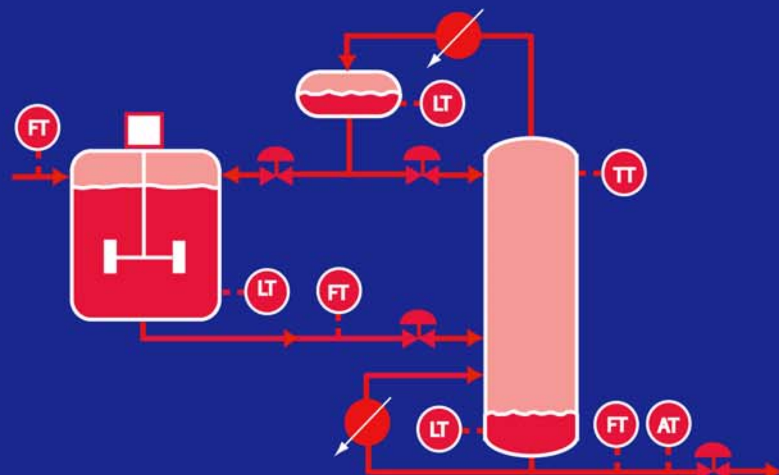
Process Dynamics and Control

Second Edition



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Process Dynamics

a) Refers to unsteady-state or transient behavior.

b) Steady-state vs. unsteady-state behavior

   i. Steady state: variables do not change with time

   ii. But on what scale? cf., noisy measurement

c) ChE curriculum emphasizes steady-state or equilibrium situations:

   i. Examples: ChE 10, 110, 120.

d) *Continuous processes*: Examples of transient behavior:

   i. Start up & shutdown

   ii. Grade changes

   iii. Major disturbance: e.g., refinery during stormy or hurricane conditions

   iv. Equipment or instrument failure (e.g., pump failure)

e) *Batch processes*

  i. Inherently unsteady-state operation

  ii. Example: Batch reactor

    1. Composition changes with time

    2. Other variables such as temperature could be constant.

Process Control

a) Large scale, continuous processes:

  i. Oil refinery, ethylene plant, pulp mill

  ii. Typically, 1000 – 5000 process variables are measured.

    1. Most of these variables are also <u>controlled</u>.

Process Control (cont'd.)

iii. Examples: flow rate, *T*, *P*, liquid level, composition

iv. Sampling rates:

1. Process variables: A few seconds to minutes
2. Quality variables: once per 8 hr shift, daily, or weekly

b) Manipulated variables

i. We implement "process control" by manipulating process variables, usually flow rates.

1. Examples: feed rate, cooling rate, product flow rate, etc.

ii. Typically, several thousand manipulated variables in a large continuous plant

Process Control (cont'd.)

c) Batch plants:

   i. Smaller plants in most industries

      1. Exception: microelectronics (200 – 300 processing steps).

   ii. But still large numbers of measured variables.

d) Question: How do we control processes?

   i. We will consider an illustrative example.

1.1 Illustrative Example: Blending system

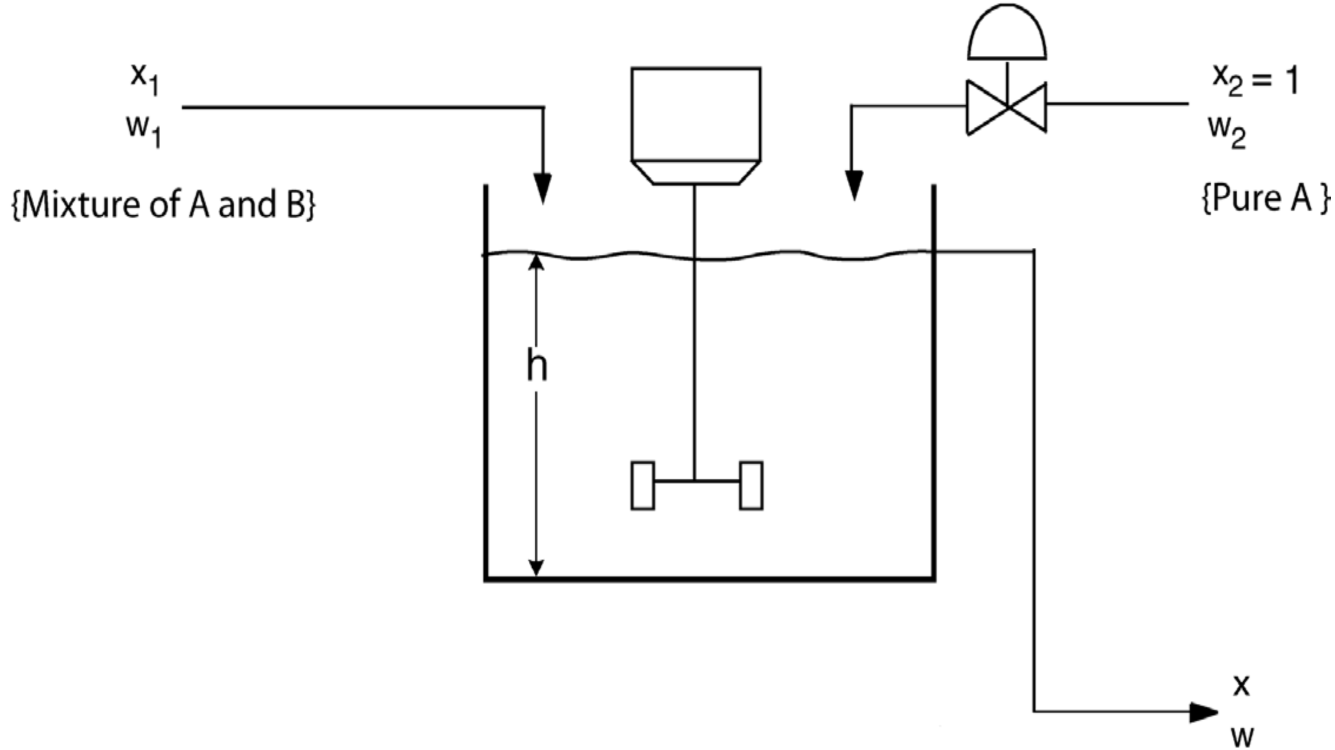

Figure 1.3. Stirred-tank blending system.

Notation:

- w_1, w_2 and w are mass flow rates
- x_1, x_2 and x are mass fractions of component A

Assumptions:

1. w_1 is constant
2. x_2 = constant = 1 (stream 2 is pure A)
3. Perfect mixing in the tank

Control Objective:

Keep x at a desired value (or "set point") x_{sp}, despite variations in $x_1(t)$. Flow rate w_2 can be adjusted for this purpose.

Terminology:

- Controlled variable (or "output variable"): x
- Manipulated variable (or "input variable"): w_2
- Disturbance variable (or "load variable"): x_1

Design Question. What value of $\bar{w}_2$ is required to have $\bar{x} = x_{SP}$?

Overall balance:

$$0 = \bar{w}_1 + \bar{w}_2 - \bar{w} \qquad (1\text{-}1)$$

Component A balance:

$$\bar{w}_1\bar{x}_1 + \bar{w}_2\bar{x}_2 - \bar{w}\bar{x} = 0 \qquad (1\text{-}2)$$

(The overbars denote nominal steady-state design values.)

- At the design conditions, $\bar{x} = x_{SP}$. Substitute Eq. 1-2, $\bar{x} = x_{SP}$ and $\bar{x}_2 = 1$, then solve Eq. 1-2 for $\bar{w}_2$:

$$\bar{w}_2 = \bar{w}_1 \frac{x_{SP} - \bar{x}_1}{1 - x_{SP}} \qquad (1\text{-}3)$$

- Equation 1-3 is the design equation for the blending system.
- If our assumptions are correct, then this value of $\overline{w}_2$ will keep $\overline{x}$ at x_{SP}. But what if conditions change?

Control Question. *Suppose that the inlet concentration* x_1 *changes with time. How can we ensure that x remains at or near the set point* x_{SP} *?*

As a specific example, if $x_1 > \overline{x}_1$ and $w_2 = \overline{w}_2$, then $x > x_{SP}$.

Some Possible Control Strategies:

Method 1. *Measure x and adjust* w_2.

- Intuitively, if x is too high, we should reduce w_2;

Chapter 1

- Manual control vs. automatic control
- Proportional feedback control law,

$$w_2(t) = \bar{w}_2 + K_c\left[x_{SP} - x(t)\right] \qquad (1\text{-}4)$$

1. where K_c is called the controller gain.
2. $w_2(t)$ and $x(t)$ denote variables that change with time t.
3. The change in the flow rate, $w_2(t) - \bar{w}_2$, is proportional to the deviation from the set point, $x_{SP} - x(t)$.

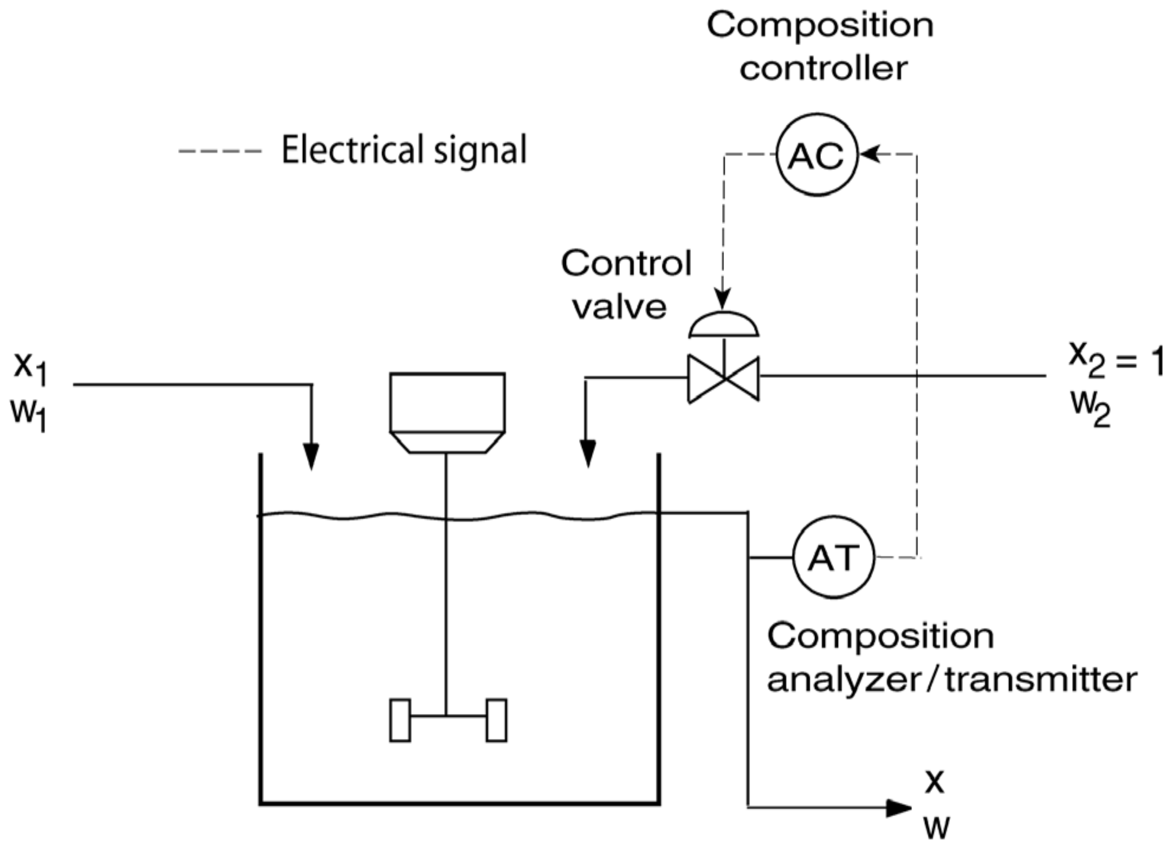

Figure 1.4. Blending system and Control Method 1.

Method 2. *Measure x_1 and adjust w_2.*

- Thus, if x_1 is greater than $\bar{x}_1$, we would decrease w_2 so that $w_2 < \bar{w}_2$;

- **One approach**: Consider Eq. (1-3) and replace $\bar{x}_1$ and $\bar{w}_2$ with $x_1(t)$ and $w_2(t)$ to get a control law:

$$w_2(t) = \bar{w}_1 \frac{x_{SP} - x_1(t)}{1 - x_{SP}} \quad (1\text{-}5)$$

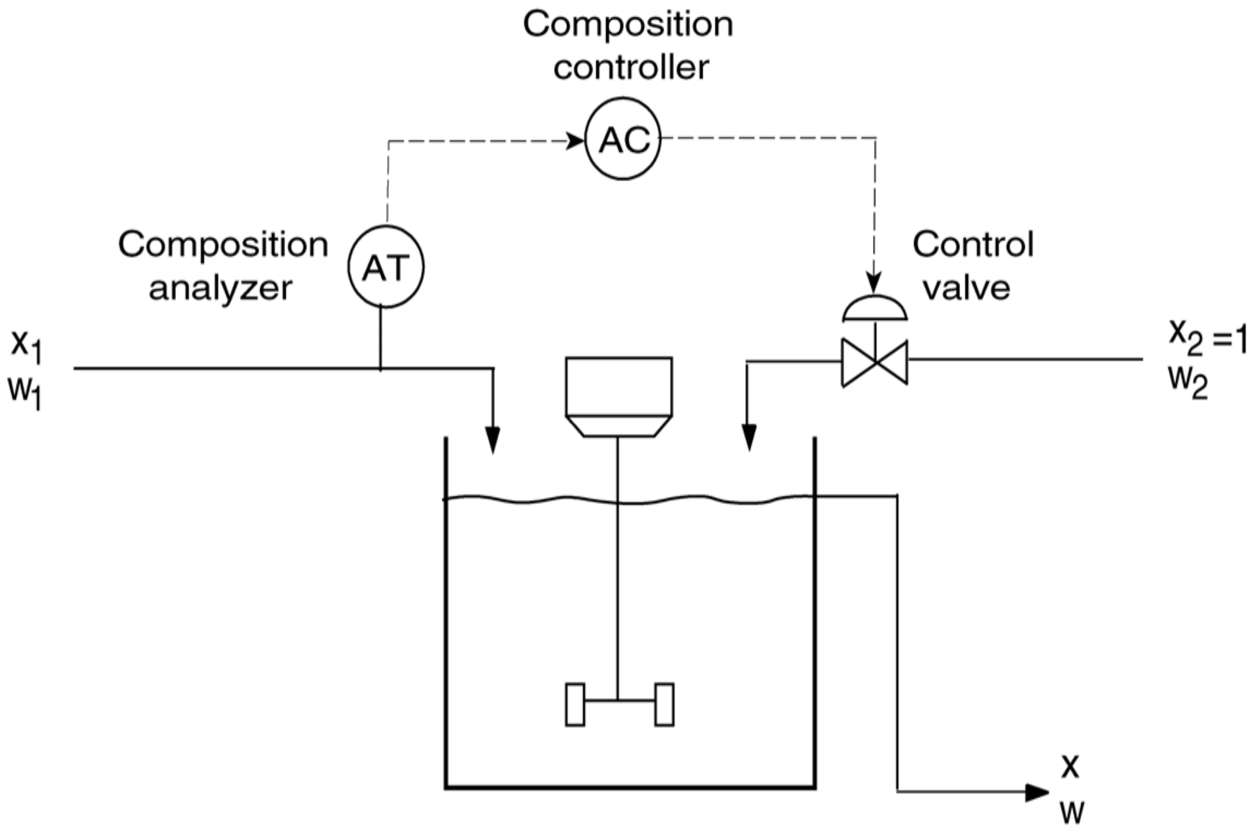

Figure 1.5. Blending system and Control Method 2.

- Because Eq. (1-3) applies only at steady state, it is not clear how effective the control law in (1-5) will be for transient conditions.

Method 3. *Measure x_1 and x, adjust w_2.*

- This approach is a combination of Methods 1 and 2.

Method 4. *Use a larger tank.*

- If a larger tank is used, fluctuations in x_1 will tend to be damped out due to the larger capacitance of the tank contents.

- However, a larger tank means an increased capital cost.

1.2 Classification of Control Strategies

Table. 1.1 Control Strategies for the Blending System

Method	*Measured Variable*	*Manipulated Variable*	*Category*
1	x	w_2	FB[a]
2	x_1	w_2	FF
3	x_1 and x	w_2	FF/FB
4	-	-	Design change

Feedback Control:

- **Distinguishing feature:** measure the controlled variable

- It is important to make a distinction between *negative feedback and positive feedback*.
  - Engineering Usage vs. Social Sciences
- **Advantages:**
  - Corrective action is taken regardless of the source of the disturbance.
  - Reduces sensitivity of the controlled variable to disturbances and changes in the process (shown later).
- **Disadvantages:**
  - No corrective action occurs until after the disturbance has upset the process, that is, until after x differs from x_{sp}.
  - Very oscillatory responses, or even instability…

Feedforward Control:

- Distinguishing feature: measure a disturbance variable

- **Advantage:**
  - Correct for disturbance before it upsets the process.
- **Disadvantage:**
  - Must be able to measure the disturbance.
  - No corrective action for unmeasured disturbances.

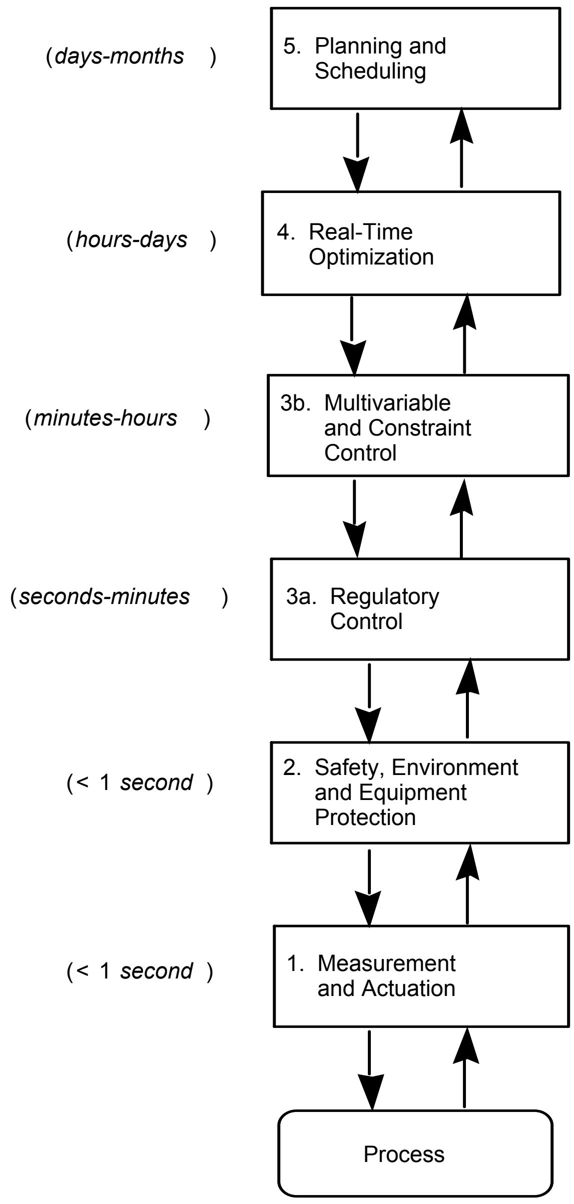

Figure 1.7 Hierarchy of process control activities.

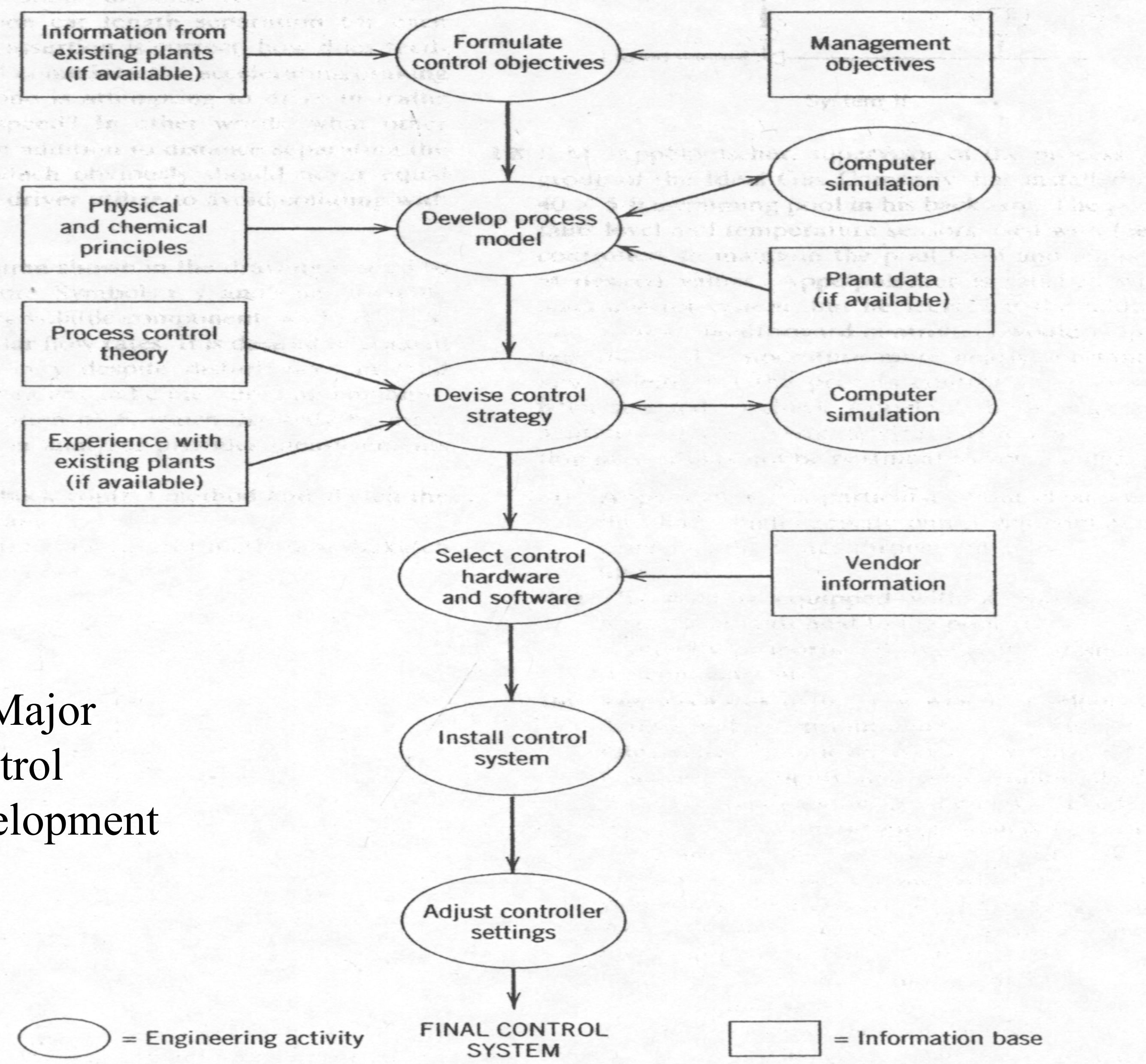

Figure 1.9 Major steps in control system development