Toilet level - The sensor is the float. The actuator is the valve on the water line. The controller is the linkage between the float and the valve. The process is the water in the toilet bowl.

Hitting a tennis ball -The sensor is the tennis player's eyes. The actuator is the tennis player's arm and the tennis racket. The controller is the tennis player's brain. The process is the trajectory of the tennis ball.

Riding a bicycle - The sensors are the driver's eyes and sense of balance. The actuator is the driver's hands and arms. The controller is the driver's brain. The process is the rider and the bicycle.

1.29 There are also a wide range of examples of these control characteristics.

a. Disturbance :

Room thermostat - opening an outside door
Automobile AC- driving from sunlight into a rain shower
Oven temperature- opening the oven door
Car thermostat - going up a long steep hill
Toilet level- flushing the toilet
Hitting a tennis ball - a gust of wind
Riding a bicycle - a gust of wind from the side

b. Deadtime (It is easy to confuse lag with deadtime. Lag is characterized by an exponential approach while deadtime results in a delay.) :

Room thermostat - when the thermostat switch closes, it can take 10 to 30 seconds before the heating/cooling unit turns on.

Toilet level- looseness in the linkage between the float and the value can behave as deadtime in the feedback of the measured level.

c. Process Constraint:

Room thermostat - the maximum heating or cooling rate available
Automobile AC - minimum AC temperature
Oven temperature - maximum heating rate
Car thermostat - when the thermostat is fully open
Toilet level - when the water addition valve is wide open
Hitting a tennis ball - the reaction time of the tennis player
Riding a bicycle - the minimum turning radius of the bicycle

d. Coupling (Coupling requires a MIMO process):

Riding a bicycle to maintain course and speed. Corrections for speed can result in deviations in the course and vice versa.

Hitting a tennis ball for trajectory and speed can result in coupling between hitting the ball for trajectory and speed.

e. Lag

The amount of lag is indicated by the time it takes an oven to heat up after it is turned on.

The amount of lag is indicated by the time required for a room to warm or cool in response to a change in the thermostat setting.

1.30 There are a wide variety of industrial process control examples including heat exchangers, distillation columns, levels in vessels, drying systems, gas transmission systems, polymer extruders, furnaces, boilers, conveyor systems, reactors, municipal waste treatment systems, solids processing processes, etc. The control system for each of these processes will have an actuator, a process, a sensor, and a controller.

1.31 Examples of SISO processes used in industry include temperature control of the outlet temperature from a heat exchanger, control of a level in a tank, a pressure controller on a vessel, a speed controller on a mixer, pH control of wastewater, and a composition controller on a mixer. Examples of MIMO processes include a two product distillation column, a crude fractionator where the composition of five to seven products are controlled, and reactors where temperature and composition are controlled simultaneously.

1.32 The process for the control loop shown in Figure 1.7 is the part of the system that is involved with causing changes in the outlet temperature of the product stream for changes in the valve position of the control valve on the steam line. Therefore, the process for this system is the line from the control valve to the exchanger, the entire heat exchanger except the entrance compartment for the feed, and the product line from the exchanger to the temperature sensor.

1.33 The process for the accumulator for the column in Figure 1.14, is the liquid in the accumulator. A disturbance is a change in the inlet flow rate to the accumulator, a change in the distillate flow rate, or a change in the reflux flow rate.

1.34 The process for the bottom product composition loop is the entire distillation column. Disturbances include changes in the feed rate, feed composition, steam enthalpy, and changes in the temperature of the heat transfer fluid used in the overhead condenser.

1.35 For process control, the manipulated variables are adjusted in order to keep the controlled variables at or near their setpoints. For process optimization, the optimizer chooses the setpoints for the control loops so that the best economic performance of the process results. For the economic optimization of a distillation column, it is usually a compromise between the separation provided by the column and the usage of utilities, such as process steam. The optimizer determines the optimum tradeoff between utility

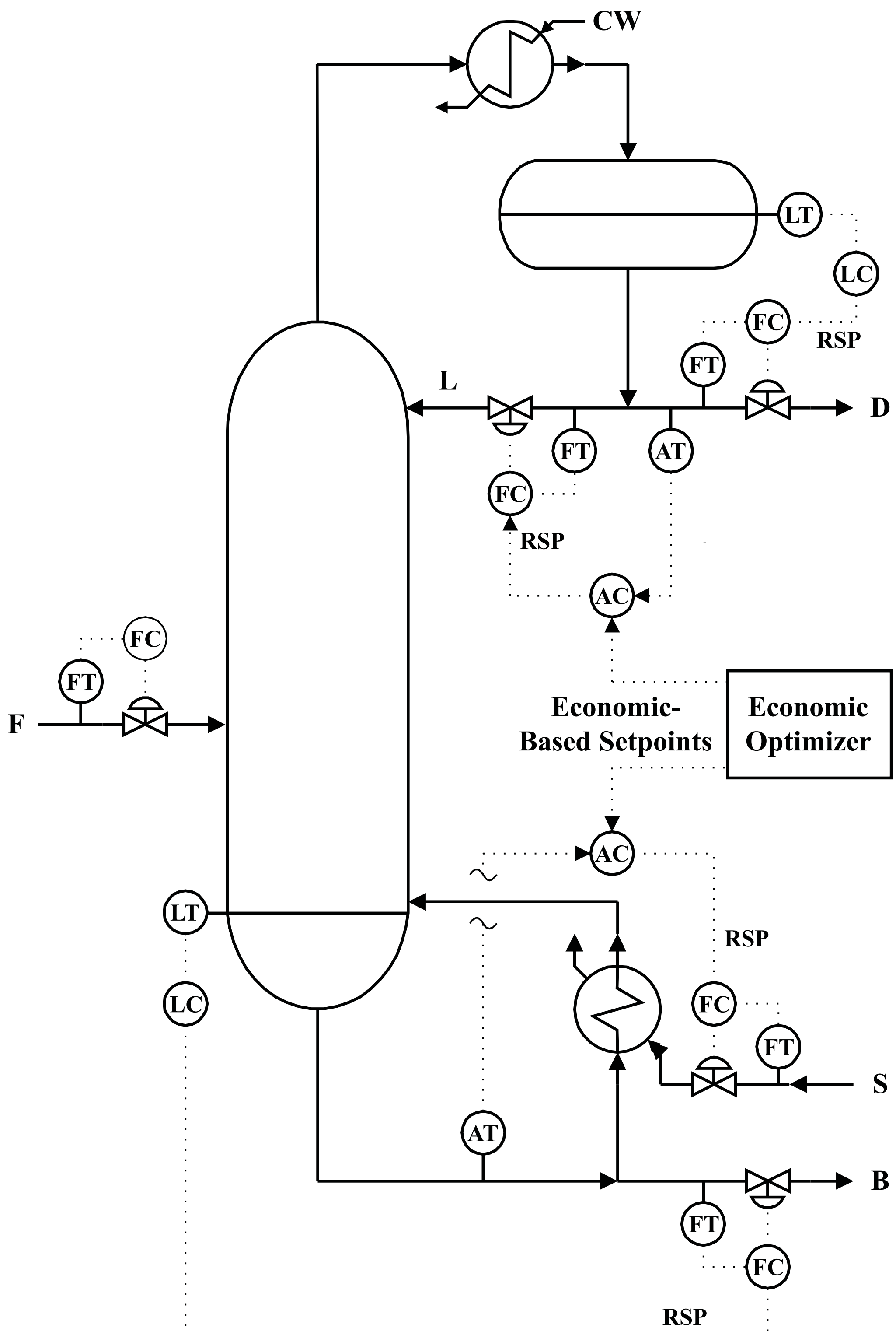

Figure P1-36 Schematic of a distillation column with control and optimization.

usage and product purities and expresses the result as setpoints for the product compositions. These setpoints are then applied by the control loops on the product compositions.

1.36 (a) $$\Phi = D V_p + B(1-x)V_b + B x V_p - S V_s$$

where Φ - the economic objective function ($/time)

D - the flow rate of distillate product (mass/time)

B - the flow rate of the bottoms product (mass/time)

x - the mass fraction of propane in the bottoms product

V_p - the value of propane fuel ($/mass)

V_b- the value of butane ($/mass)

S - the flow rate of steam to the reboiler (mass/time)

V_s - the cost of steam ($/mass)

(b) The schematic for the integrated optimizer/controller for the distillation column is shown in Figure P1-36.

1.37 Several examples of everyday optimization problem:

- Optimize the way you spend your monthly income. Objective function is a combination of savings and money for entertainment. Constraints include fixed expenses such as rent, car payment, tuition, etc. Some of the degrees of freedom include the type and amount of food, how you use your utilities in your apartment or room, how much and where you eat out, etc.

-Optimize the route to class. The objective function is a combination of the time to get to class and how enjoyable the route is. The degrees of freedom include the mode of transportation, the speed, and the route. Constraints include the speed limit and the restrictions on certain types of transportation, e.g., bicycles can travel on certain paths that automobiles cannot.

1.38 Maximize the feed rate processed by the separation train.