y$, regardless of the values of $X$. Disturbances can affect all the apparatuses that make up the control chain.
Error, $E(Y)$ (distance, deviation, gap, variance) In the general model of the control system, the variable “$E(Y)_t = \Delta(Y)_t = Y^*_t - Y_t$,” which represents the distance or deviation between the values of the objective $Y^*_t$ and those of “$Y_t$.”

Feedback control systems Control system in which the control of $Y_t$ is achieved through decisions to vary $X_t$ over a succession of repetitions of the control cycle.

Feedforward control systems, also called decision or one-shot control systems Control system which try to reach the objective through a single cycle, and thus through a single initial decision made based on precise calculations; however, when an error is detected in the attempt to achieve $Y^*_t$ the manager cannot correct this through other regulating decisions to eliminate the error. They are typically systems that “fire a single shot” to achieve the objective.

Forrester, Jay Founder of system dynamics, in his fundamental work industrial dynamics (1961).

Gap See Error, $E$.

Goals In the general model of the control system, any specific value, $Y^*$, or any trajectory of values, $Y^*_t$, however defined, that must be reached and possibly maintained by the control variables. If $Y$ is a vector $[Y^*]$, then the control system is a multi-objective system and the manager must establish a policy of control. Goals can be quantitative or qualitative.

Governance of the control system The process through which a subject, the governor, determines the objective $Y^*$ or the vector $[Y^*]$ that management must achieve.

Interfering control systems Two or more control systems interfere with each other if they are interrelated, so that the values of $Y_A$ of a control system $A$ determine and are determined by the values of $Y_B$ of other interfering control systems. The interference can also occur in both directions.

iThink, Stella See simulations softwares.

I/O systems See type of control systems.

Levers In a control system, each control variable, $X$, which—through some process—acts on the variable to control, $Y$, in order to eliminate $E(Y)$. If $X$ is a vector of variables $[X]$, then the system is multi-lever and the manager of the system should establish a strategy for the control.

Loop A closed causal chain formed by a circular link between two variables, $X$ and $Y$, which can be linked by two opposite directions with respect to the causal link. Loops can be basic, when there are only two variables, or compound, when more than two variables are joined in a circular link. There are only two basic types of loop: reinforcing loops $[R]$, which produce a reciprocal increase or reduction—in successive repetitions of the system’s cycle—in the values of the two variables having reciprocal causal links; and balancing loops $[B]$, which maintain relatively stable the values of the connected variables.
Manager of the control system  The subject that maneuvers the control system in order to achieve the goals established by the governance, by adjusting the control levers and deciding on the strategy and policy to be adopted. The subject can be external to the control system or internal to the system itself, replacing some apparatus.

Multi-lever control systems  See type of control systems.

Multi-objective control systems  See type of control systems.

Objective variable, $Y$  Synonym for variable to control.

ON/OFF systems  See type of control systems.

Open causal chain  Connection among a succession of several variables entailing some causal link.

$$X \xrightarrow{s/o} Y \xrightarrow{s/o} Z$$

Passive variable, $Y_t$  Synonym for variable to control.

Period of control  The number of intervals, over the typical time frame of the system, which are necessary to stably achieve the objective in the absence of outside disturbances.

Pluri-lever  Synonym for multi-lever.

Pluri-objective  Synonym for multi-objective.

Policy (in control)  In multi-objective systems, policy represents the order of priority in achieving different objectives.

Powersim  See simulation softwares.

Problem solving (PS)  The process through which we seek the solution of any problem. The PS can be interpreted as a control system, because a problem can be interpreted as an error or deviation, $E(Y)$, between two states—current ($Y$) and desired ($Y^*$)—of a variable, $Y$ (which we assess as useless or harmful) and that we want to eliminate or reduce as far as possible by acting on the variables $X$ that can change $Y$. In PS, solving the problem means designing the control system in order to identify the lever $X_t$, which, by producing the values $Y_t$—taking into account the states of nature, $D_t$—enables you to eliminate $E(Y)$. Notice that the deviation is not the problem but the symptom that is revealed. The problem lies in the malfunctioning of the system that generates the symptom.

Reaction rate “$h(X/Y)$”  Indicates the variation in $X$ for each unit of variation in $Y$; usually “$h = 1/g$” if the system is perfectly symmetrical to the control.

Reaction time “$r(X/Y)$” (time to eliminate the error)  Indicates the speed with which the control system moves toward the objective; a reaction time of $r = 1$ indicates an immediate but sudden control; a reaction time $r > 1$ makes the control slower but smoother.

Regulation  In a broad sense, this is synonymous with control. In a strict sense, it is a process that assigns values to the control levers, based on the deviation and the reaction rate.

Senge, Peter  He is considered to be the popularizer of systems thinking, with his fundamental text: *Fifth Discipline: The Art and Practice of the Learning Organization* (Senge, 1990).
Simulation softwares  Software programs (simulation tools) created to simulate the behavior of systems with a high number of variables. I would mention:

- Powersim (www.powersim.com).
- MyStrategy and SYSDEA (www.strategydynamics.com/mystrategy/).
- Vensim (www.vensim.com).
- Excel Software (www.excelsoftware.com/).

Sixth discipline See control discipline.

Stock and flow diagram (SFD) or level and flow structure (LFS) System dynamics theory assumes that a dynamic system can normally be viewed as composed of stock or level variables and of flow or rate variables that change the amount of stock. The flow variables that increase the stock (in various ways to be defined) can be considered as inputs; those that decrease it, as outputs. Several simulation softwares are based on this logic.

Strategy (in control) Control with two independent control variables always implies a strategy that defines an order of priorities regarding action on the control “levers.”

Symptom In problem solving, understood as a process of control, this indicates the meaning that the manager gives to the deviation $E(Y)$.

System (from a systems thinking perspective) Systems thinking defines a “system” as a unitary set of interconnected variables possessing its own autonomy, which is capable of producing emerging macro-dynamics that do not coincide with any of the micro-dynamics of the individual variables or their partial subsystems.

System dynamics The technique for translating the qualitative models (causal loop diagrams) into quantitative (stock and flow diagrams) ones that, by quantifying the initial values of the temporal variables and specifying the variation parameters, are able to generate the dynamics of those variables. This technique was developed as industrial dynamics by Jay Forrester in the 1960s.

Systems archetypes See Archetypes.

Systems thinking Discipline that recommends that we observe the world as a system of dynamic systems, recursive and repetitive—often with memory—each composed of interacting and interconnected variables. Systems thinking was presented by Peter Senge in The Fifth Discipline: The Art and Practice of the Learning Organization (Senge, 1990). Systems thinking does not only represent a specific technique for constructing models but also a mental attitude, an approach, a logic, and a language. The systems are represented through qualitative models called causal loop diagrams.

Systems thinking laws There are two fundamental laws that derive from systems theory:

1. The Law of Structure and Component Interaction: in order to understand and control the dynamics in the world it is necessary to identify the systemic structures that make up this world. Corollary: in observing a dynamic world, the “ceteris paribus” assumption is never valid.

2. Law of Dynamic Instability: expansion and equilibrium are processes that do not last forever; they are not propagated ad infinitum. Sooner or later stability is disturbed. Sooner or later the dynamics are stabilized.
Type of control systems (CSs) Minimal typology:

- **Artificial** and natural CSs; Control systems designed and constructed by man are artificial or manmade control systems.
- Manually controlled systems, automatic CSs, or cybernetic systems. Systems which involve continuous manual control by a human operator are manually controlled control systems; control systems which incorporate the manager in their chain of control can be defined as automatic control systems.
- **Quantitative** CSs; the control is quantitative if the variable $Y_t$ represents a quantitative measure and the objective is a value that $Y_t$ must reach (set reference) or a set of values to be achieved (track reference).
- **Qualitative** CSs; systems in which both the variable $Y_t$ and the objective $Y^*$ are qualitative in the broadest sense of the term (objects, colors, flavors, forms, etc.).
- **Attainment** CSs; I shall define attainment control systems as those control systems that act to “attain” a quantitative objective, independently of the control context.
- **Recognition** and identification CSs; a general class of qualitative control system where the qualitative variable to control, $Y_n$, represents an “object” that the system scans in order to recognize or identify a “model-objective,” $Y^*$.
- **Steering** CSs (also called “two-way” systems); systems acting to achieve the objective through positive or negative adjustments of $Y_t$ that converge toward $Y^*$, independently of the initial value of $Y$.
- **Halt** CSs (also called “one-way” systems); systems in which $Y^*$ is by nature a non-exceedable limit or constraint.
- **Collision, anti-collision, and alignment** CSs. Two interfering systems whose objectives are dynamic and tend to coincide are defined as “collision systems.” If the objectives tend not to coincide they are defined as “anti-collision systems.” If the objectives maintain a constant distance they are defined as “alignment systems.”
- **Goal-seeking** CSs. Those in which $Y^*$ represents a quantitative objective: to achieve a result, or to attain or maintain operating standards.
- **Constraint-keeping** CSs, in which $Y^*$ represents a constraint to respect or a limit not to be exceeded; these are usually halt systems.
- **Regulator** CSs, where $Y^*$ (objective or constraint) is a specific value (goal, constraint, or limit) that $Y_t$ must reach and maintain over time.
- **Tracking** CSs, or path systems, where $Y^*$ (goal, constraint, or limit) is a trajectory, that is, a sequence of values, $Y^*_t$, however formed, which $Y_t$ must follow.
- **Multi-lever** or pluri-lever CSs, if the control is via a vector of levers $[X]$; if $[X] = X$, the system is single lever.
- **Independent levers** CSs; multi-lever systems whose levers can be adjusted independently; dependent lever systems, if the levers allow only variations in the opposite direction.
- **Multi-objective**, or pluri-objective CSs; if the control is a vector of objectives $[Y^*]$; if $[Y^*] = Y^*$, the system is single objective, in which case $[Y^*]$ must be equivalent to $[Y]$.
- **Independent objectives** CSs; multi-objective systems whose objectives can be achieved independently; bound objective systems if a goal impedes the achievement of other goals.
- CSs with or without delays.
- CSs of direct or indirect control; a control system is direct if $X$ and $Y$ vary in the same direction “s”; otherwise, it is indirect.
- Autonomous, or interfering CSs; interfering systems are those whose values of $Y$ are influencing each other.
- CSs with fixed or variable objectives (or systems of pursuit); in the former, the variable must achieve a passive constant, $Y^*$; in the latter, the target $Y_t^*$ represents a variable that depends on “t,” $Y$ and/or on $X$.
- On/off CSs. Halt systems that achieve $Y^*$ by activating [on] the $X_t$ lever for a set time, $T^*$, until the system stops [off], only to start up again when the disturbances, $D$, once again produce an error of a set amount, $\Delta E^*$.
- I/O CSs. Particular steering systems that try to achieve the objective $Y^*$ by “turning on” [I] the $X$ lever once or several times and for a given length of time, which is decided on each occasion by the manager, in order to obtain a fixed value $\Delta Y$, after which the lever is “turned off” [O], thereby eliminating $E(Y)$. The lever is once again turned on when $D$ produces another error.
- Tendential CSs. In these systems $Y_t$ represents a time series (for example, the scores over time in an archery competition by participants trying to improve their performance) which, through some statistical procedure (trend, moving average, etc.), aims to ensure that $Y_t$ tends toward a value-objective, $Y^*$, through a statistical measure.
- Combinatory CSs. Systems in which each $Y_t$ represents a synthetic value, $[Y_{tN}]$, derived from the combination (to be specified in some manner) of the values of a vector of $N$ variables, each of which is controlled by its own control variable.

**Variable to control** Any variable $Y$ controlled by $X$ in order to achieve a value $Y^*$ set as an objective.

**Symbols (minimal)**

$X_t$ Values of the control lever  
$Y_t$ Values of the variable to be controlled  
$Y^*$ Fixed objective  
$Y_t^*$ Variable objective  
$D_t$ External disturbance values  
$\Delta(Y)_t = Y^* - Y_t$ (or $E(Y)_t$) Deviation, gap, error for systems $[s \rightarrow o \rightarrow s]$  
$\Delta(Y^*)_t = Y_t - Y^*$ (or $E(Y^*)_t$) Deviation, gap, error for systems $[s \rightarrow s \rightarrow o]$  
$g(Y/X)$ Action rate  
$h(X/Y)$ Reaction rate  
$r(X,Y)$ Reaction time
References


1 We know nothing at all. All our knowledge is but the knowledge of schoolchildren. The real nature of things we shall never know (Albert Einstein).

As this book deals with Control Systems considered from various points of view, a complete bibliography may appear to be boundless. Here I have only listed the works cited in the book. All the sites mentioned have been visited in April 2014. In order to make it easier for the reader to directly examine the sources, I have tried, whenever possible, to indicate those sources available online.
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