Control and Automation – An Introduction

Part 1

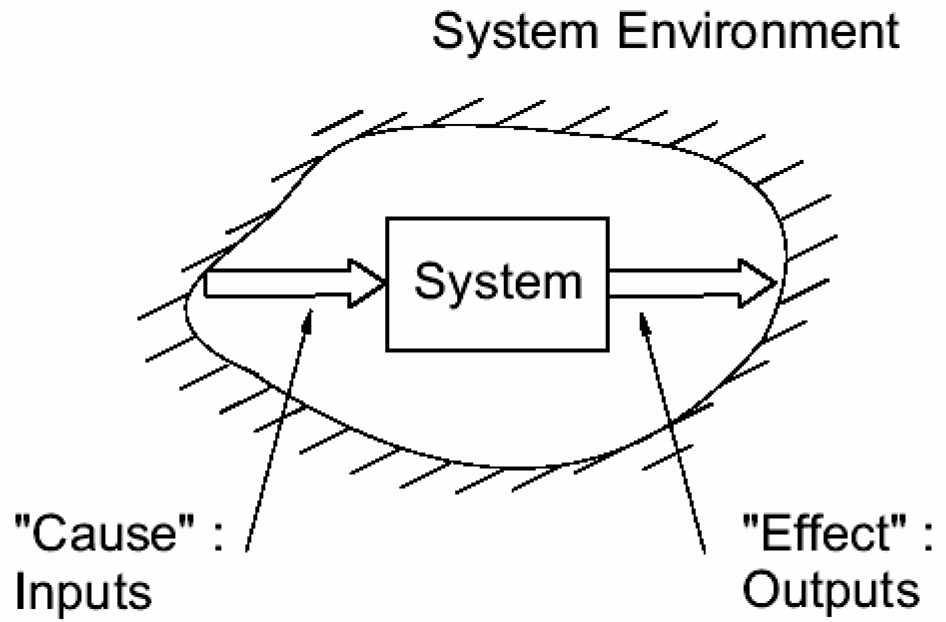
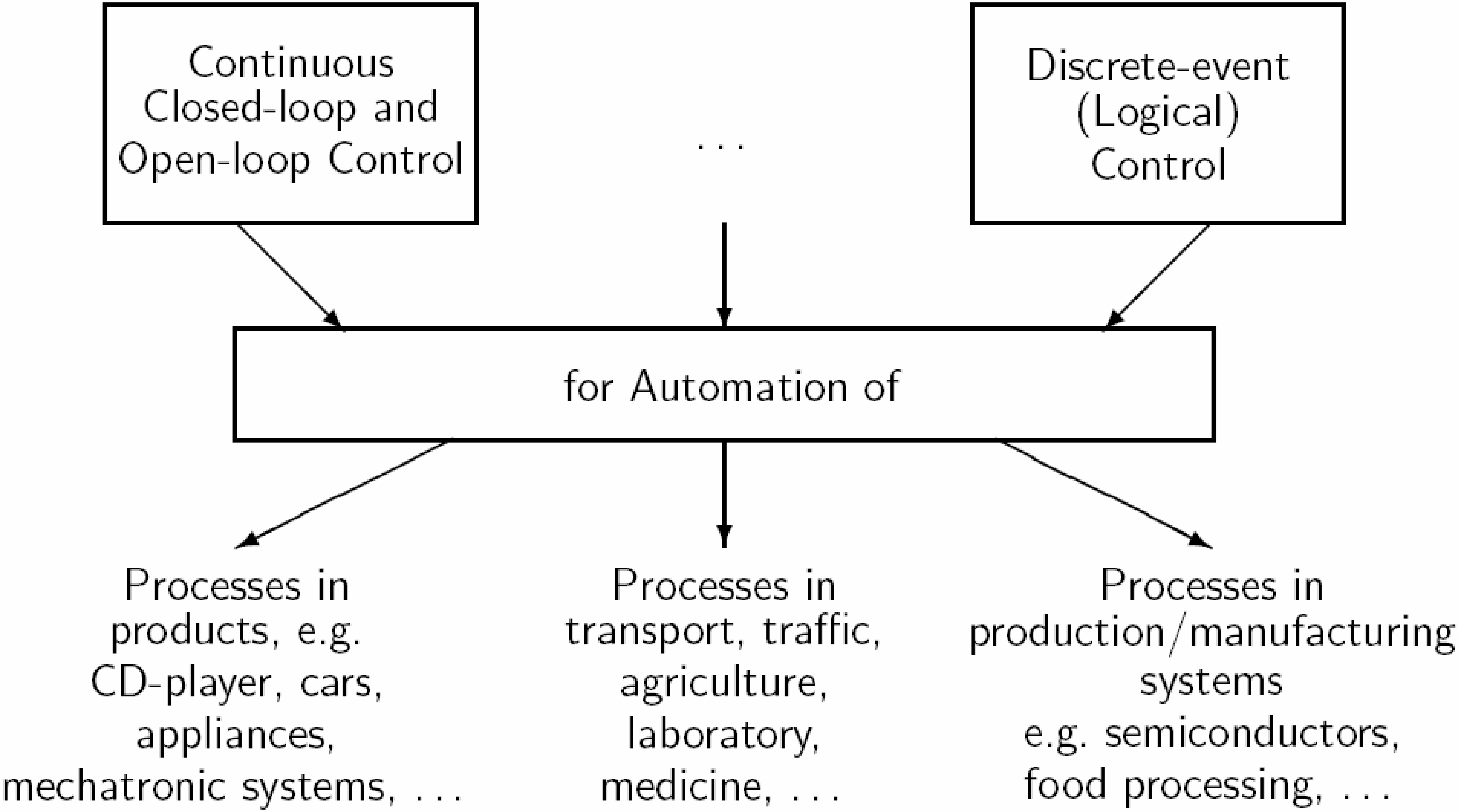


Figure I.1: System and system environment



Continuous
Closed-loop and
Open-loop Control

. . .

Discrete-event
(Logical)
Control

for Automation of

Processes in
products, e.g.
CD-player, cars,
appliances,
mechatronic systems, . . .

Processes in
transport, traffic,
agriculture,
laboratory,
medicine, . . .

Processes in
production/manufacturing
systems
e.g. semiconductors,
food processing, . . .

Figure I.2: Control and automation

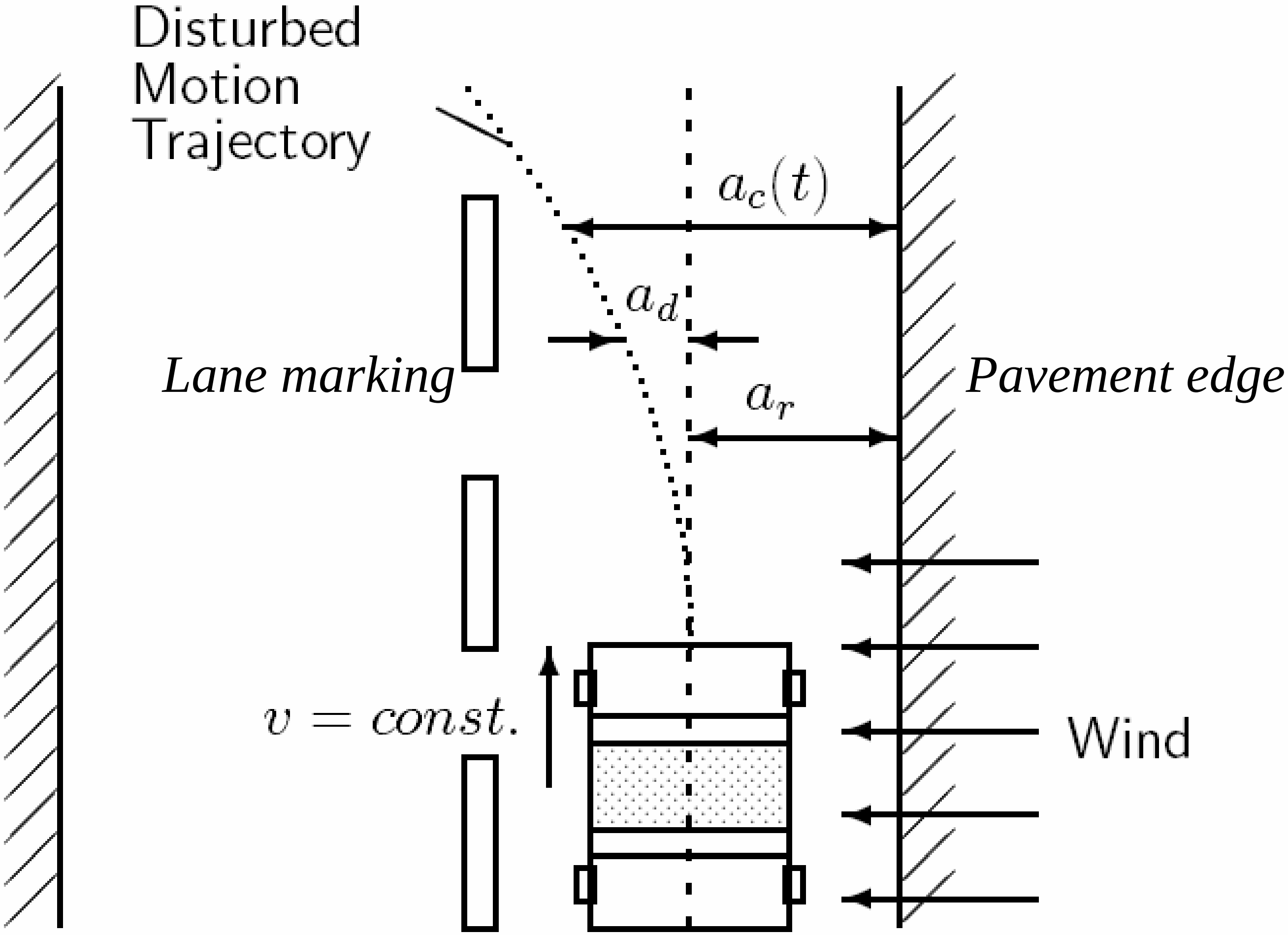


Figure I.3: Lane-keeping by means of manual or automatic control

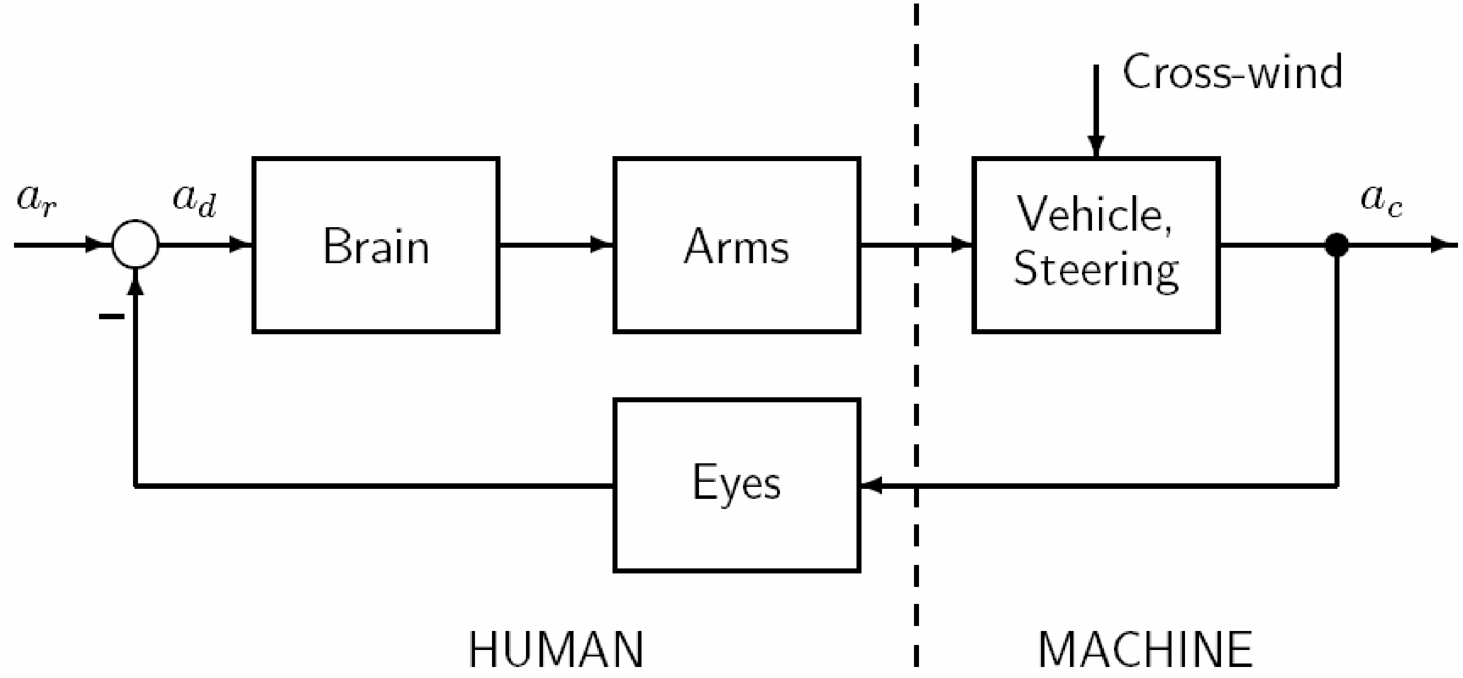


Figure I.4: Block diagram of manual closed-loop control (human-machine) system

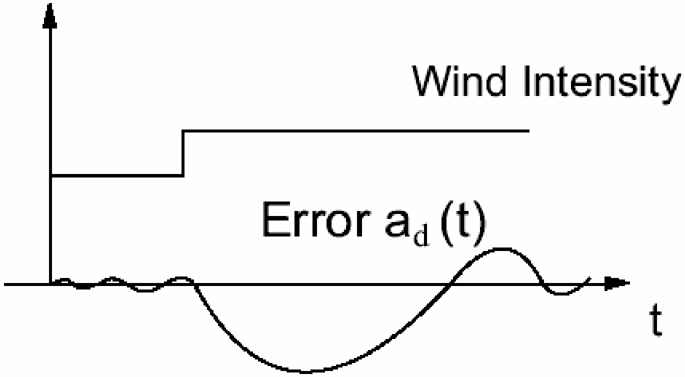


Figure I.5: Transient response of lateral distance error during manual closed-loop control

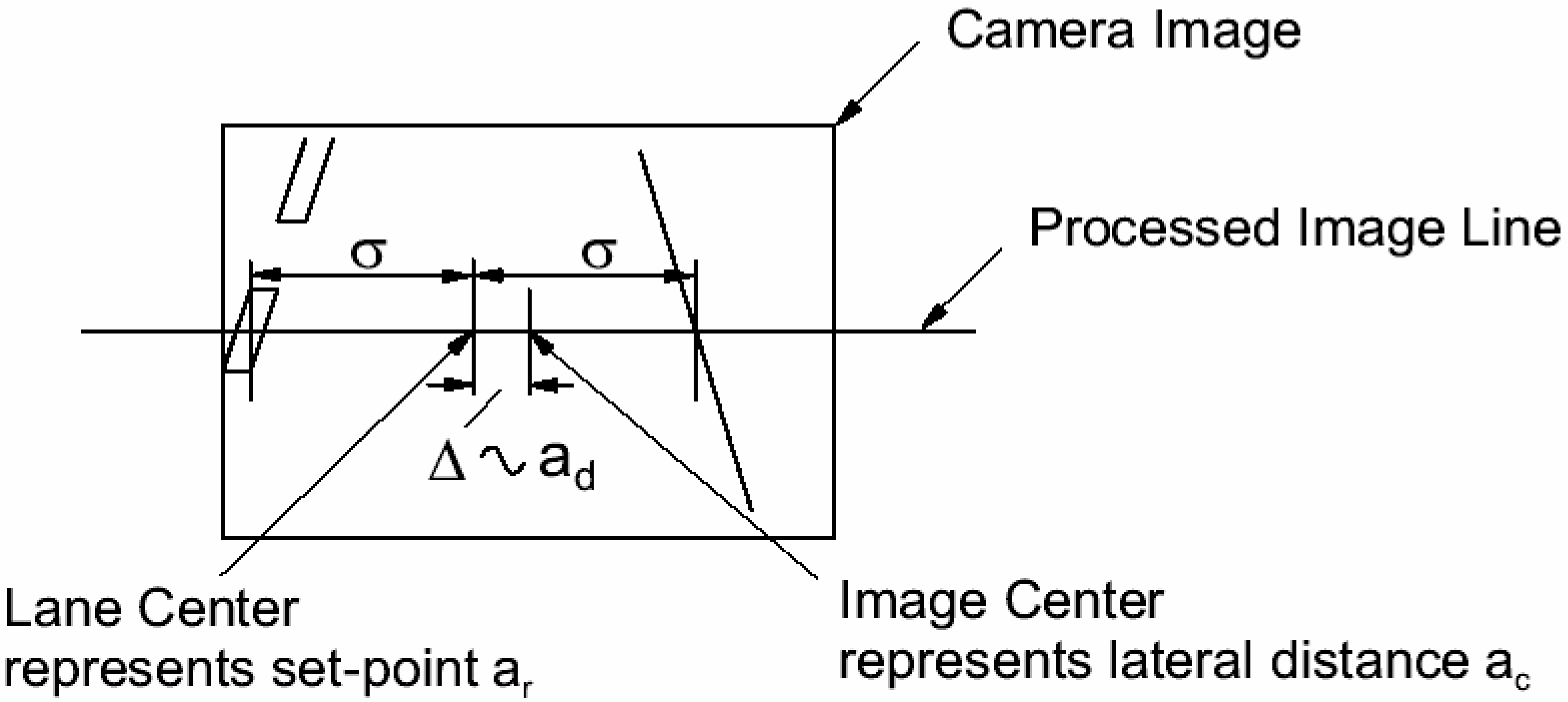


Figure I.6: Determination of control error a_d from camera image

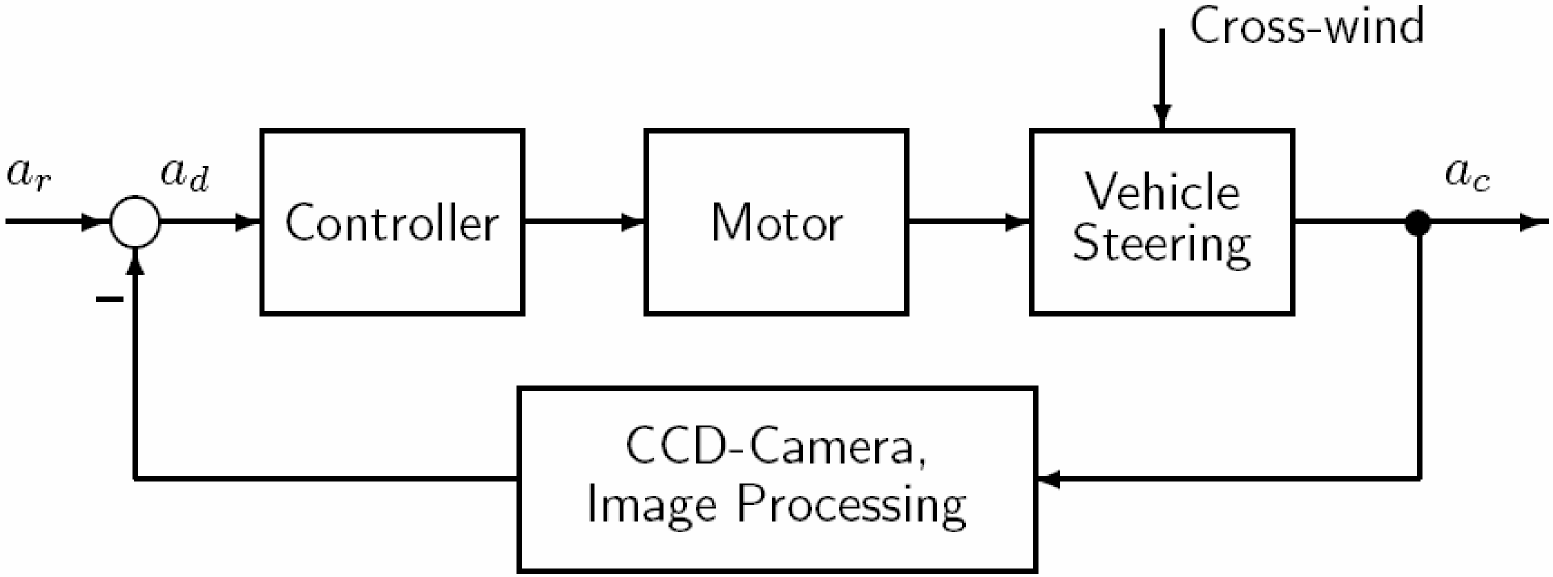


Figure I.7: Block diagram of an automatic control system for lane-keeping task

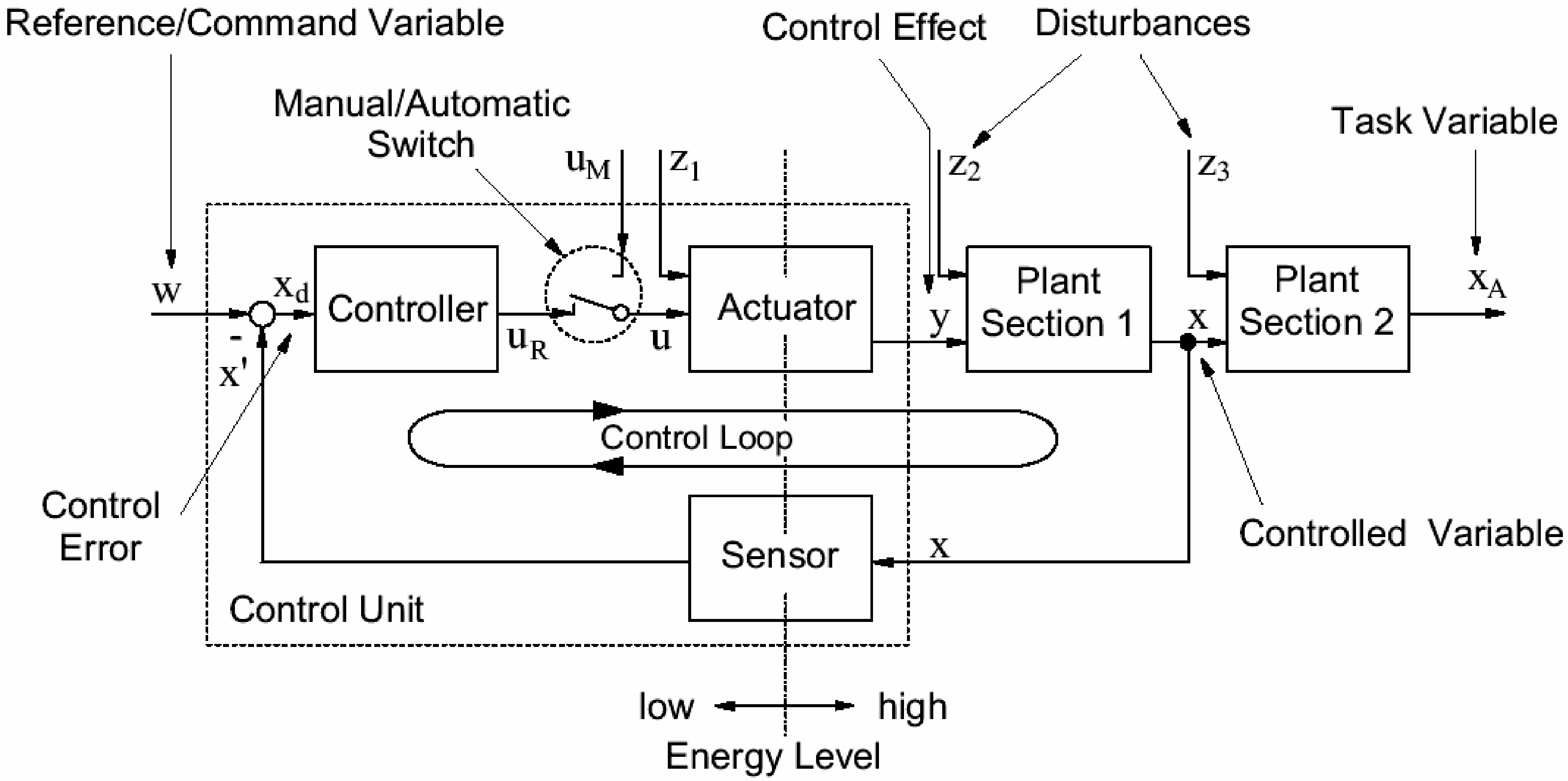
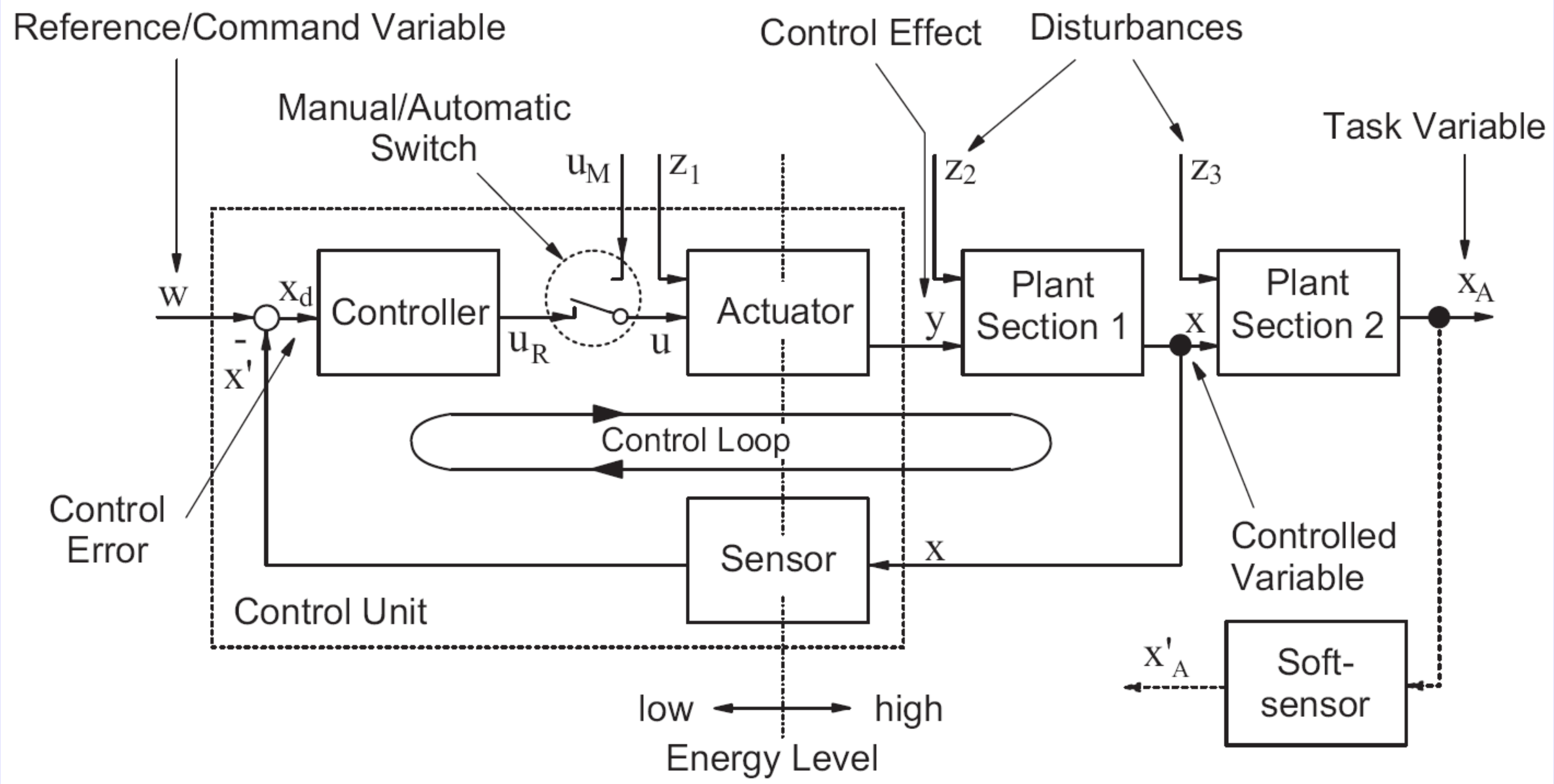


Figure I.8: Basic elements of a feedback control loop



Feedback control loop with model-based reconstruction of task variable by estimator (= soft-sensor)

Networked Control Systems

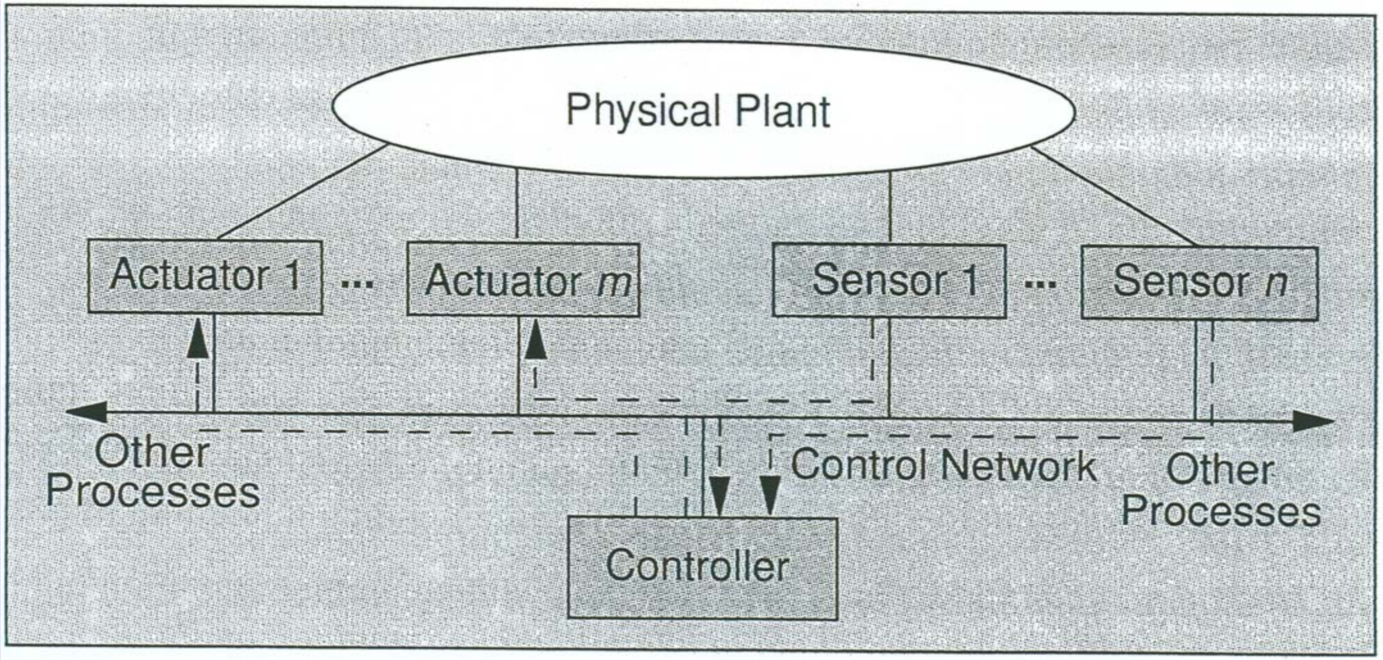


Figure 1. *A typical NCS setup and information flows.*

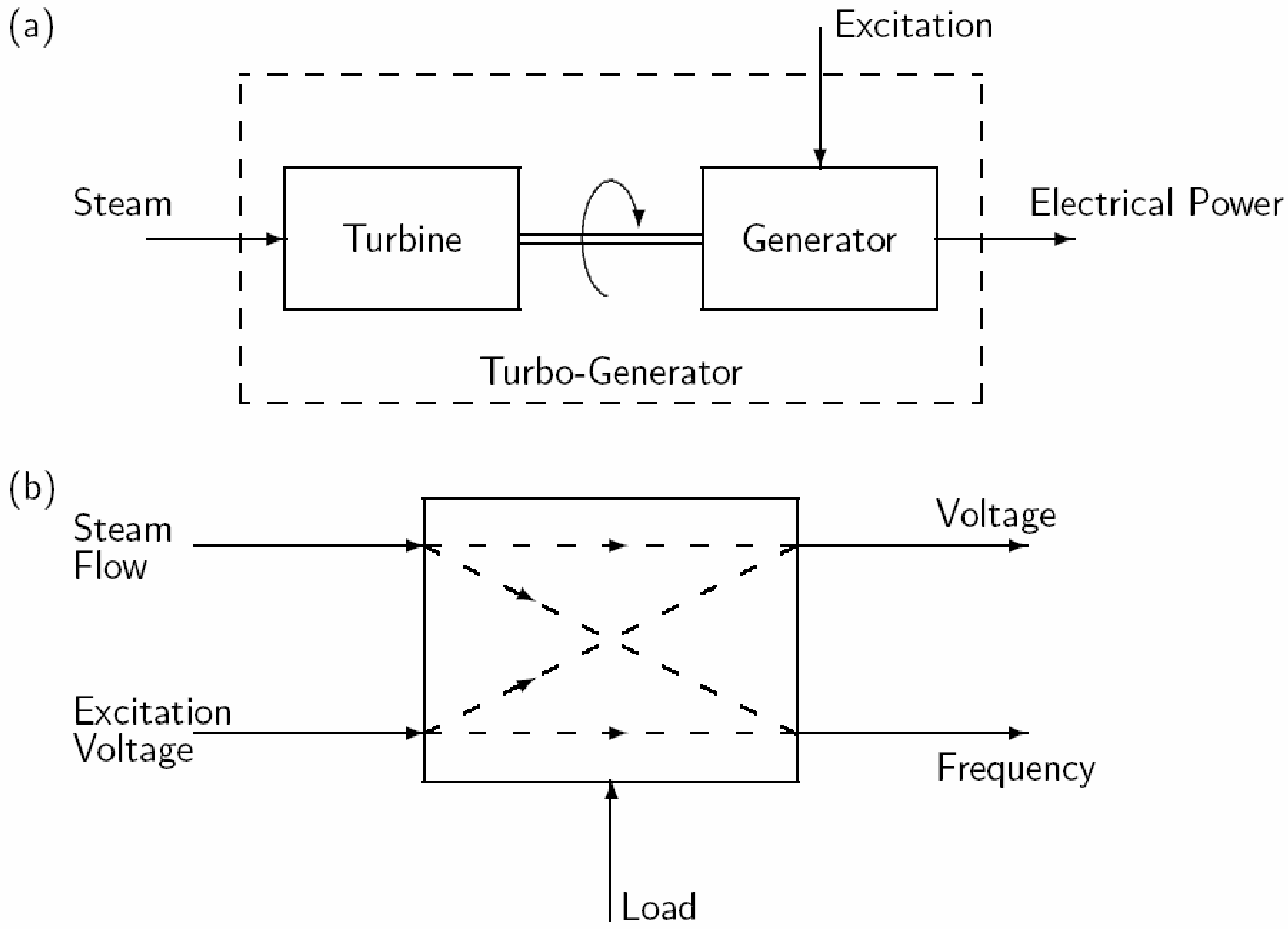


Figure I.22: Thermo-electric power generation. Set-up (a) and 2-input-2-output block diagram of turbo-generator (b). Control objectives: fixed frequency (50 Hz) and fixed voltage (230 V.)

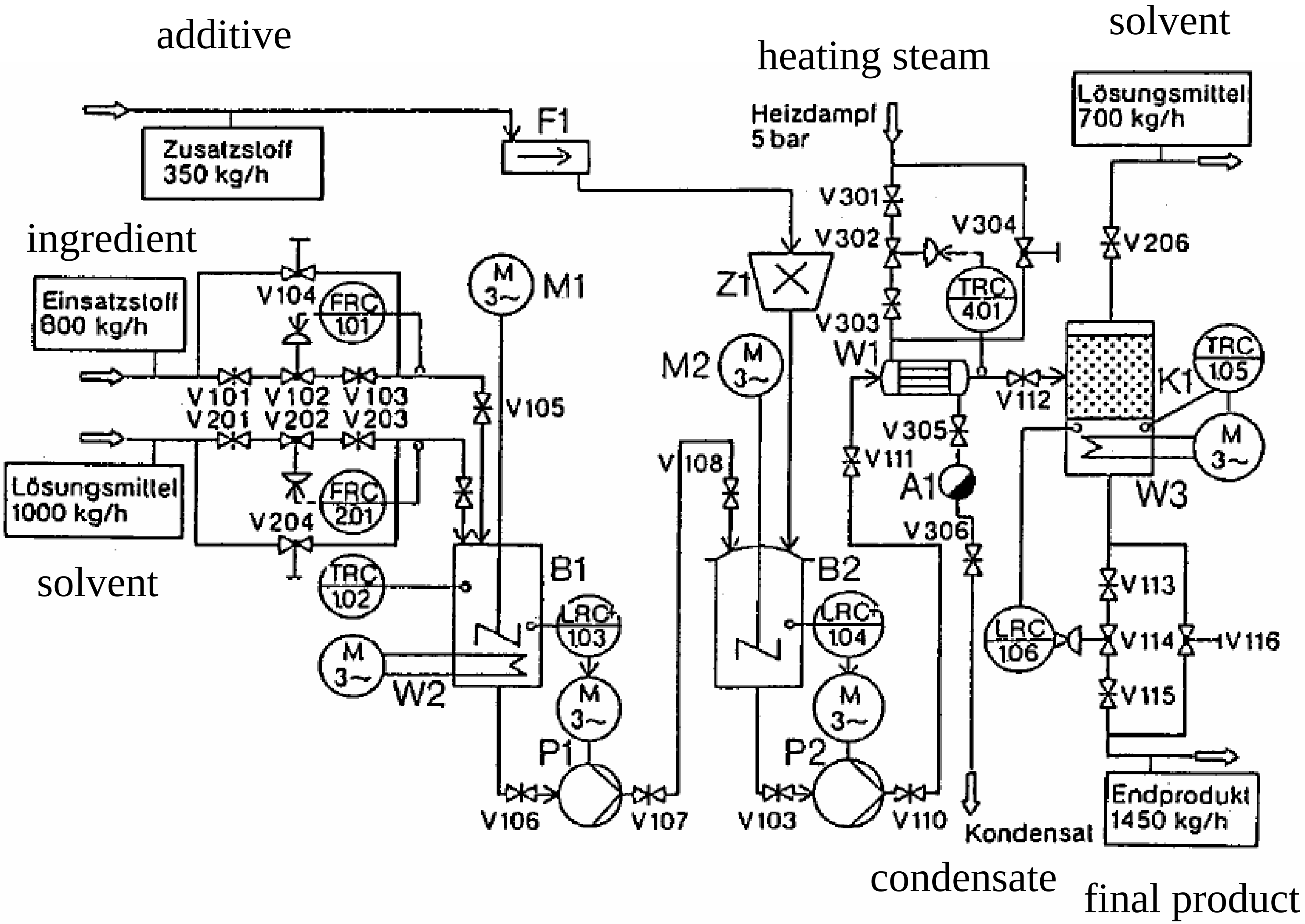


Figure I.9: Processing equipment and instrumentation scheme of a chemical plant

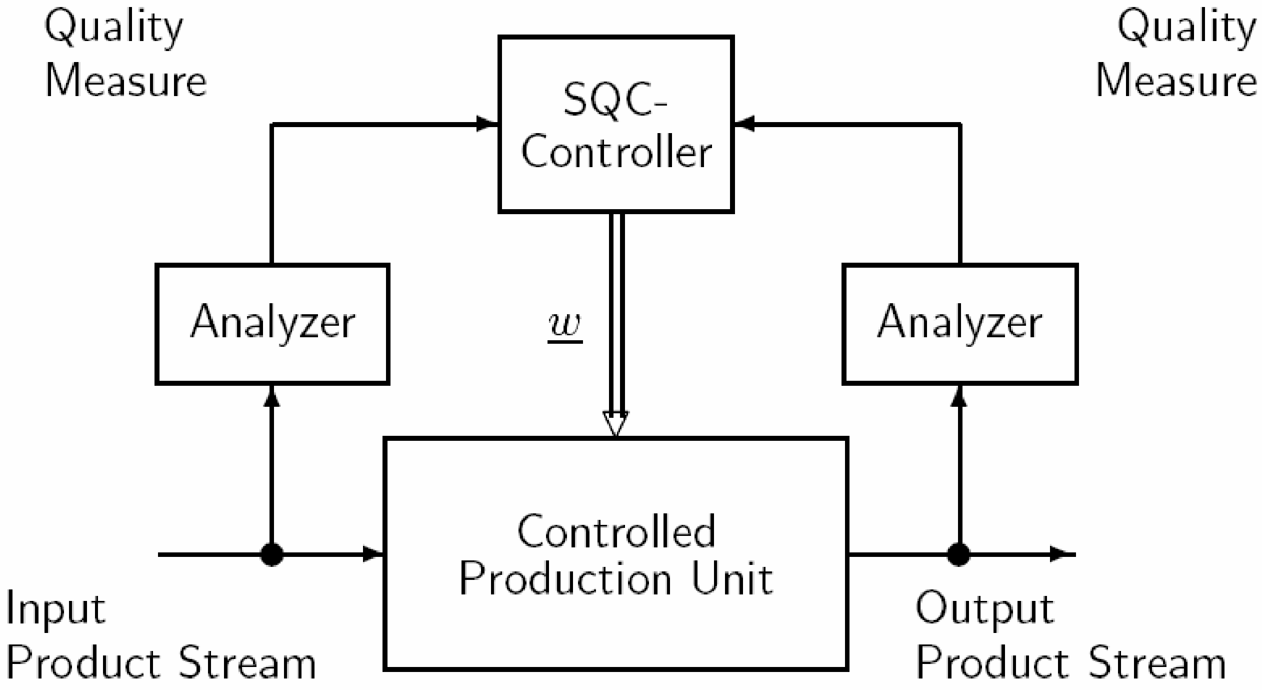
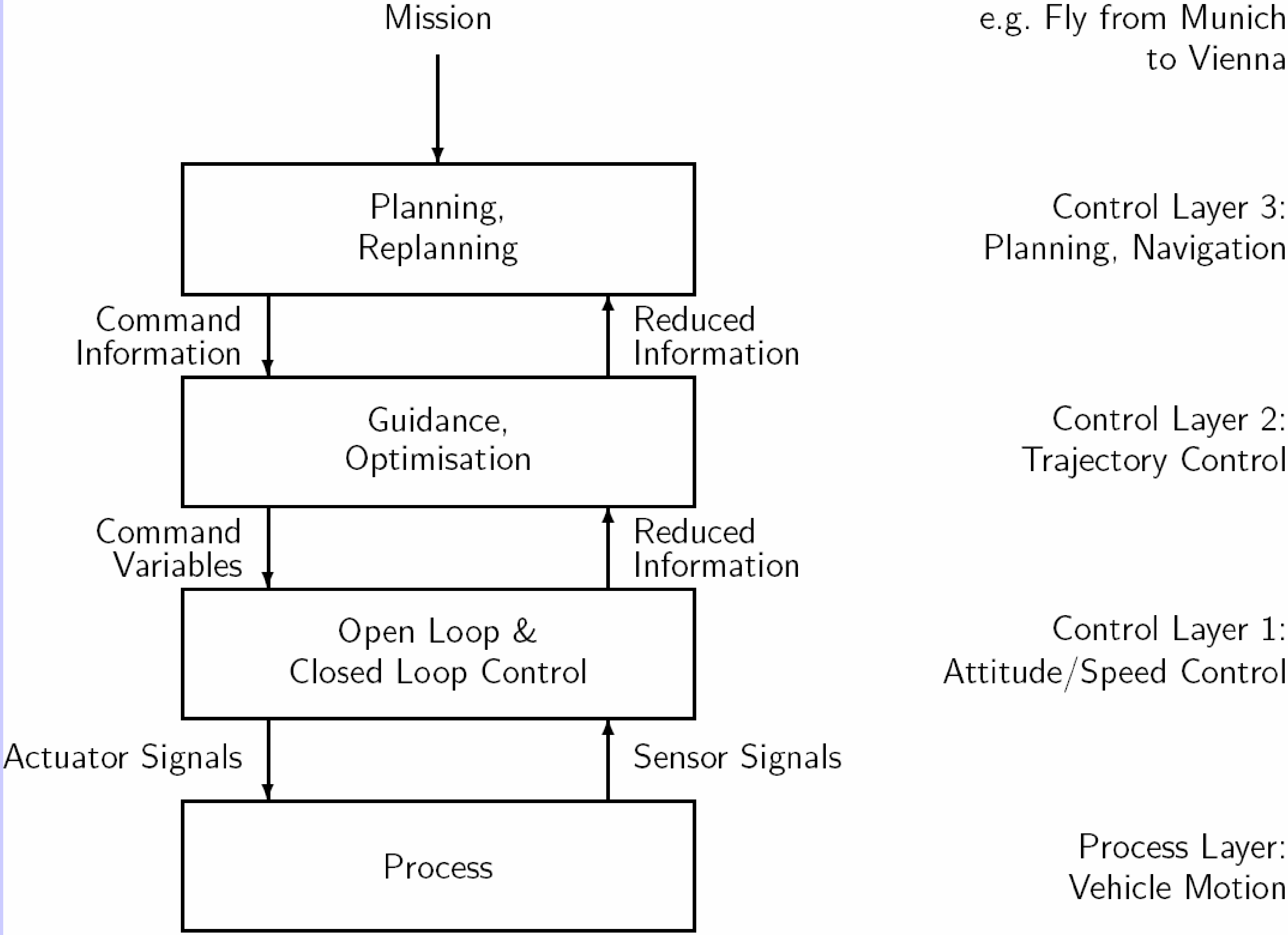


Figure I.10: Production process with multiple control loops on lower level and SQC functions on higher level



Mission

e.g. Fly from Munich
to Vienna

Planning,
Replanning

Control Layer 3:
Planning, Navigation

Command
Information

Reduced
Information

Guidance,
Optimisation

Control Layer 2:
Trajectory Control

Command
Variables

Reduced
Information

Open Loop &
Closed Loop Control

Control Layer 1:
Attitude/Speed Control

Actuator Signals

Sensor Signals

Process

Process Layer:
Vehicle Motion

Figure I.11: Scheme of multi-layer hierarchical control architecture

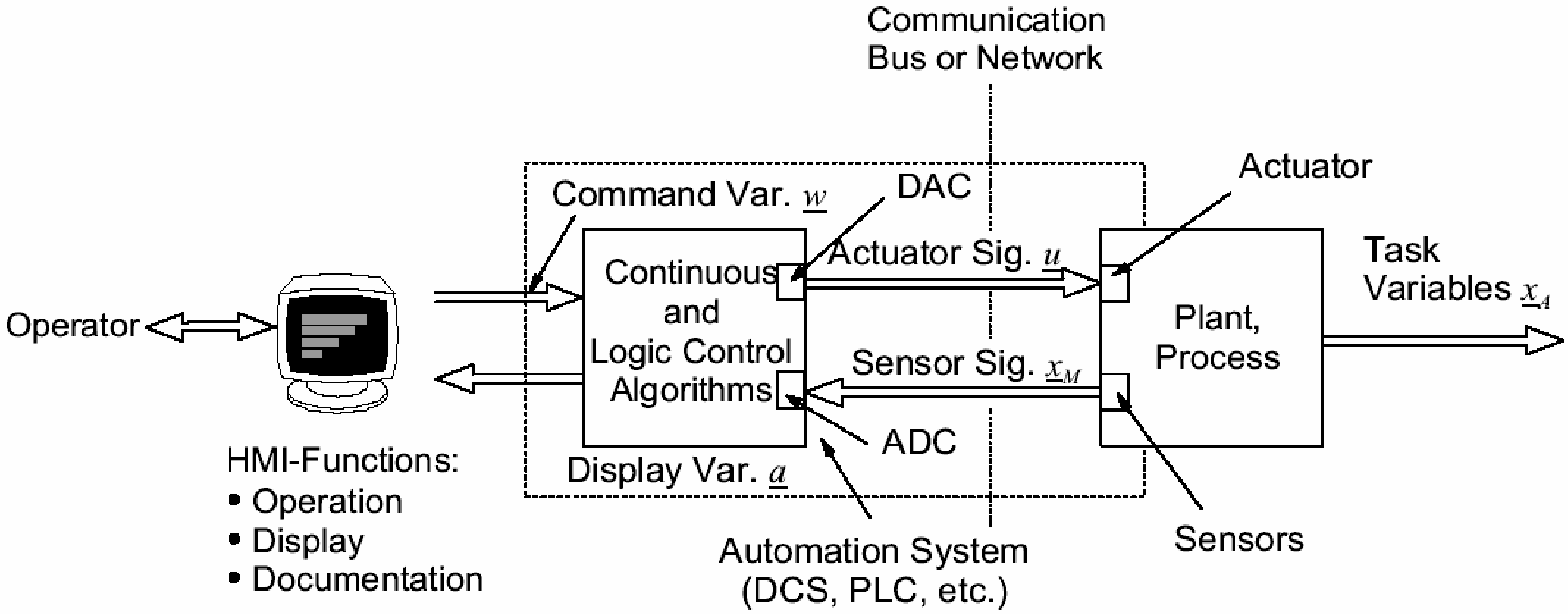


Figure I.12: Equipment and implementation aspects of control systems

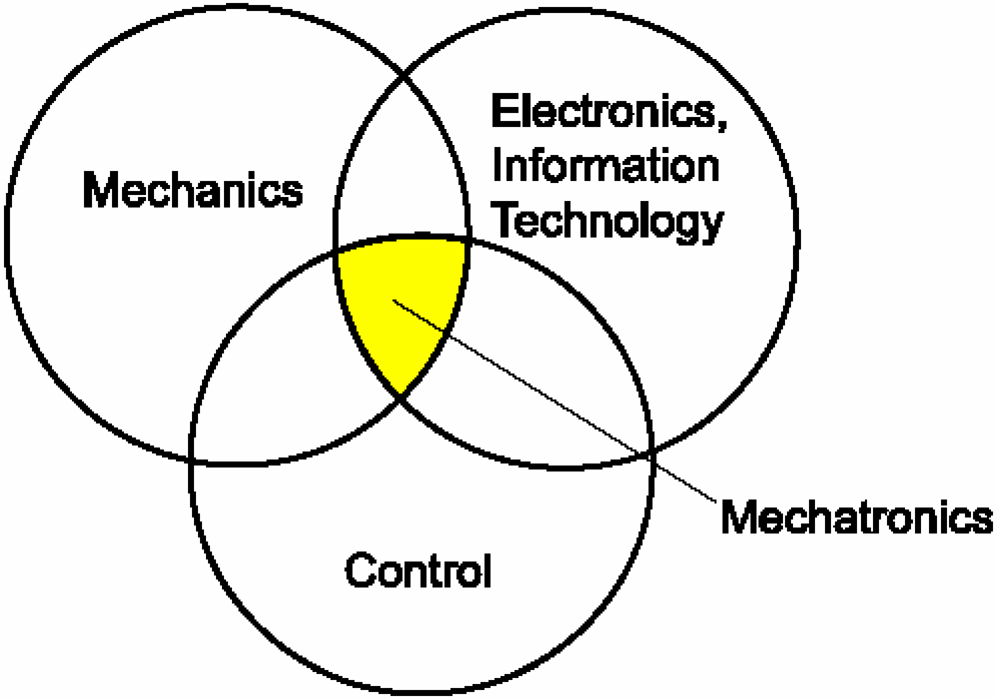
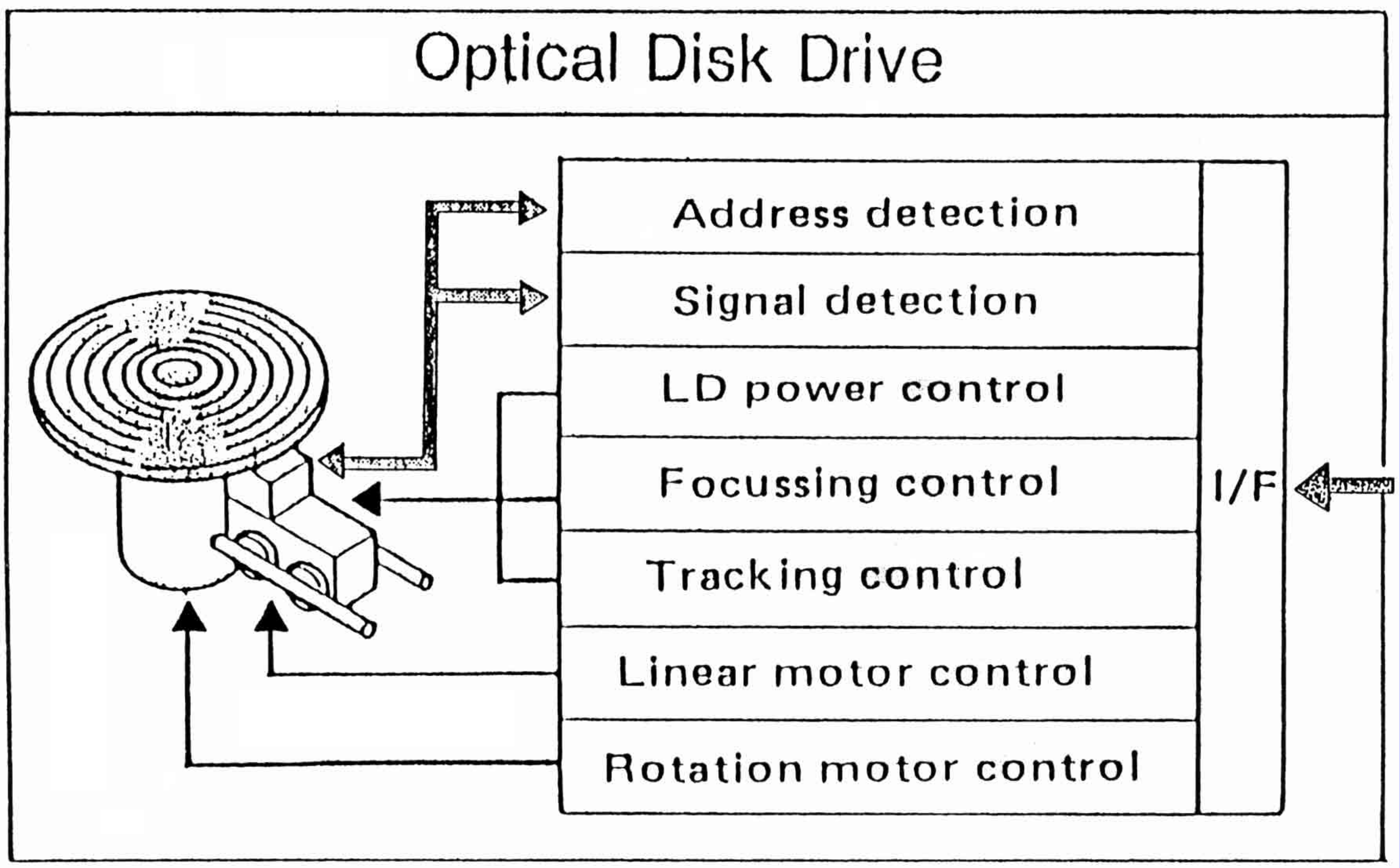
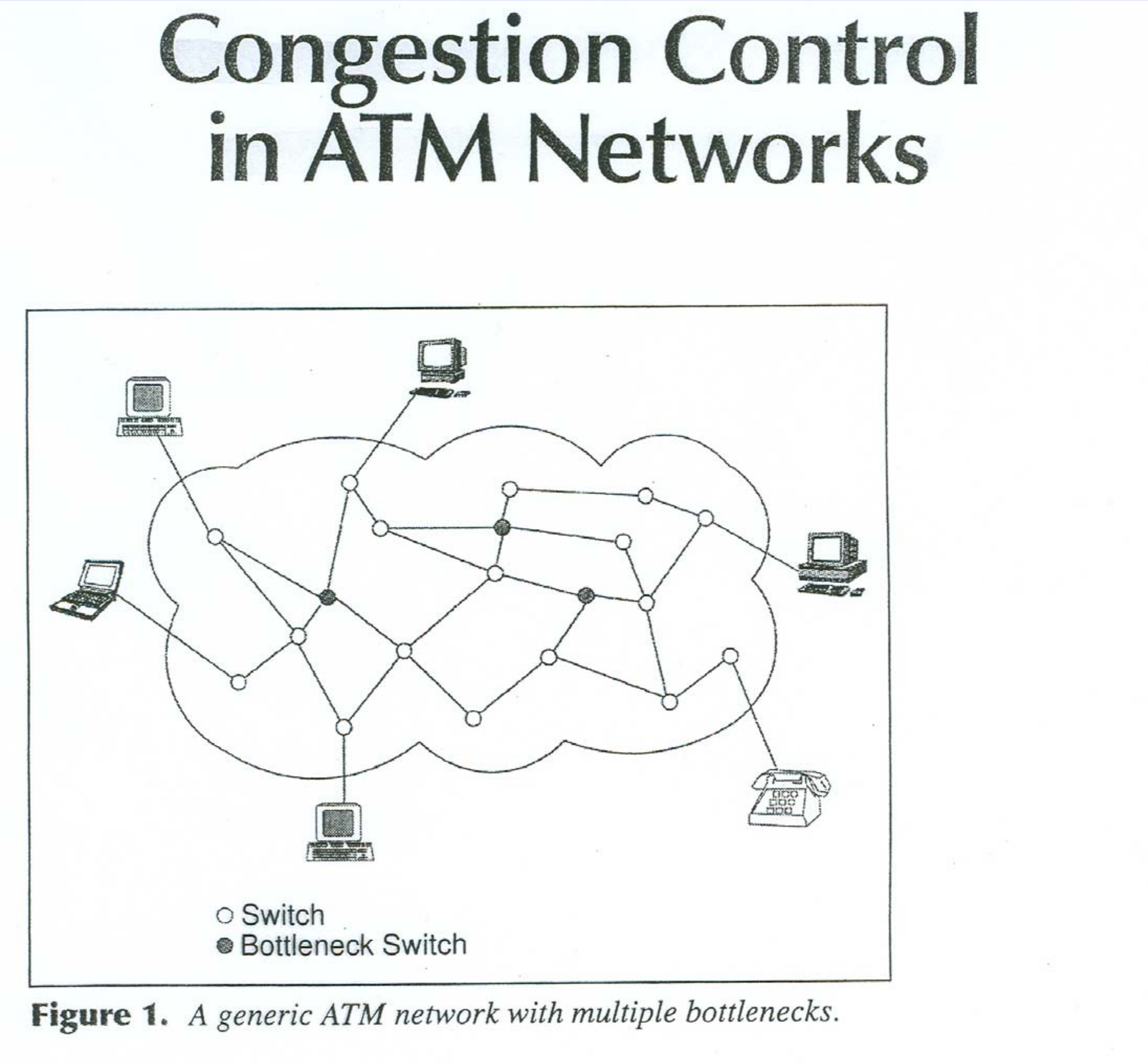


Figure I.13: CE and mechatronics


Optical Disk Drive
Address detection
Signal detection
LD power control
Focussing control
Tracking control
Linear motor control
Rotation motor control
I/F



Congestion Control in ATM Networks

Figure 1. *A generic ATM network with multiple bottlenecks.*

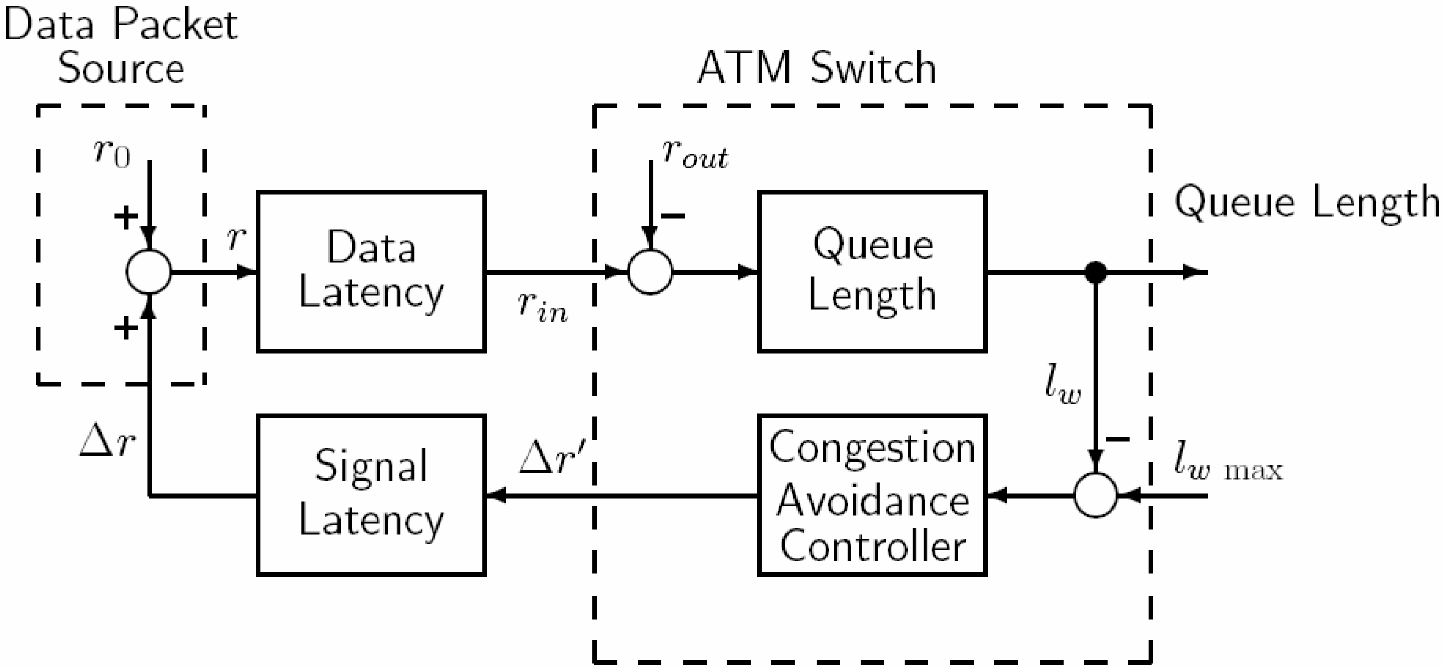


Figure I.14: Scheme of congestion avoidance control in an ATM switch, r_0: nominal data stream of source , r_{out}: outgoing data stream from switch

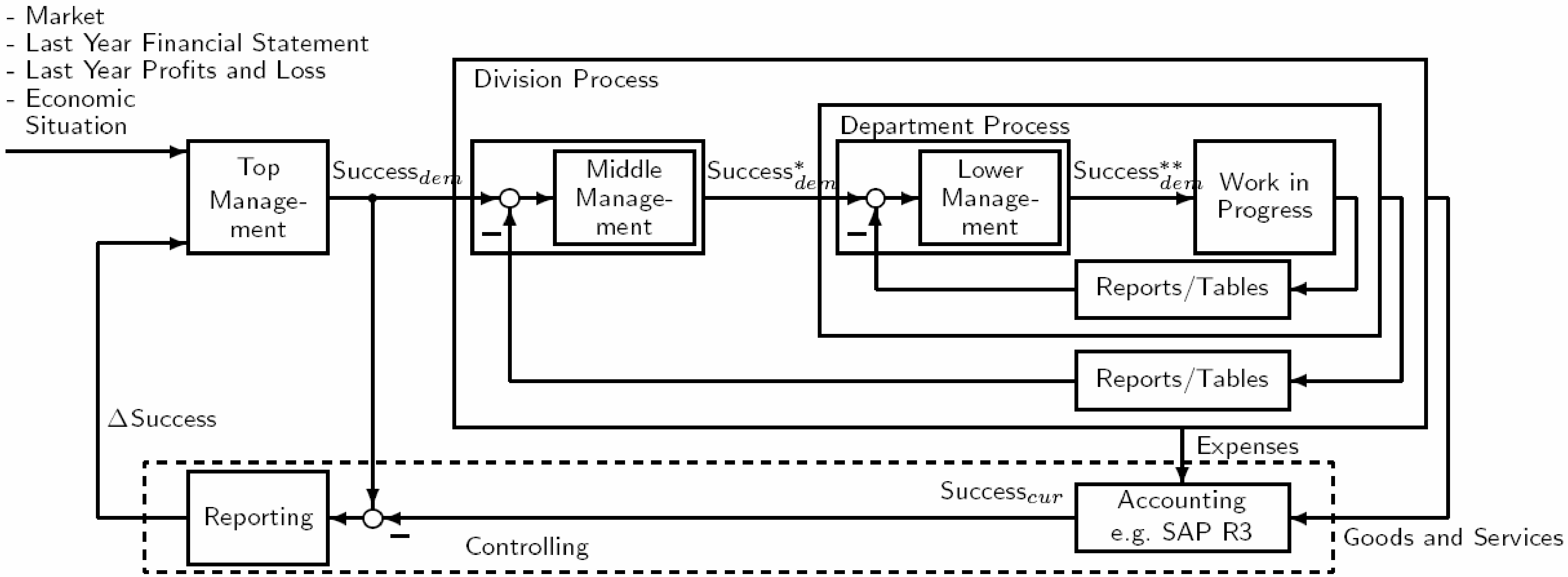


Figure I.15: Management und Controlling in an Enterprise from a CE viewpoint

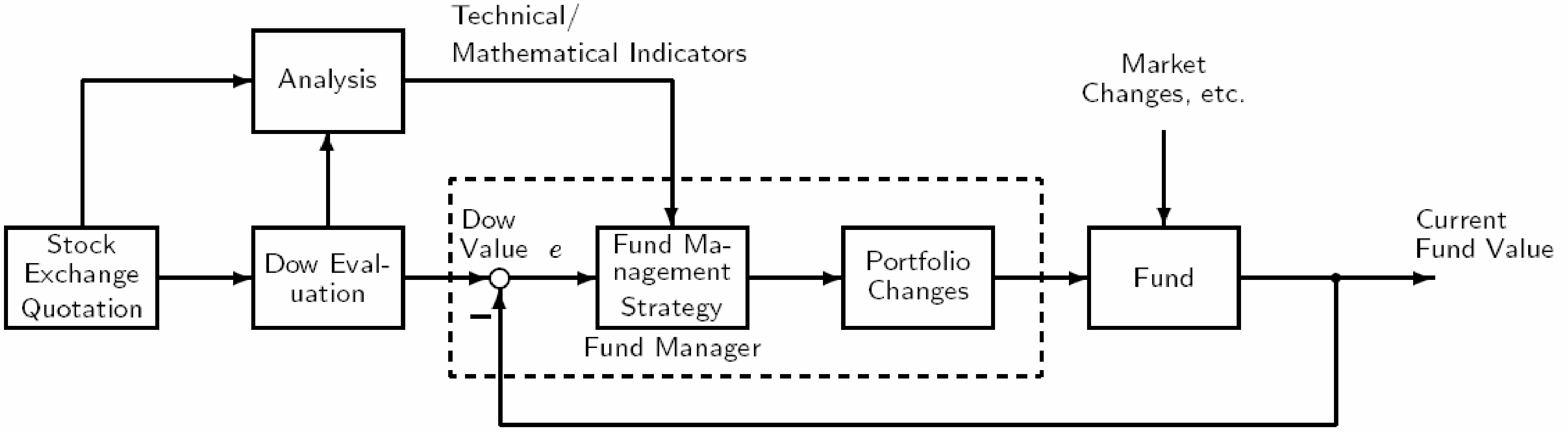


Figure I.16: Control scheme of portfolio management, passive fund management strategy

Time-driven

Event-driven

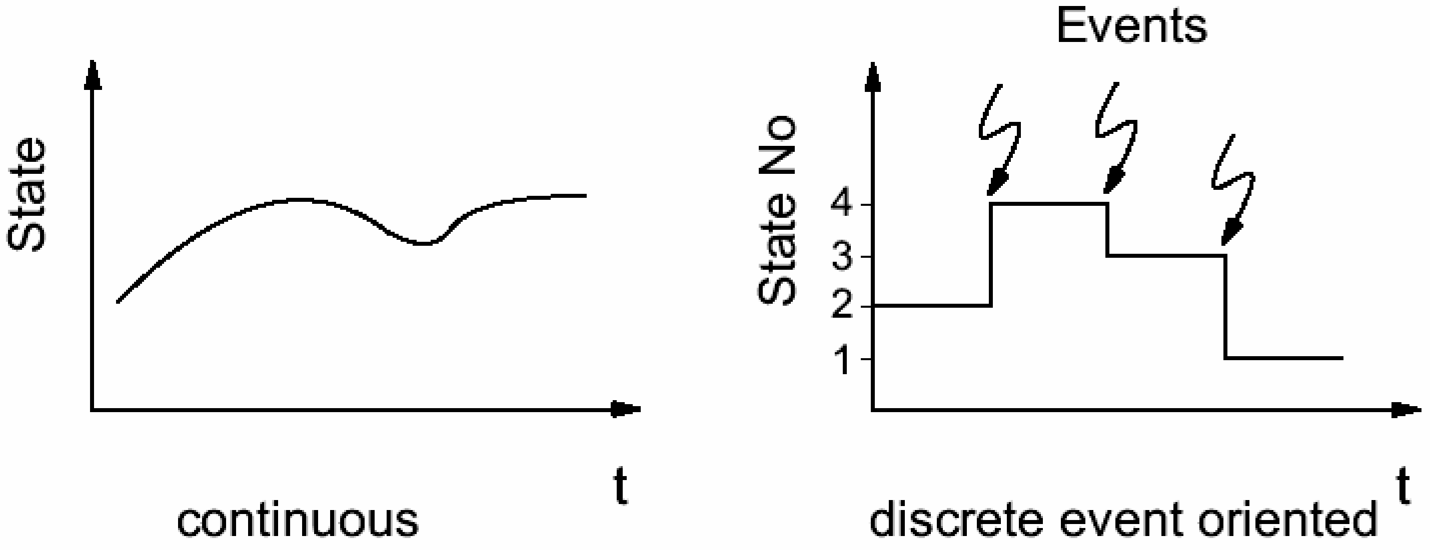


Figure I.17: Continuous and discrete event systems

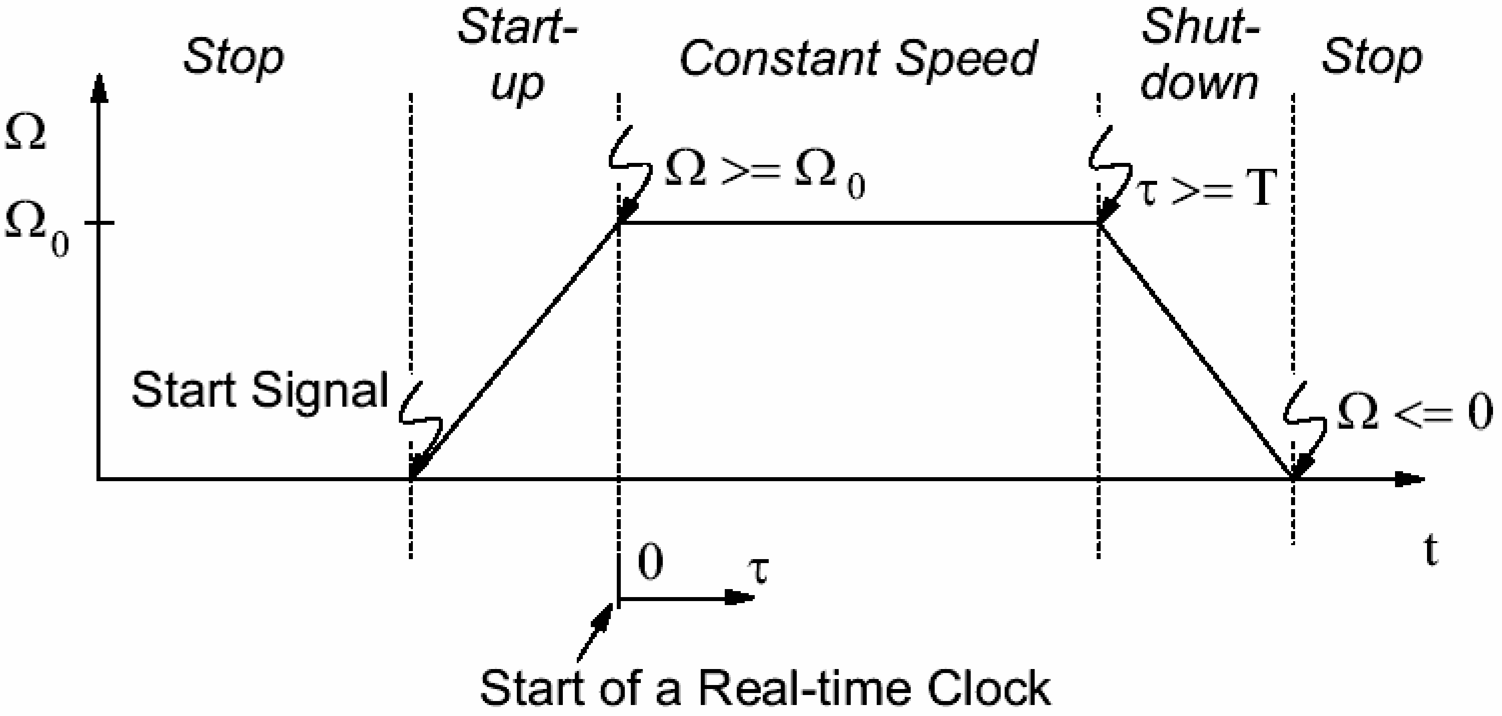


Figure I.18: Typical speed profile of a vehicle test facility

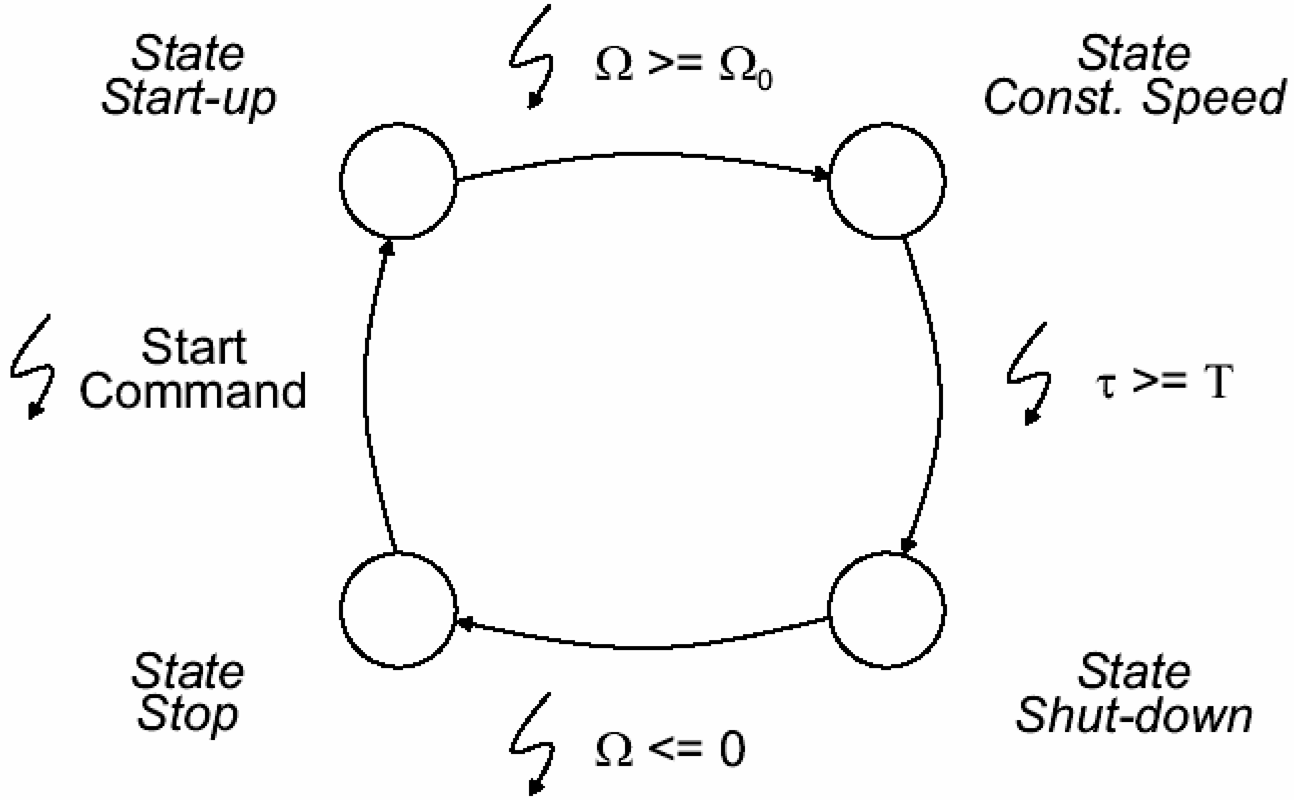


Figure I.19: State transition graph for desired operation of test facility

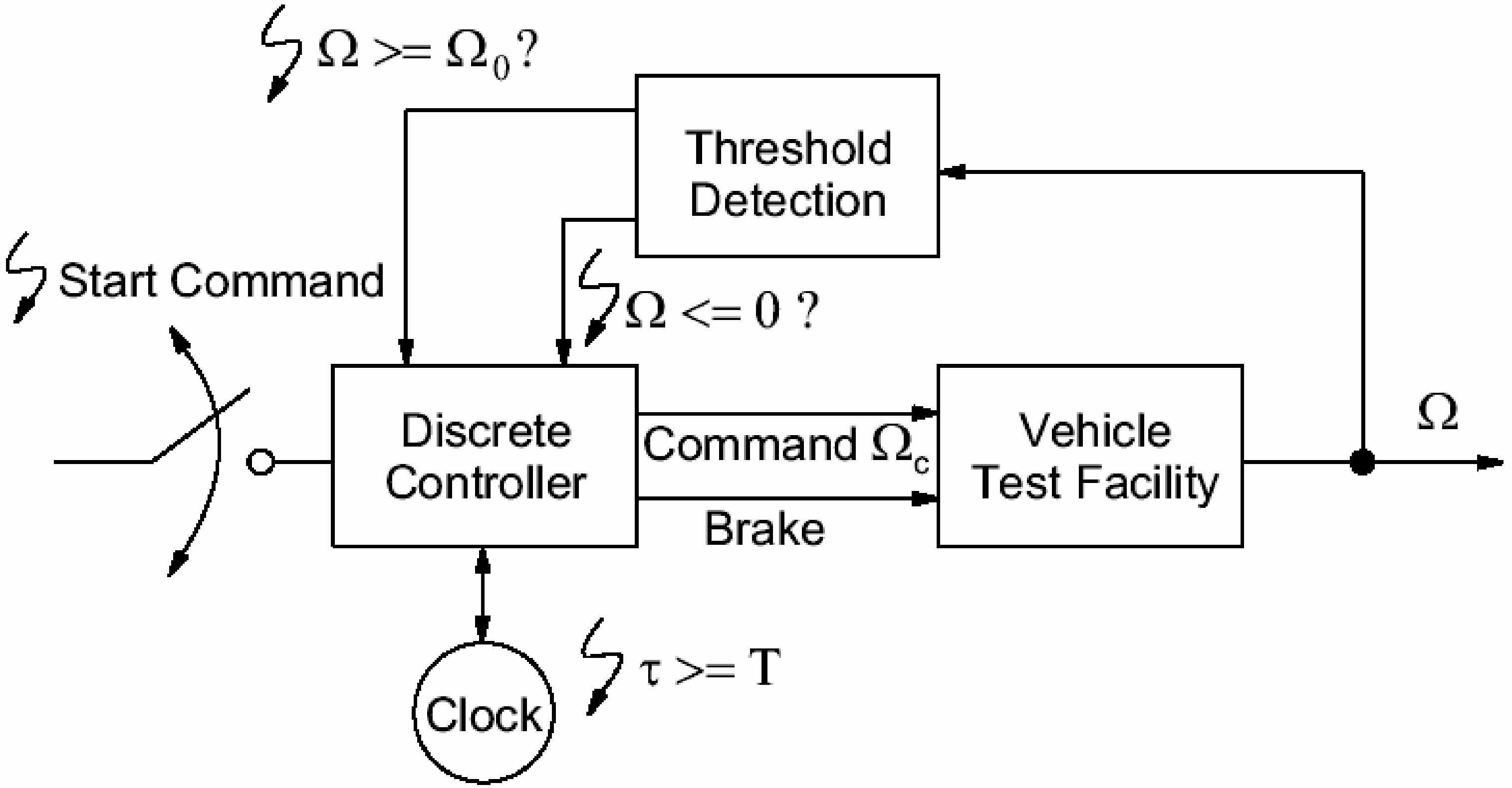


Figure I.20: Block diagram of discrete event control system for test facility

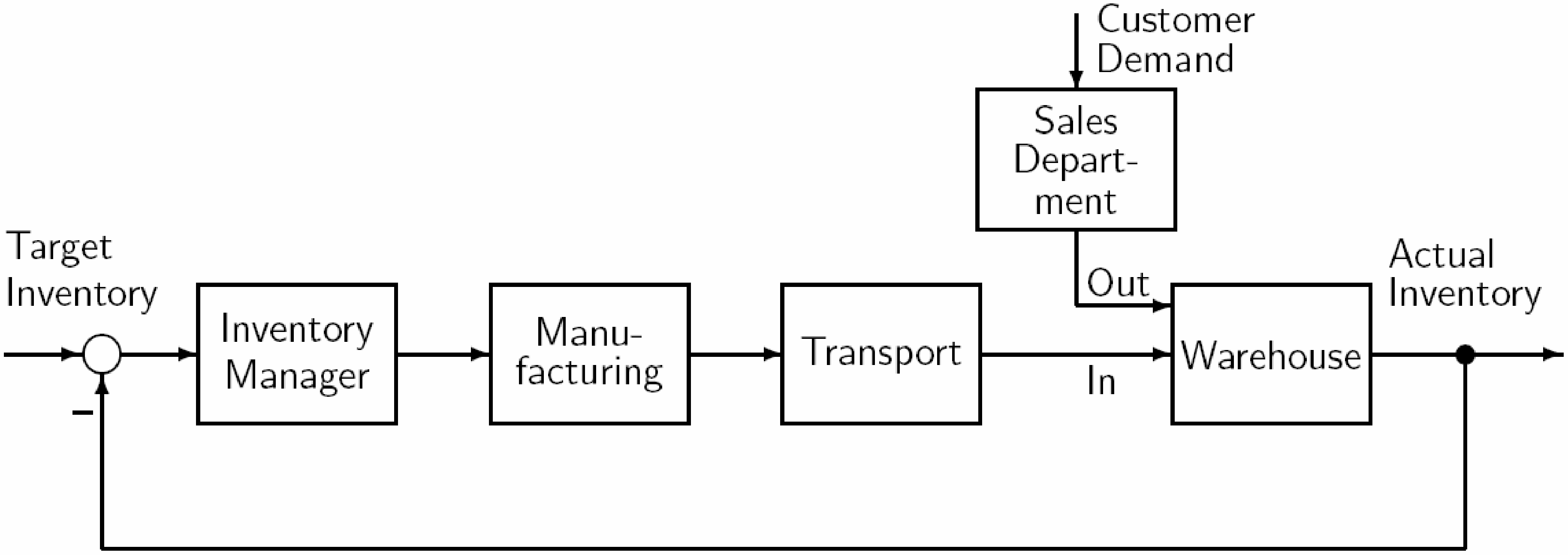


Figure I.21: Warehouse Inventory Control

Steps of Control System Development

Understand Control Task and Specifications

Analyze Plant or Process

Model Process

Simulate Process

**Select Control Architecture,
incl. Sensor and Actuator Locations**

Design Control Laws and Algorithms

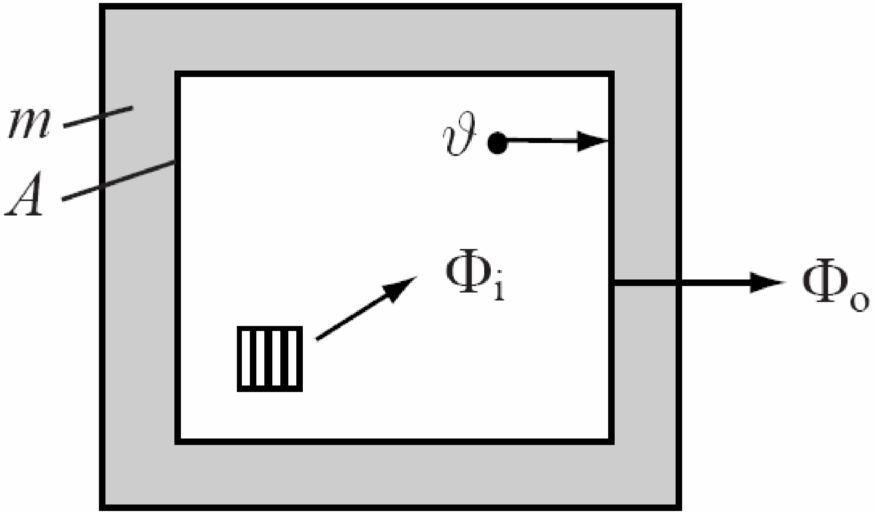
Simulate Total Control System

HW/SW Implementation of Control System

Test and Performance Evaluation

On-site Start-up and Fine-tuning

Part 2

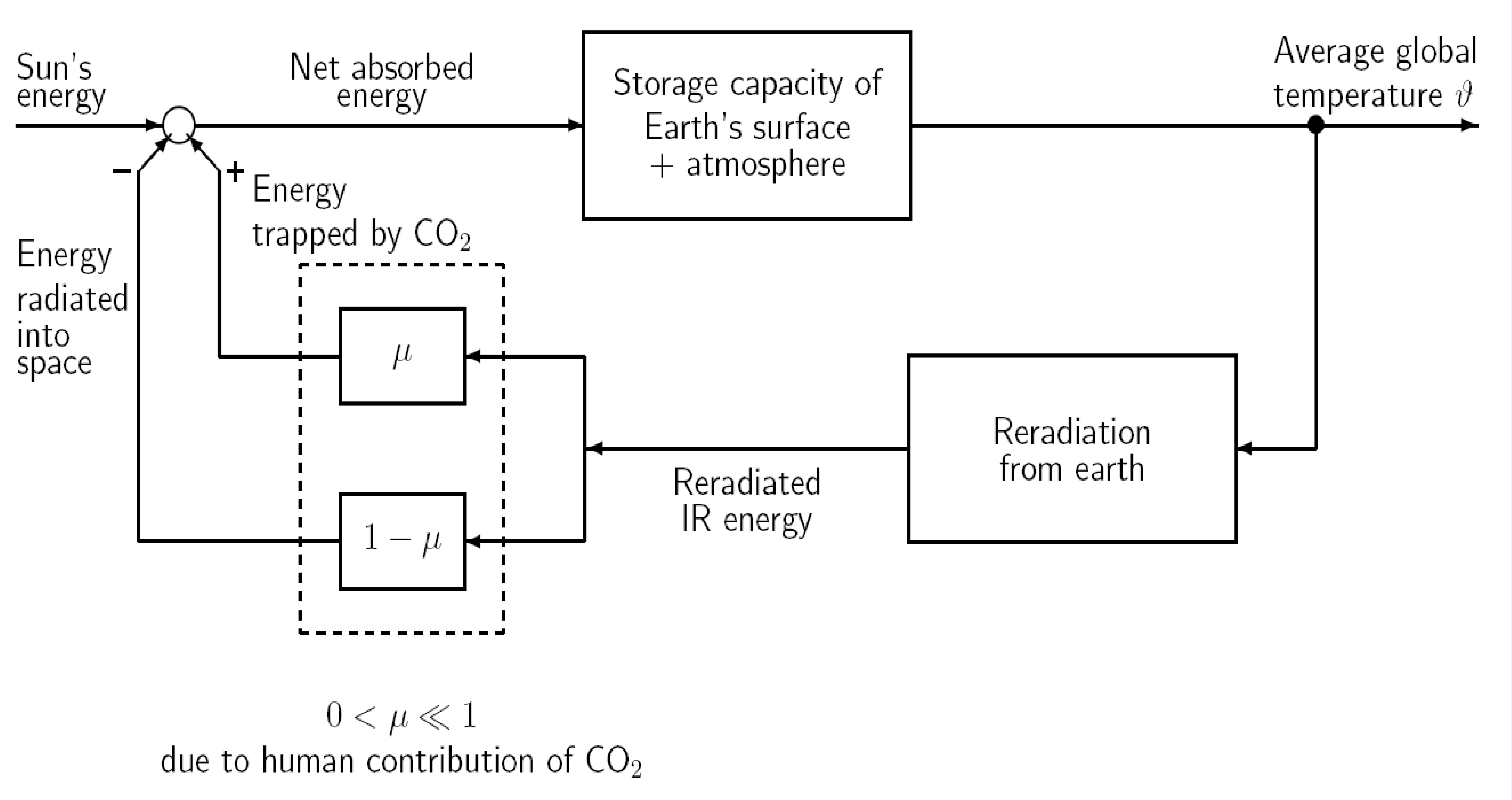


thermal capacity of wall
$C_{therm} = m \cdot c$

thermal conductance of wall
$\Lambda_{therm} = \lambda \cdot A$

Figure II.1: Room heating

Greenhouse Effect: Retention of Energy
A prominent example of a natural feedback process

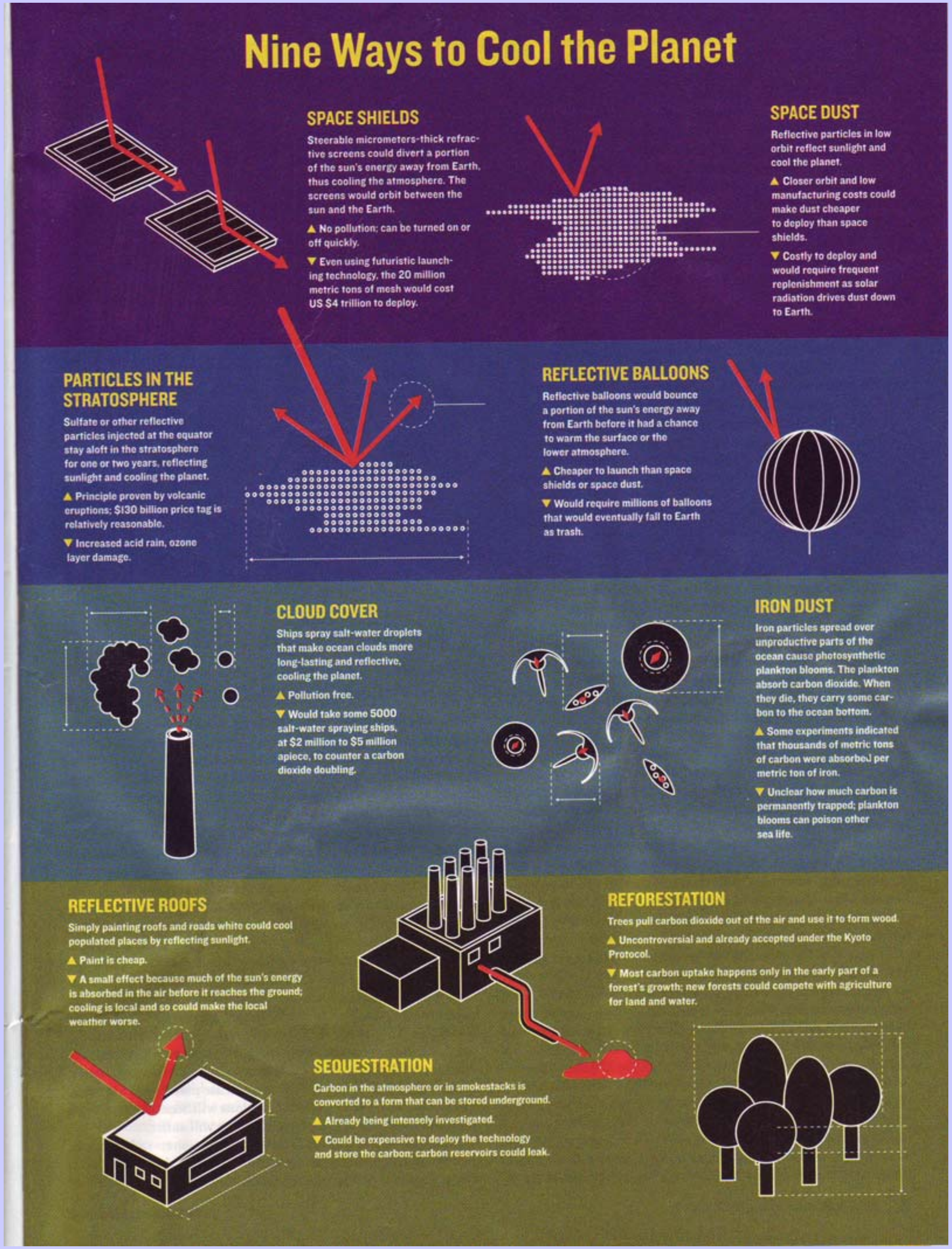


$0 < \mu \ll 1$

due to human contribution of CO_2

Climate Control to Counteract Greenhouse Effect

IEEE Spectrum, May 2007



Nine Ways to Cool the Planet

SPACE SHIELDS

Steerable micrometers-thick refractive screens could divert a portion of the sun's energy away from Earth, thus cooling the atmosphere. The screens would orbit between the sun and the Earth.

▲ No pollution; can be turned on or off quickly.

▼ Even using futuristic launching technology, the 20 million metric tons of mesh would cost US $4 trillion to deploy.

SPACE DUST

Reflective particles in low orbit reflect sunlight and cool the planet.

▲ Closer orbit and low manufacturing costs could make dust cheaper to deploy than space shields.

▼ Costly to deploy and would require frequent replenishment as solar radiation drives dust down to Earth.

PARTICLES IN THE STRATOSPHERE

Sulfate or other reflective particles injected at the equator stay aloft in the stratosphere for one or two years, reflecting sunlight and cooling the planet.

▲ Principle proven by volcanic eruptions; $130 billion price tag is relatively reasonable.

▼ Increased acid rain, ozone layer damage.

REFLECTIVE BALLOONS

Reflective balloons would bounce a portion of the sun's energy away from Earth before it had a chance to warm the surface or the lower atmosphere.

▲ Cheaper to launch than space shields or space dust.

▼ Would require millions of balloons that would eventually fall to Earth as trash.

CLOUD COVER

Ships spray salt-water droplets that make ocean clouds more long-lasting and reflective, cooling the planet.

▲ Pollution free.

▼ Would take some 5000 salt-water spraying ships, at $2 million to $5 million apiece, to counter a carbon dioxide doubling.

IRON DUST

Iron particles spread over unproductive parts of the ocean cause photosynthetic plankton blooms. The plankton absorb carbon dioxide. When they die, they carry some carbon to the ocean bottom.

▲ Some experiments indicated that thousands of metric tons of carbon were absorbed per metric ton of iron.

▼ Unclear how much carbon is permanently trapped; plankton blooms can poison other sea life.

REFLECTIVE ROOFS

Simply painting roofs and roads white could cool populated places by reflecting sunlight.

▲ Paint is cheap.

▼ A small effect because much of the sun's energy is absorbed in the air before it reaches the ground; cooling is local and so could make the local weather worse.

REFORESTATION

Trees pull carbon dioxide out of the air and use it to form wood.

▲ Uncontroversial and already accepted under the Kyoto Protocol.

▼ Most carbon uptake happens only in the early part of a forest's growth; new forests could compete with agriculture for land and water.

SEQUESTRATION

Carbon in the atmosphere or in smokestacks is converted to a form that can be stored underground.

▲ Already being intensely investigated.

▼ Could be expensive to deploy the technology and store the carbon; carbon reservoirs could leak.

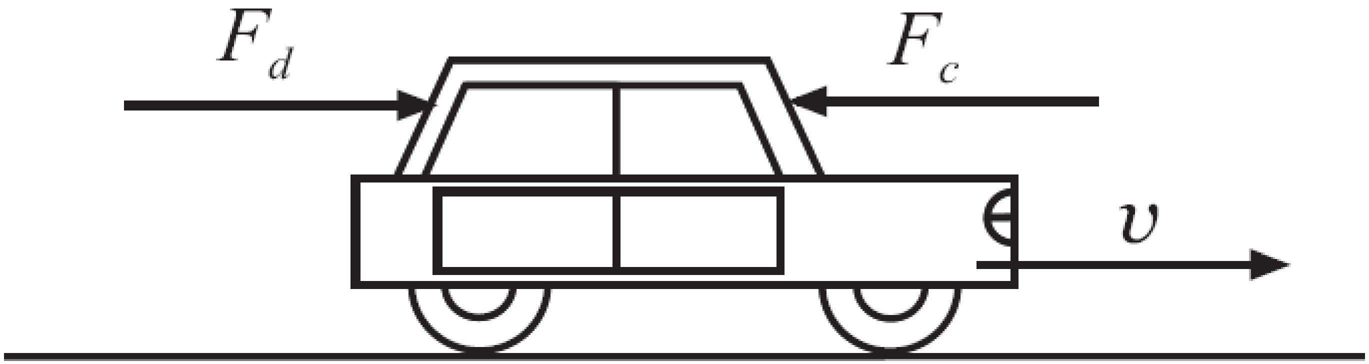


Figure II.2: Longitudinal vehicle motion

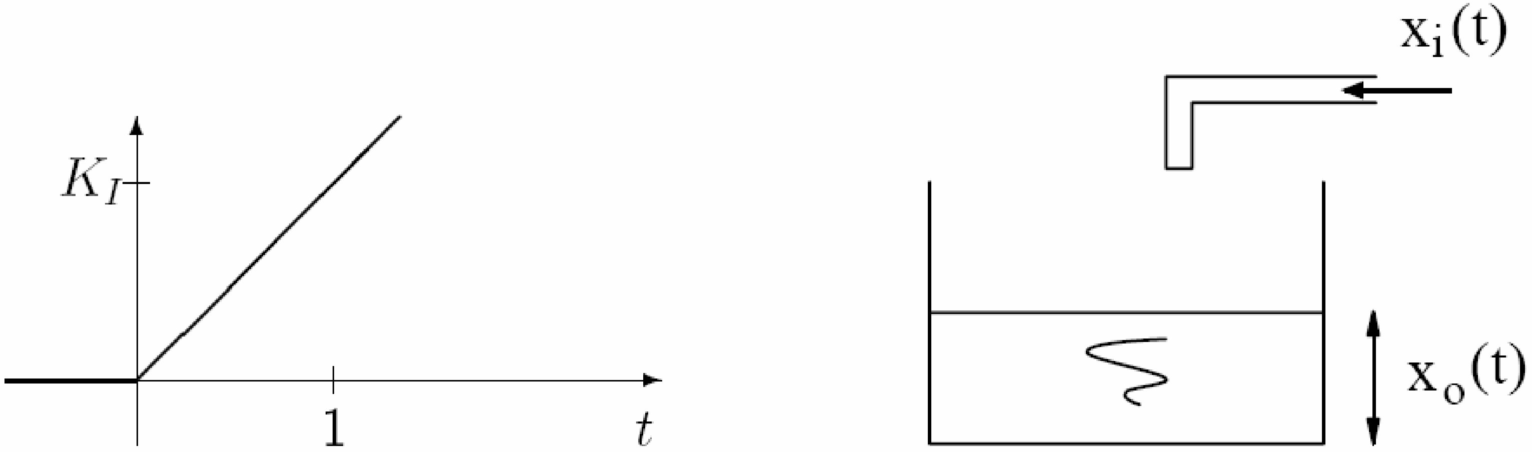


Figure II.3: Graph of step response of I-system and liquid tank as example

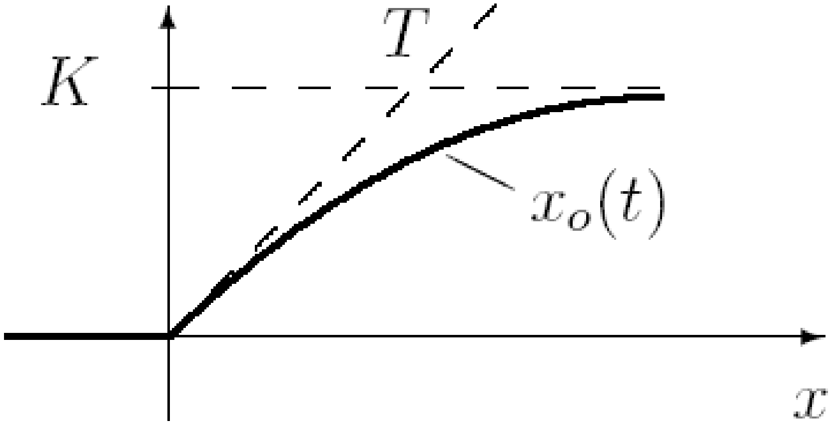


Figure II.4: Step response of 1st order (PT_1)-system

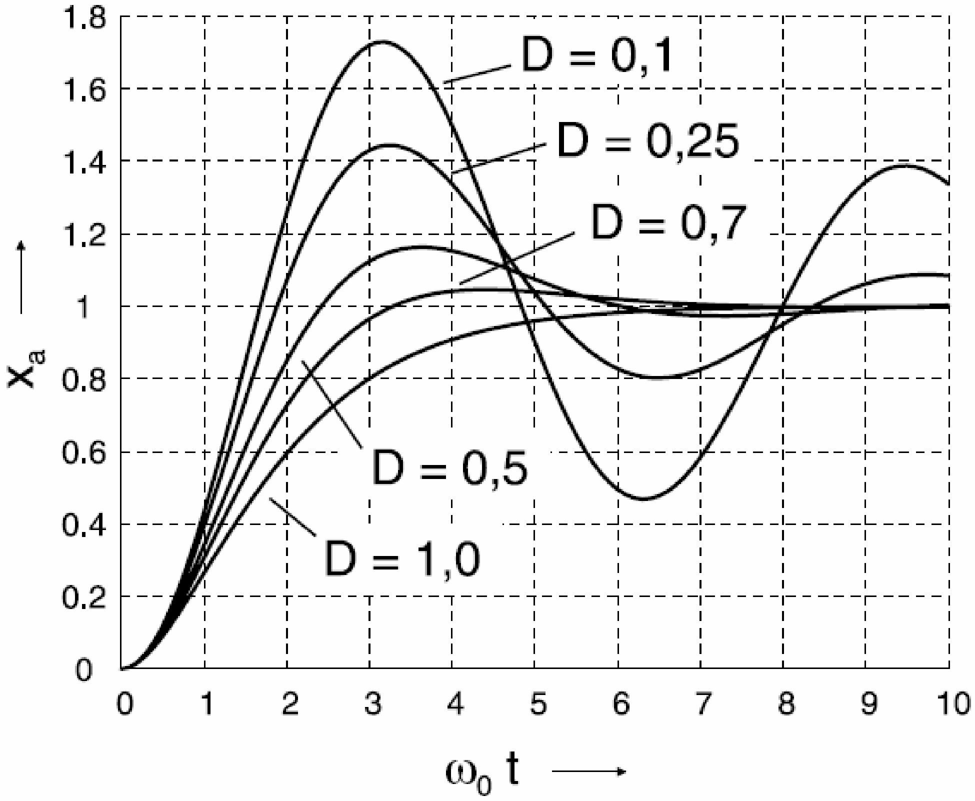


Figure II.5: Step response of 2nd order (PT_2)*-system for damping* $0 < D < 1$

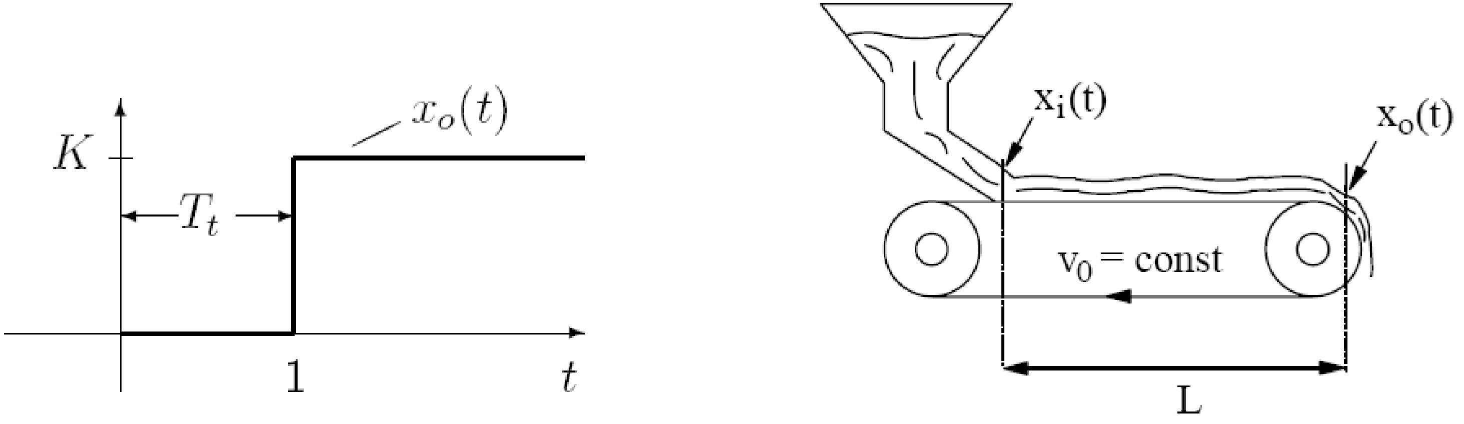


Figure II.6: Step response of time-delay (T_t) system and conveyor belt as example

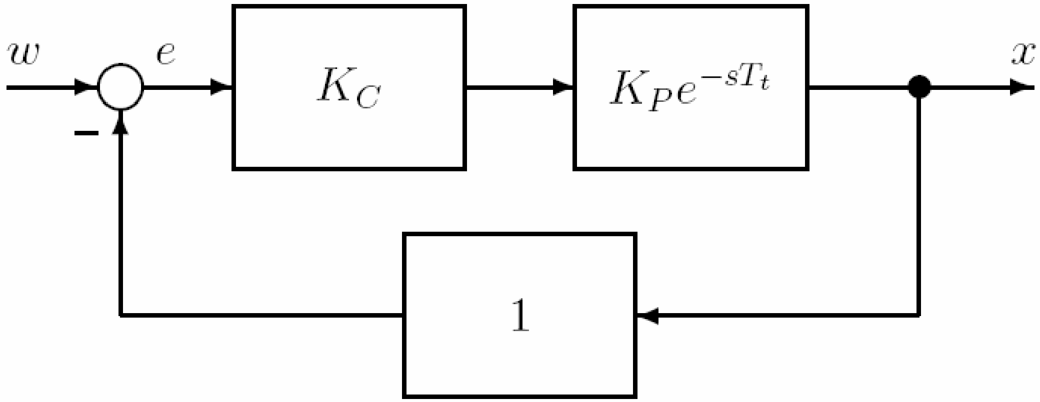


Figure II.7: Feedback control system with time-delay plant, P-controller and sensor

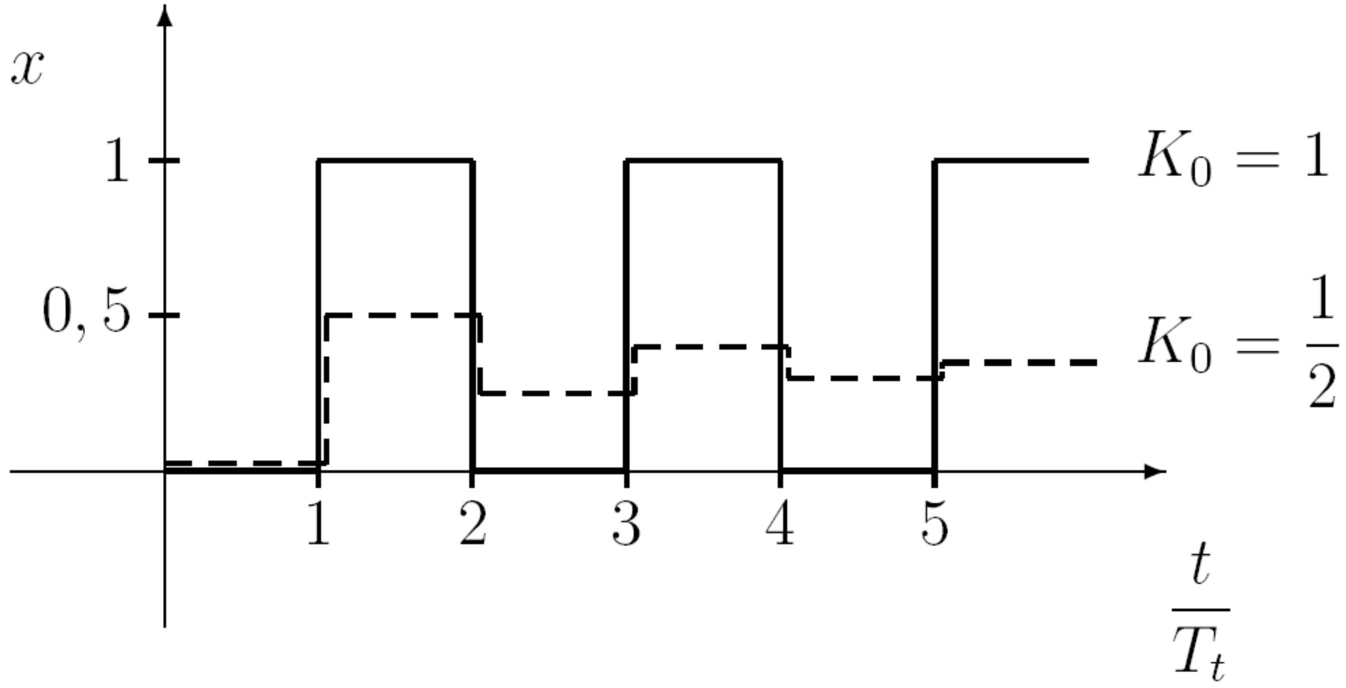
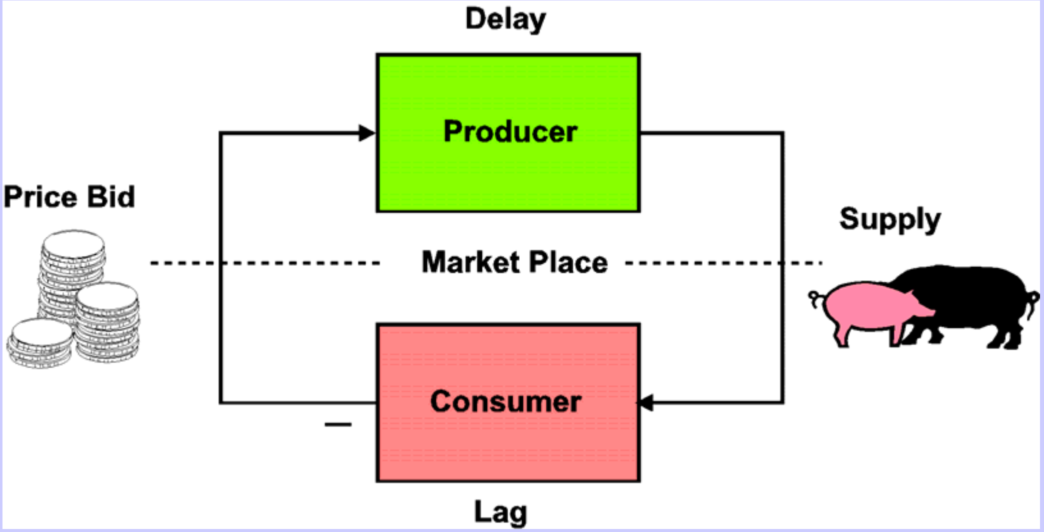
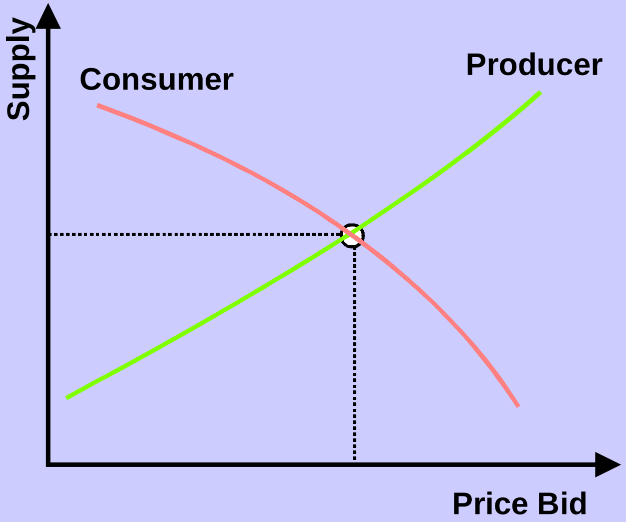


Figure II.8: Step responses of time delay control system





Market Mechanism - A Feedback System: Explanation of Business or Economic Cycles

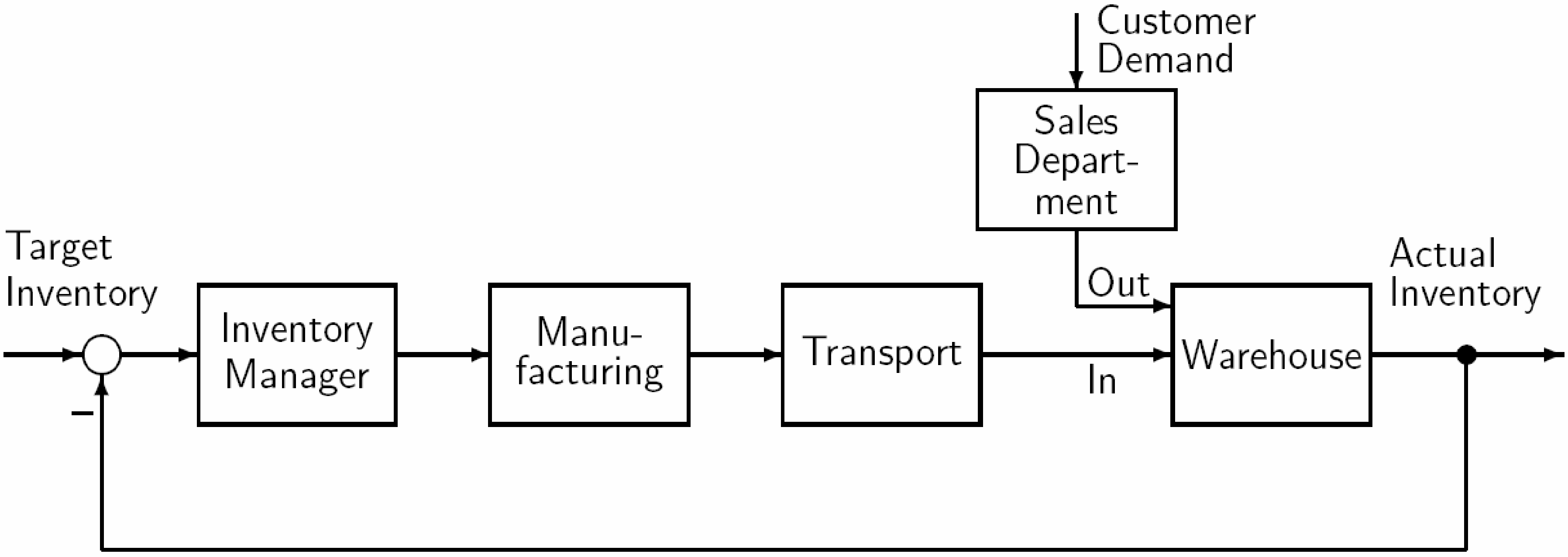


Figure II.9: Warehouse Inventory Control

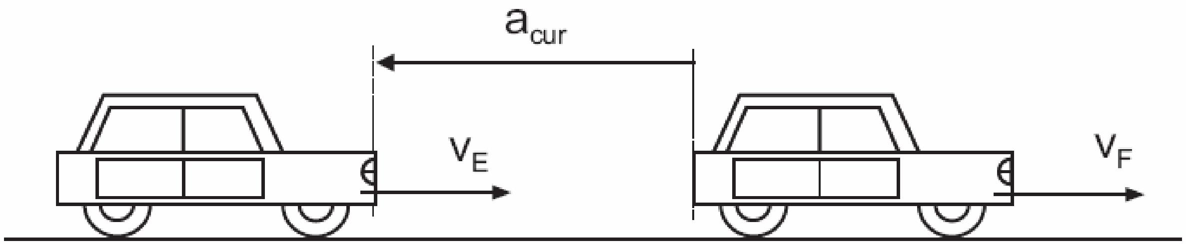


Figure II.10: Vehicle queue with vehicle E to be (safely) distance controlled

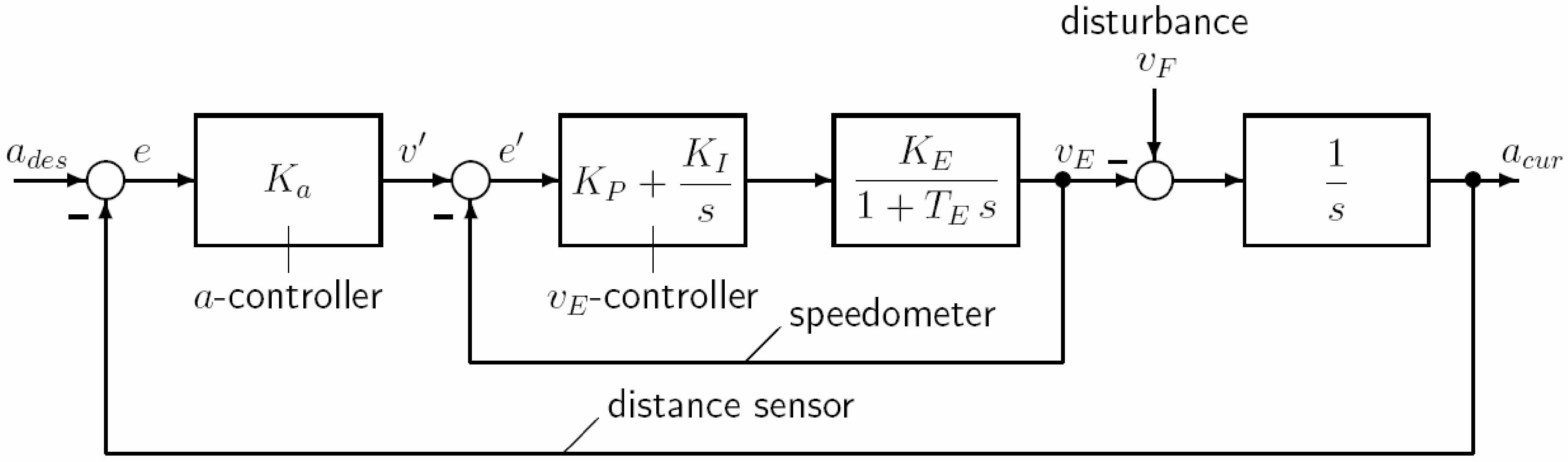


Figure II.11: Scheme of cascaded speed/distance control system for cruise control around operating point $v_{E_0} = v_{F_0}$*, e.g. 75 km/h*

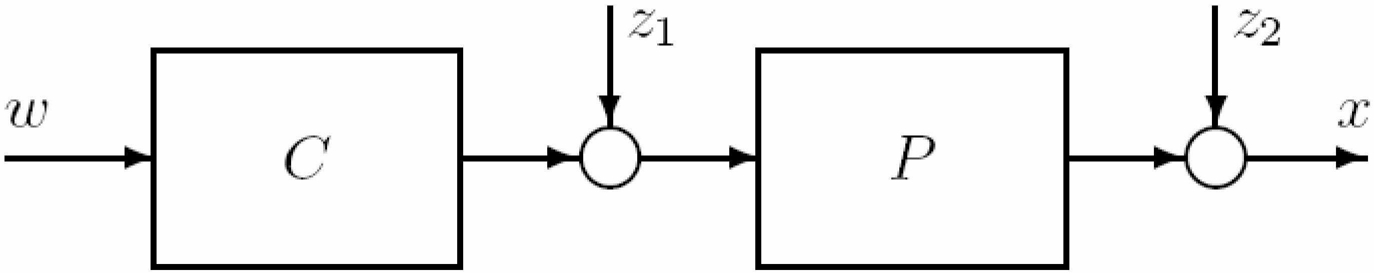


Figure II.12: Block diagram of open-loop control system

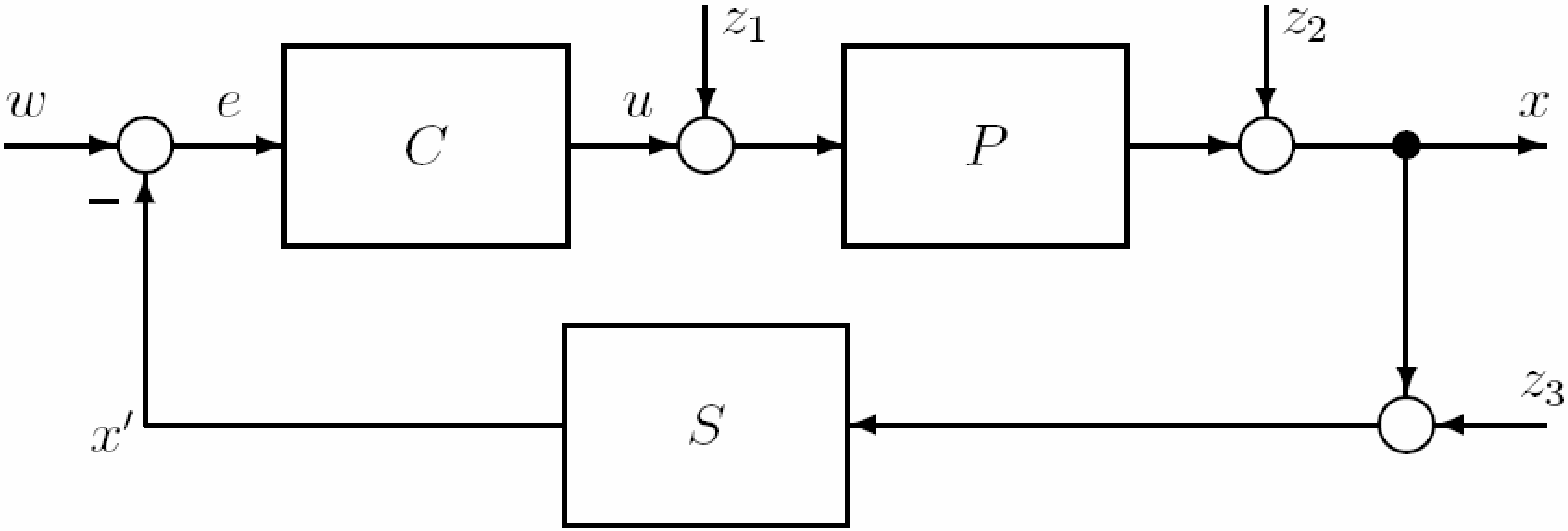


Figure II.13: Block diagram of single loop feedback control system

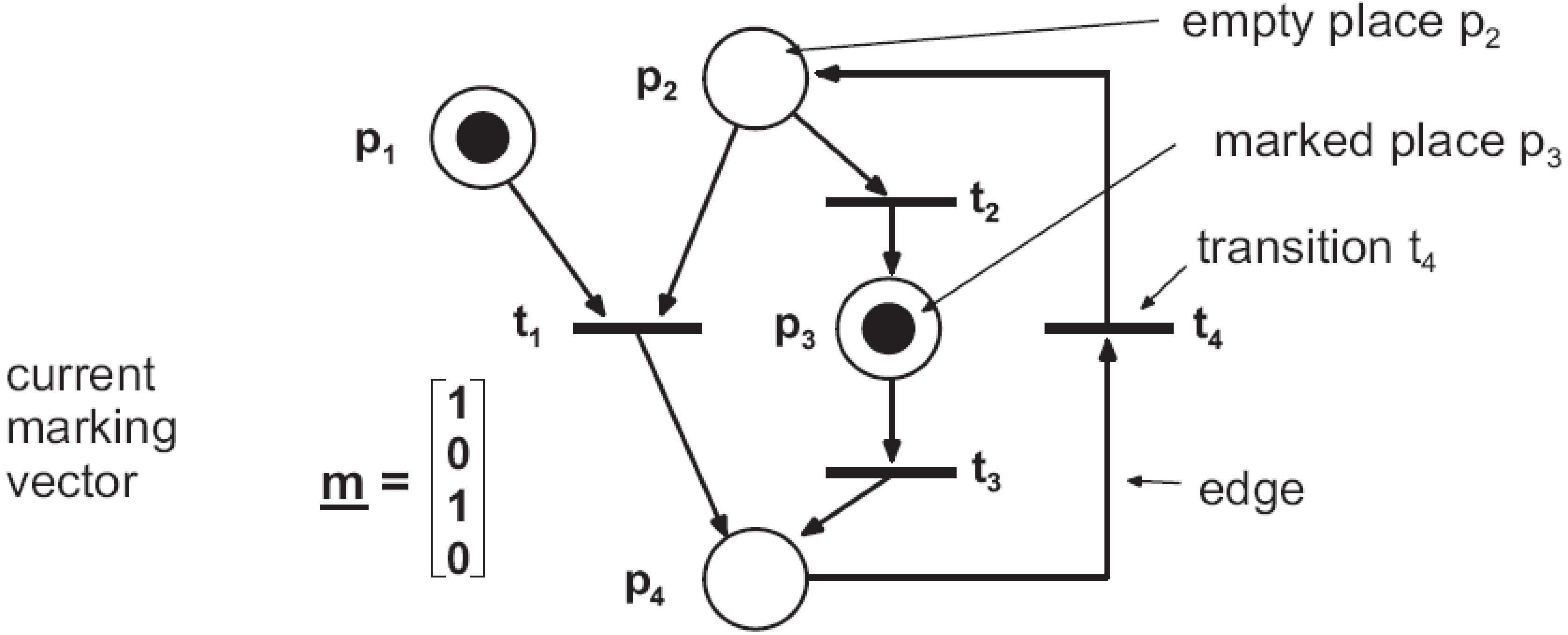


Figure II.14: Example of single-token Petri net

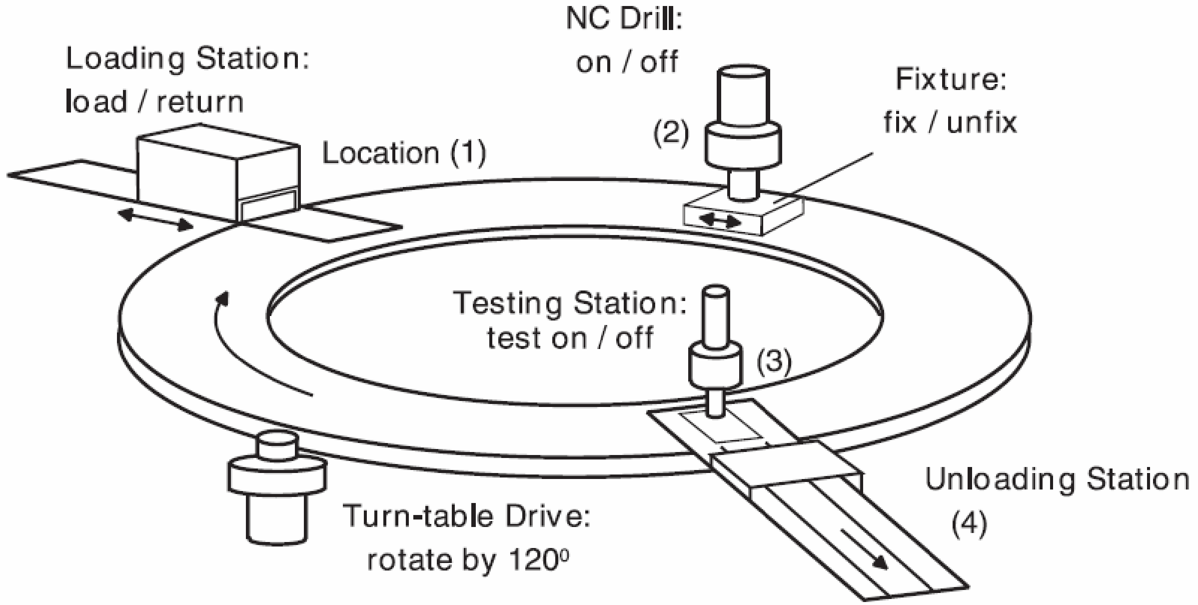
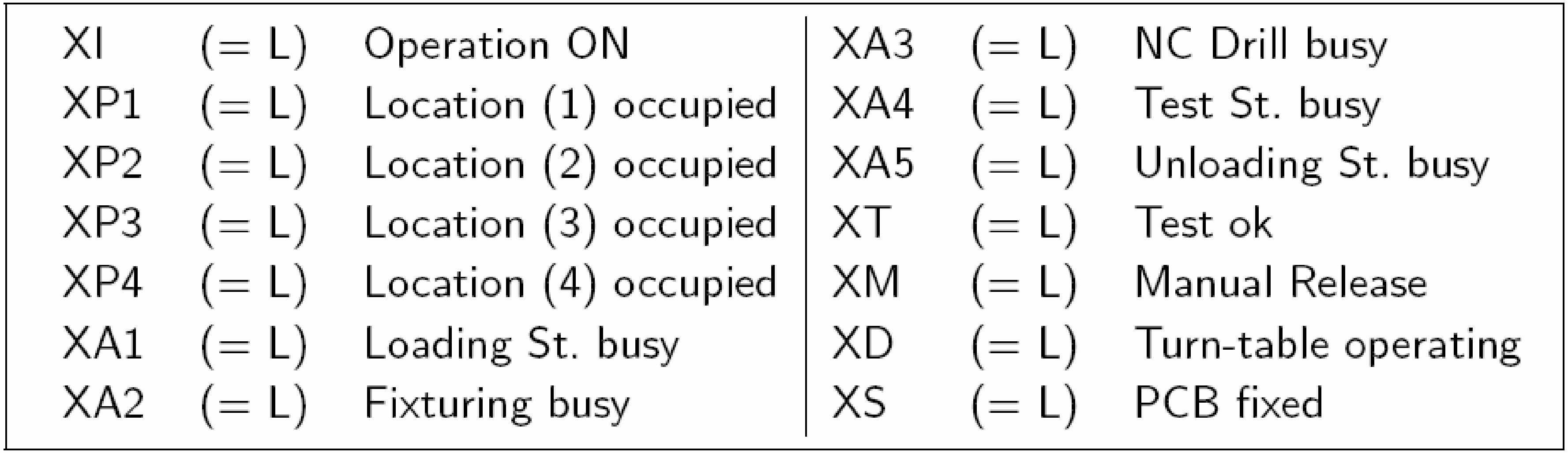
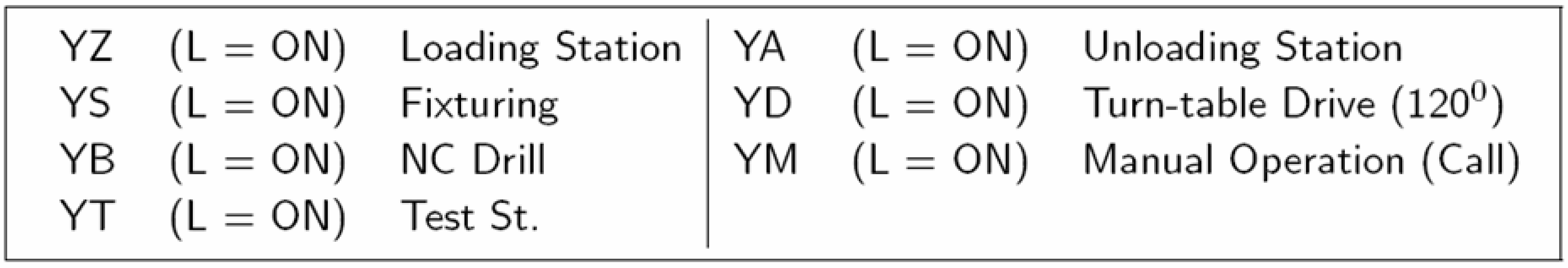


Figure II.15: Coordination of the 4 resources within a workcell for PCB manufacturing



XI	$(=\mathrm{L})$	Operation ON	XA3	$(=\mathrm{L})$	NC Drill busy
XP1	$(=\mathrm{L})$	Location (1) occupied	XA4	$(=\mathrm{L})$	Test St. busy
XP2	$(=\mathrm{L})$	Location (2) occupied	XA5	$(=\mathrm{L})$	Unloading St. busy
XP3	$(=\mathrm{L})$	Location (3) occupied	XT	$(=\mathrm{L})$	Test ok
XP4	$(=\mathrm{L})$	Location (4) occupied	XM	$(=\mathrm{L})$	Manual Release
XA1	$(=\mathrm{L})$	Loading St. busy	XD	$(=\mathrm{L})$	Turn-table operating
XA2	$(=\mathrm{L})$	Fixturing busy	XS	$(=\mathrm{L})$	PCB fixed

Figure II.16: Input signals to coordination controller



YZ	(L = ON)	Loading Station	YA	(L = ON)	Unloading Station
YS	(L = ON)	Fixturing	YD	(L = ON)	Turn-table Drive (120^0)
YB	(L = ON)	NC Drill	YM	(L = ON)	Manual Operation (Call)
YT	(L = ON)	Test St.			

Figure II.17: Output signals from coordination controller

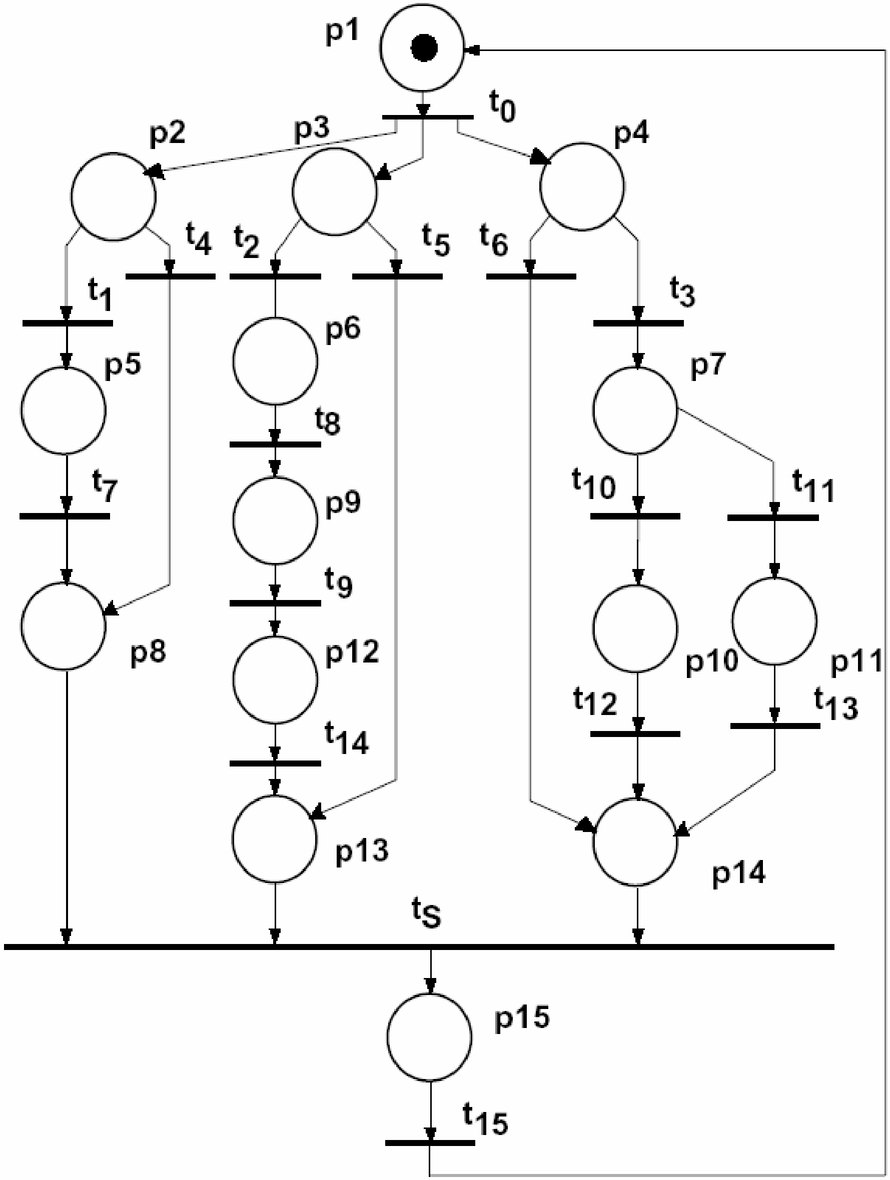
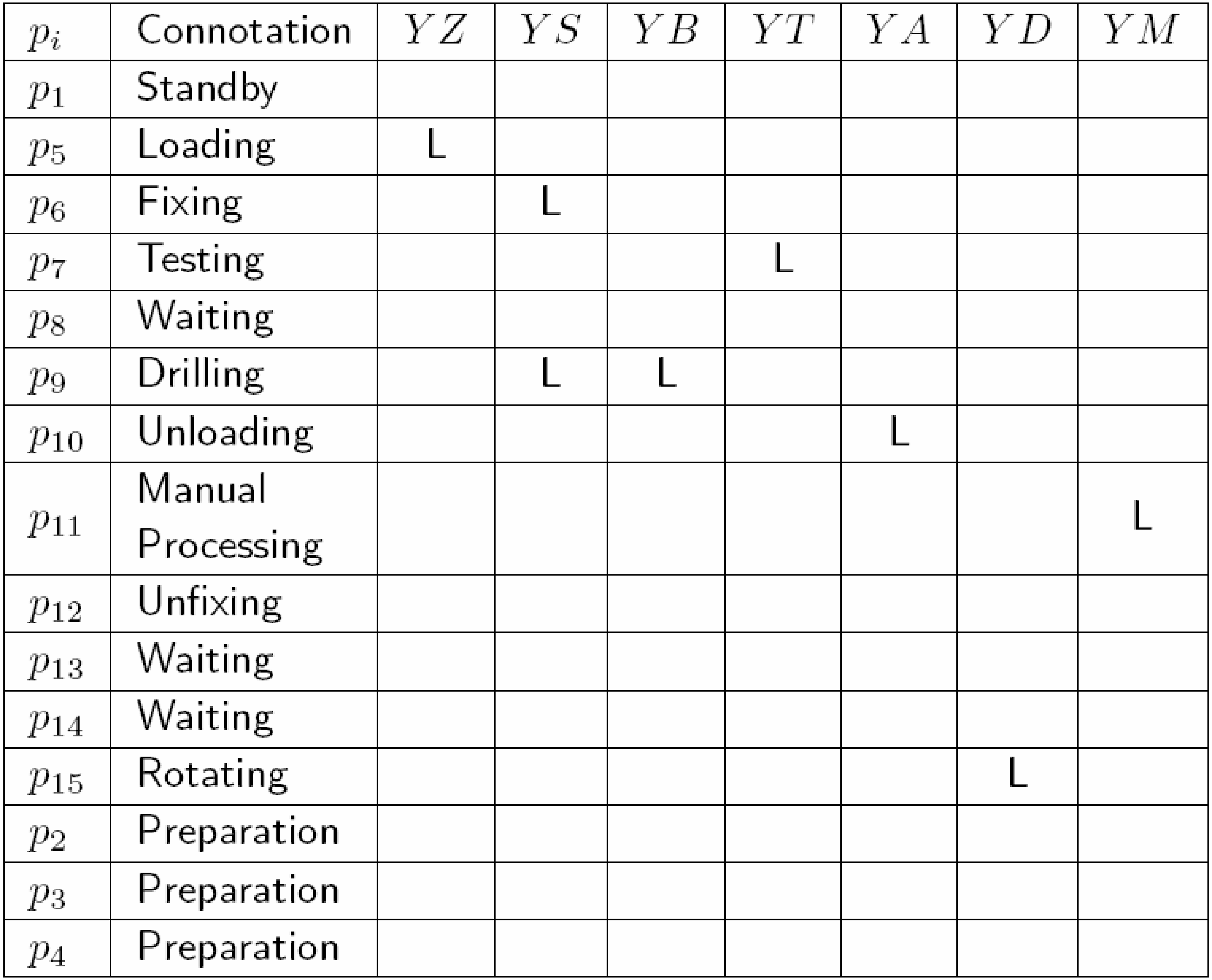
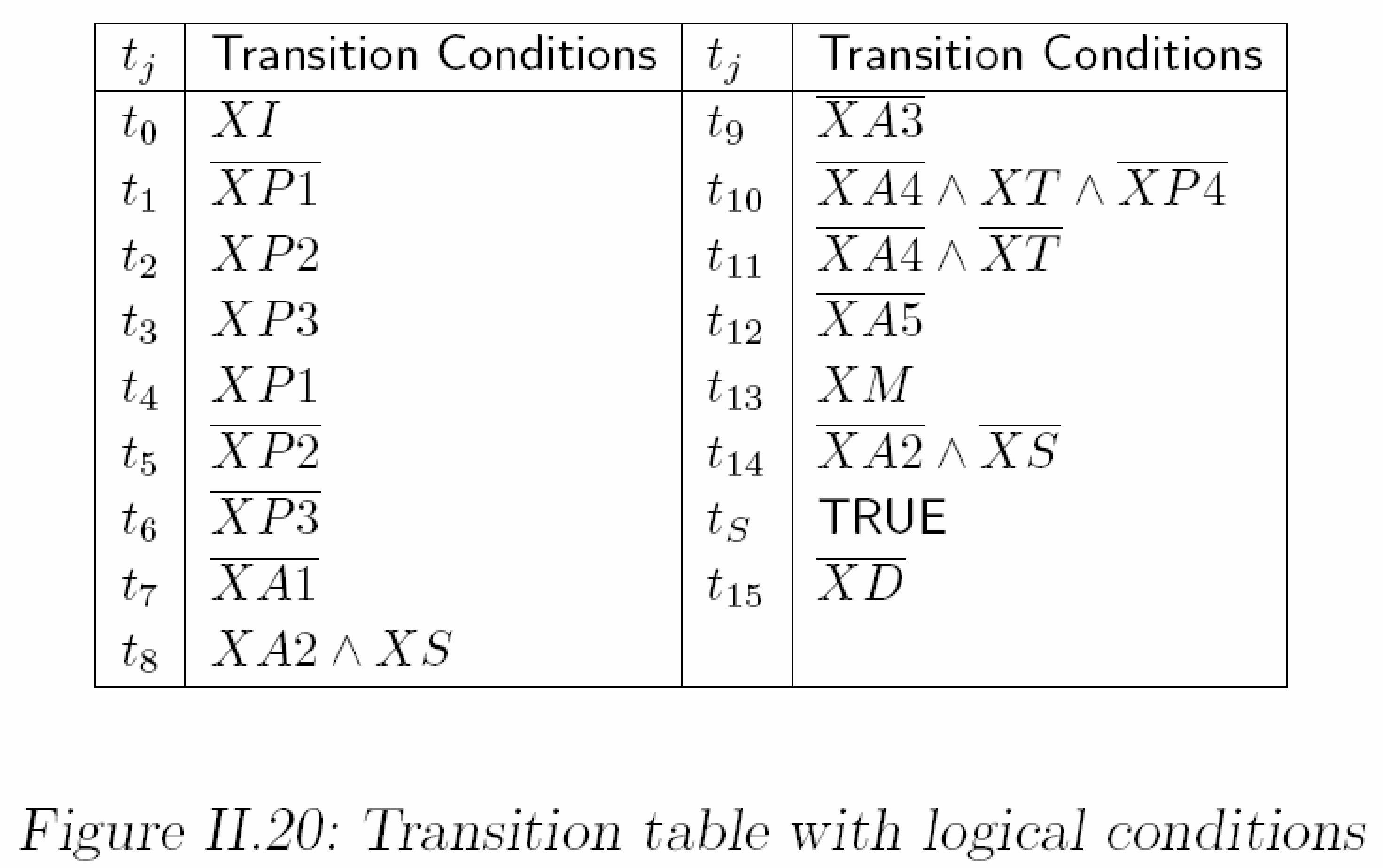


Figure II.18: CIPN-model of coordination controller with initial marking



p_i	Connotation	YZ	YS	YB	YT	YA	YD	YM
p_1	Standby							
p_5	Loading	L						
p_6	Fixing		L					
p_7	Testing				L			
p_8	Waiting							
p_9	Drilling		L	L				
p_{10}	Unloading					L		
p_{11}	Manual Processing							L
p_{12}	Unfixing							
p_{13}	Waiting							
p_{14}	Waiting							
p_{15}	Rotating						L	
p_2	Preparation							
p_3	Preparation							
p_4	Preparation							

Figure II.19: Output (actuator) table



t_j	Transition Conditions	t_j	Transition Conditions
t_0	XI	t_9	$\overline{XA3}$
t_1	$\overline{XP1}$	t_{10}	$\overline{XA4} \wedge XT \wedge \overline{XP4}$
t_2	$XP2$	t_{11}	$\overline{XA4} \wedge \overline{XT}$
t_3	$XP3$	t_{12}	$\overline{XA5}$
t_4	$XP1$	t_{13}	XM
t_5	$\overline{XP2}$	t_{14}	$\overline{XA2} \wedge \overline{XS}$
t_6	$\overline{XP3}$	t_S	TRUE
t_7	$\overline{XA1}$	t_{15}	$\overline{XD}$
t_8	$XA2 \wedge XS$		

Figure II.20: Transition table with logical conditions

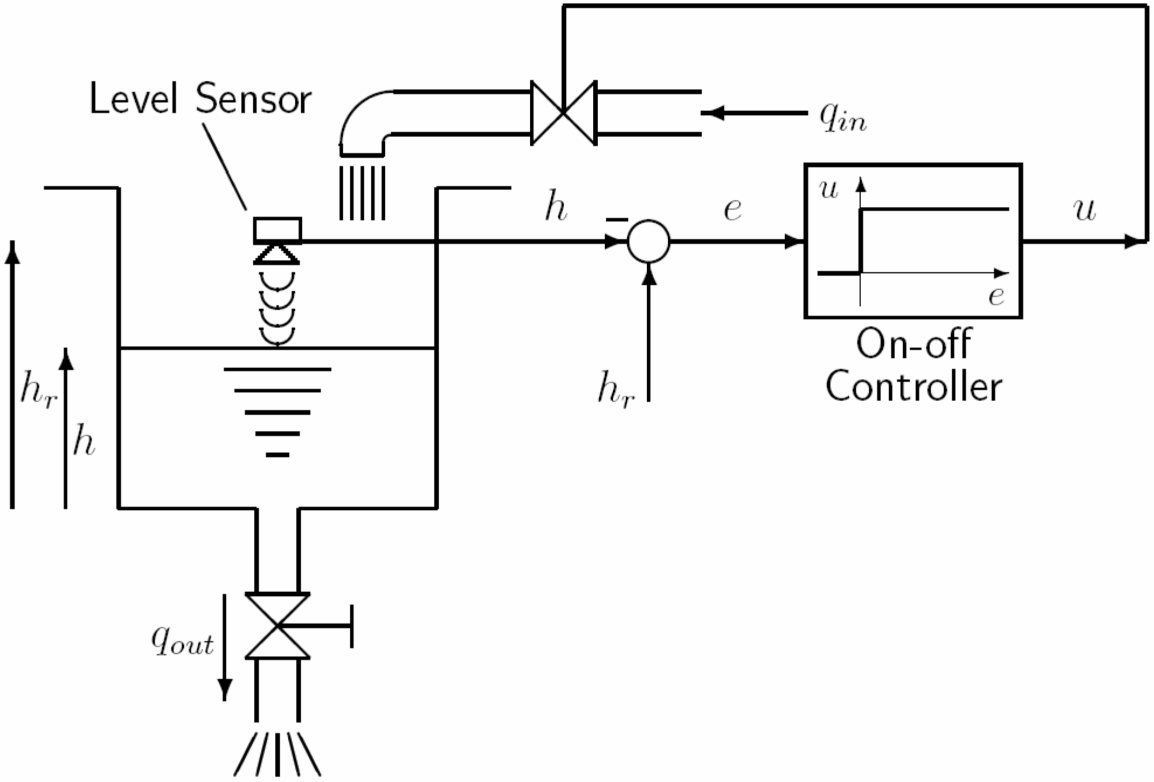


Figure II.21: Liquid level control system with US level sensor and on-off controller showing controller switching characteristic

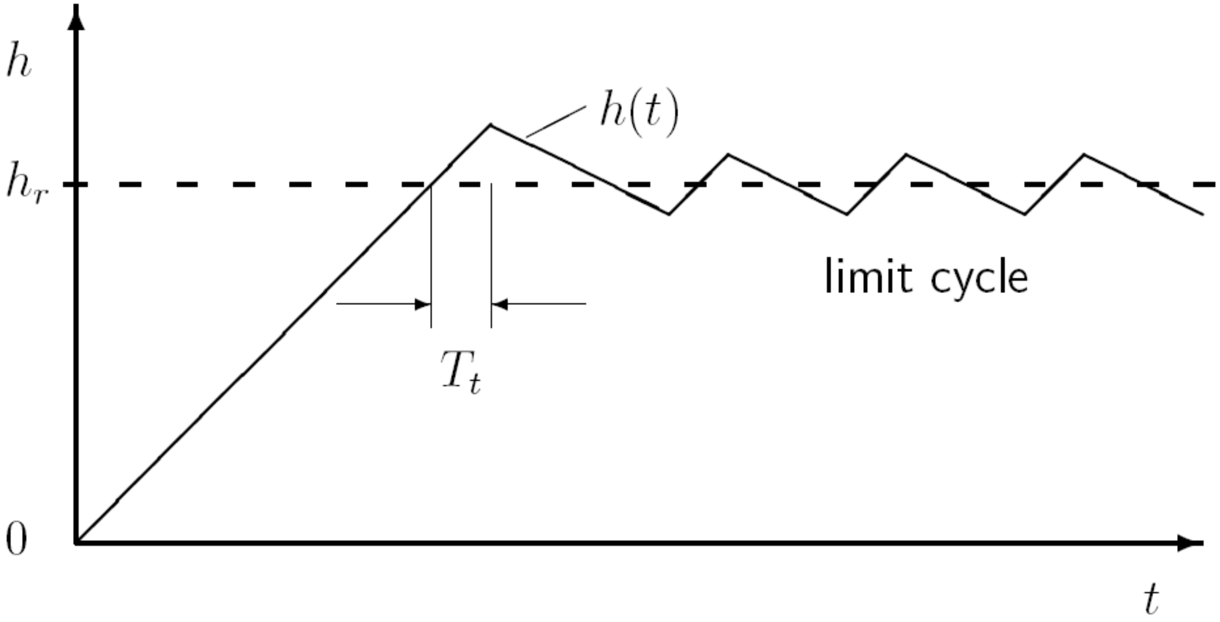
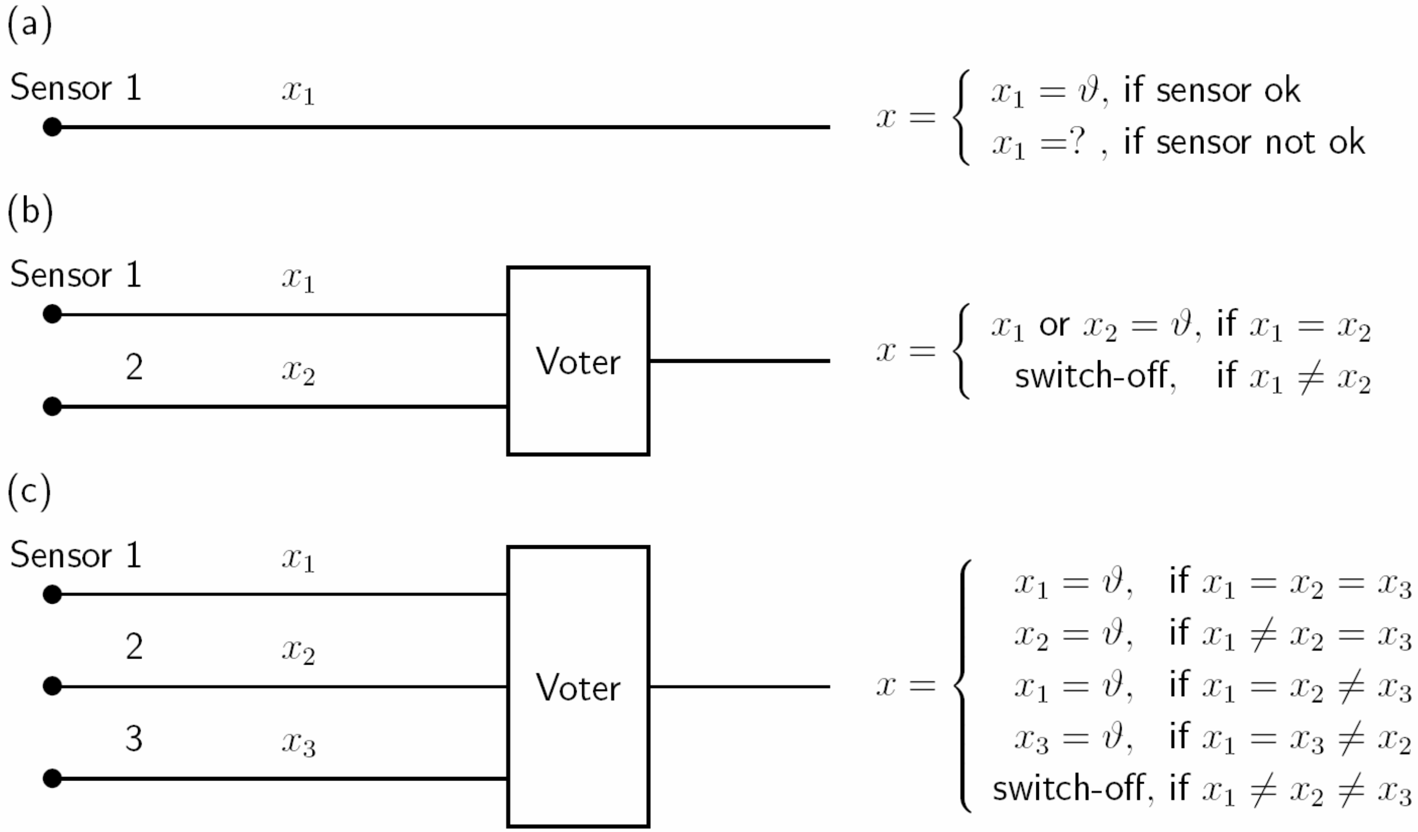


Figure II.22: Time response of level control loop with limit cycle in the steady state



$$x = \begin{cases} x_1 = \vartheta, \text{ if sensor ok} \\ x_1 = ?\ , \text{ if sensor not ok} \end{cases}$$

$$x = \begin{cases} x_1 \text{ or } x_2 = \vartheta, \text{ if } x_1 = x_2 \\ \text{switch-off}, \quad \text{if } x_1 \neq x_2 \end{cases}$$

$$x = \begin{cases} x_1 = \vartheta, & \text{if } x_1 = x_2 = x_3 \\ x_2 = \vartheta, & \text{if } x_1 \neq x_2 = x_3 \\ x_1 = \vartheta, & \text{if } x_1 = x_2 \neq x_3 \\ x_3 = \vartheta, & \text{if } x_1 = x_3 \neq x_2 \\ \text{switch-off}, & \text{if } x_1 \neq x_2 \neq x_3 \end{cases}$$

Figure II.23: Hardware-based redundancy schemes for sensing: simplex (a), duplex (b) and triplex configuration (c)