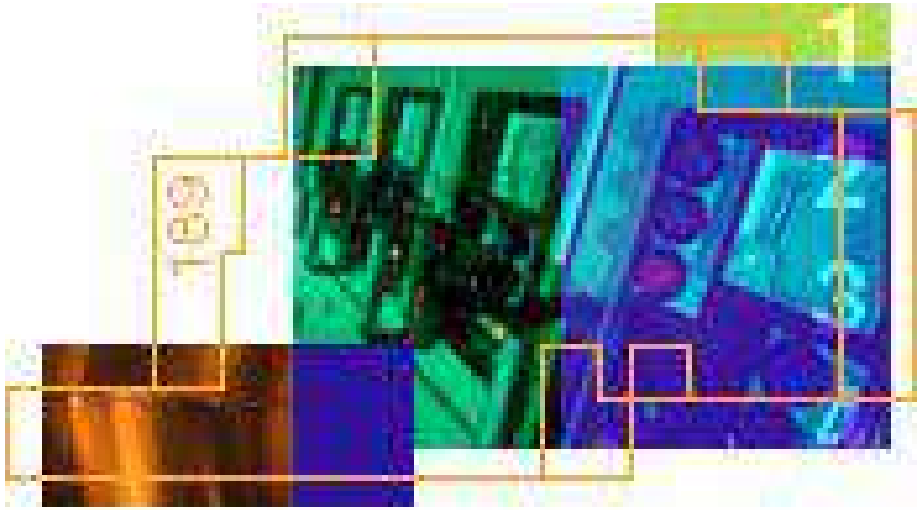
Industrial Automation
Automation Industrielle
Industrielle Automation



Automation Overview

1.1 *Automation -vue d'ensemble*
Automation - Übersicht

Prof. Dr. H. Kirrmann
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Contents

Automation Applications

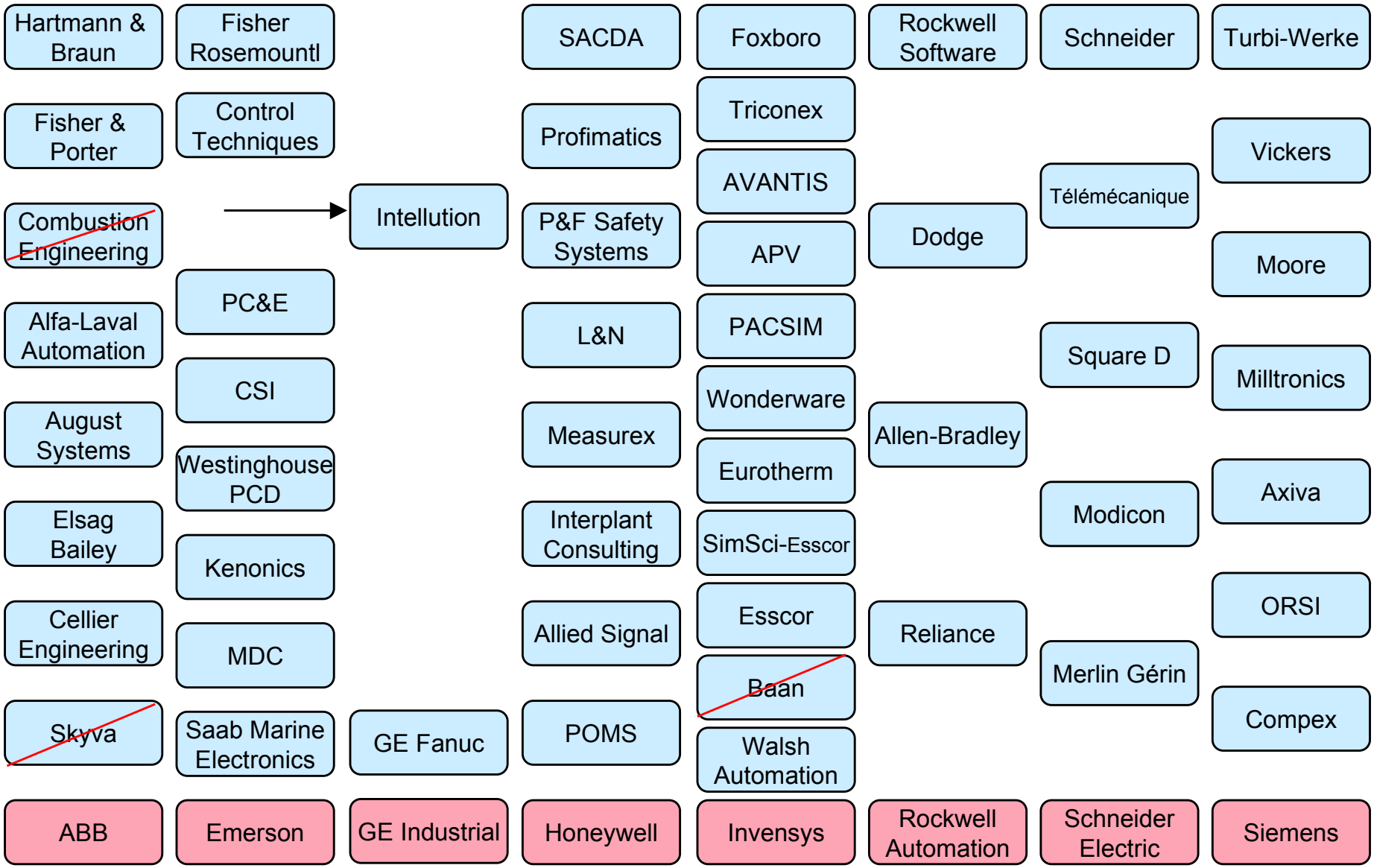
Power generation	hydro, coal, gas, oil, shale, nuclear, wind, solar
Transmission	electricity, gas, oil
Distribution	electricity, water
Process	paper, food, pharmaceutical, metal production and processing, glass, cement, chemical, refinery, oil & gas
Manufacturing	computer aided manufacturing (CIM) flexible fabrication, appliances, automotive, aircrafts
Storage	silos, elevator, harbor, retail houses, deposits, luggage handling
Building	heat, ventilation, air conditioning (HVAC) access control, fire, energy supply, tunnels, parking lots, highways,....
Transportation	rolling stock, street cars, sub-urban trains, busses, trolley busses, cars, ships, airplanes, rockets, satellites,...

Automation Systems - World Players

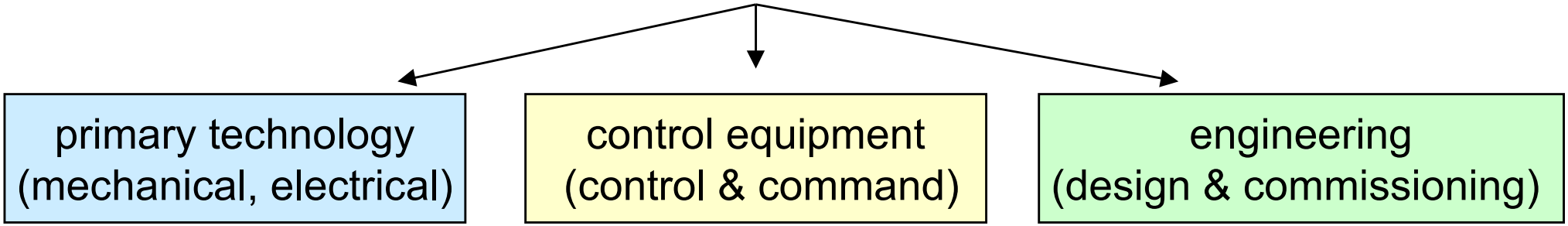
Company (alpha. order)	Location	Major mergers
ABB	CH-SE	Brown Boveri, ASEA, CE, Alfa-Laval, Elsag-Bailey
Alstom	FR	Alsthom, GEC, CEGELEC, ABB Power,..
Ansaldo	IT	
Emerson	US	Fisher Rosemount
General Electric	US	
Hitachi	JP	
Honeywell	US	
Rockwell Automation	US	Allen Bradley, Rockwell,..
Schneider Electric	FR	Télémécanique, Square-D, ...
Invensys	UK	Foxboro, Siebe, BTR, Triconex,…
Siemens	DE	Plessey, Landis & Gyr, Stäfa, Cerberus,..
Yokogawa	JP	

€ 80 Mia / year business
(depends on viewpoint),
growing 5 % annually

Worldwide Consolidation Process: the Big Eight



Three distinct businesses



general contractor: organizes the suppliers of the different components.

turnkey factory: the client only hires consultants to supervise the contractor

increasingly, the general contractor has to pay itself by operating the plant.

increasingly, the suppliers are paid on results….

plant:
site, usine, centrale (électricité)
Prozess, Werk, Fabrik, Kraftwerk

Life-phases of a Plant (Example: Rail Vehicle)

Manufacturers

Equipment Design
(développement, Entwicklung*)*

Equipment Production
(production, Herstellung*)*

Assembler (ensemblier)

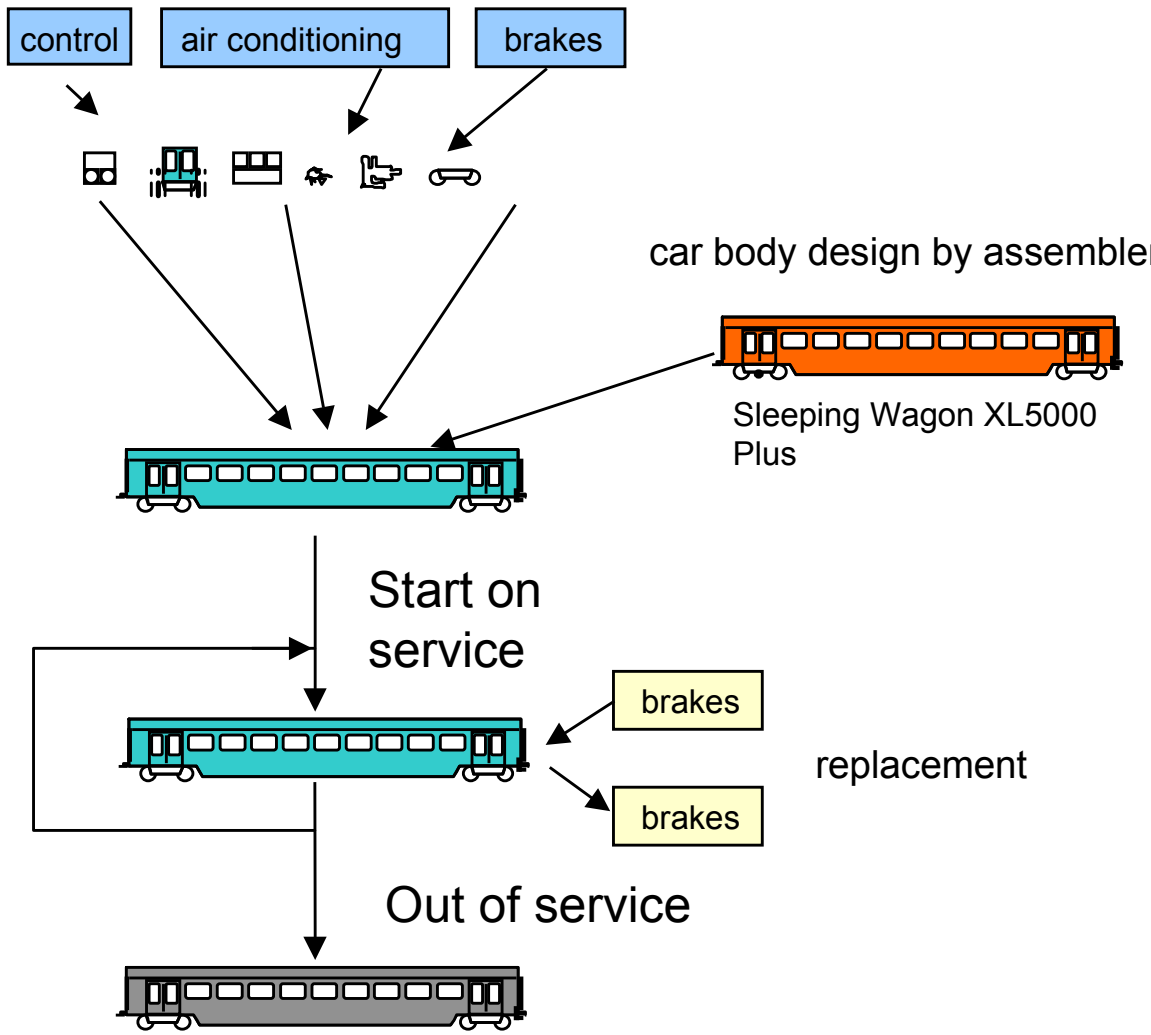
Engineering
(bureau d'étude, Projektierung*)*

Commissioning
(mise en service, Inbetriebnahme*)*

Client, Service

Maintenance
(entretien, Unterhalt*)*

Recycling
(Recyclage, Wiederverwertung*)*



Technical necessity of automation

- Processing of the information flow
- Enforcement of safety and availability
- Reduction of personal costs

Expectations of automation

Process Optimisation

- Energy, material and time savings
- Quality improvement and stabilisation
- Reduction of waste, pollution control
- Compliance with regulations and laws, product tracking
- Increase availability, safety
- Fast response to market
- Connection to management and accounting (SAP™)

-> Acquisition of large number of “Process Variables”, data mining

Personal costs reduction

- Simplify interface
- Assist decision
- Require data processing, displays, data base, expert systems

-> Human-Machine Interface (MMC = Man-Machine Communication)

Asset Optimisation (gestion des moyens de production)

- Automation of engineering, commissioning and maintenance
- Software configuration, back-up and versioning
- Life-cycle control
- Maintenance support

-> Engineering Tools

Data quantity in plants

Power Plant 25 years ago

100 measurement and action variables (called "points")
Analog controllers, analog instruments
one central "process controller" for data monitoring and protocol.

Coal-fired power plant today

10'000 points, comprising
8'000 binary and analog measurement points and
2'000 actuation point
1'000 micro-controllers and logic controllers

Nuclear Power Plant

three times more points than in conventional power plants

Electricity distribution network

100’000 - 10’000’000 points
information flow to the personal: > 5 kbit/s.
human processing capacity: about 25 bit/s
without computers, 200 engineers (today: 3)

Data reduction and processing is necessary to operate plants

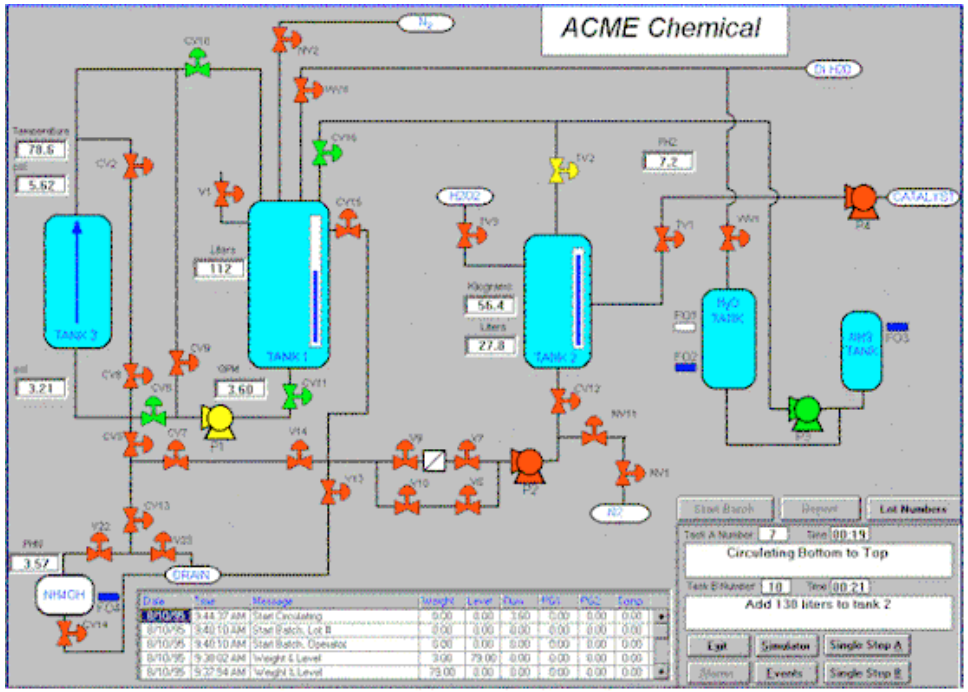
Assessment

How is automation justified ?

Which are the expectations put on automation ?

What quantity of data can be expected in a typical plant ?


EPFL



Automation Examples
1.2 *Exemples de sites automatisés*
Beispiele Automatisierungssysteme

Prof. Dr. H. Kirrmann

EPFL /ABB Research Center, Baden, Switzerland

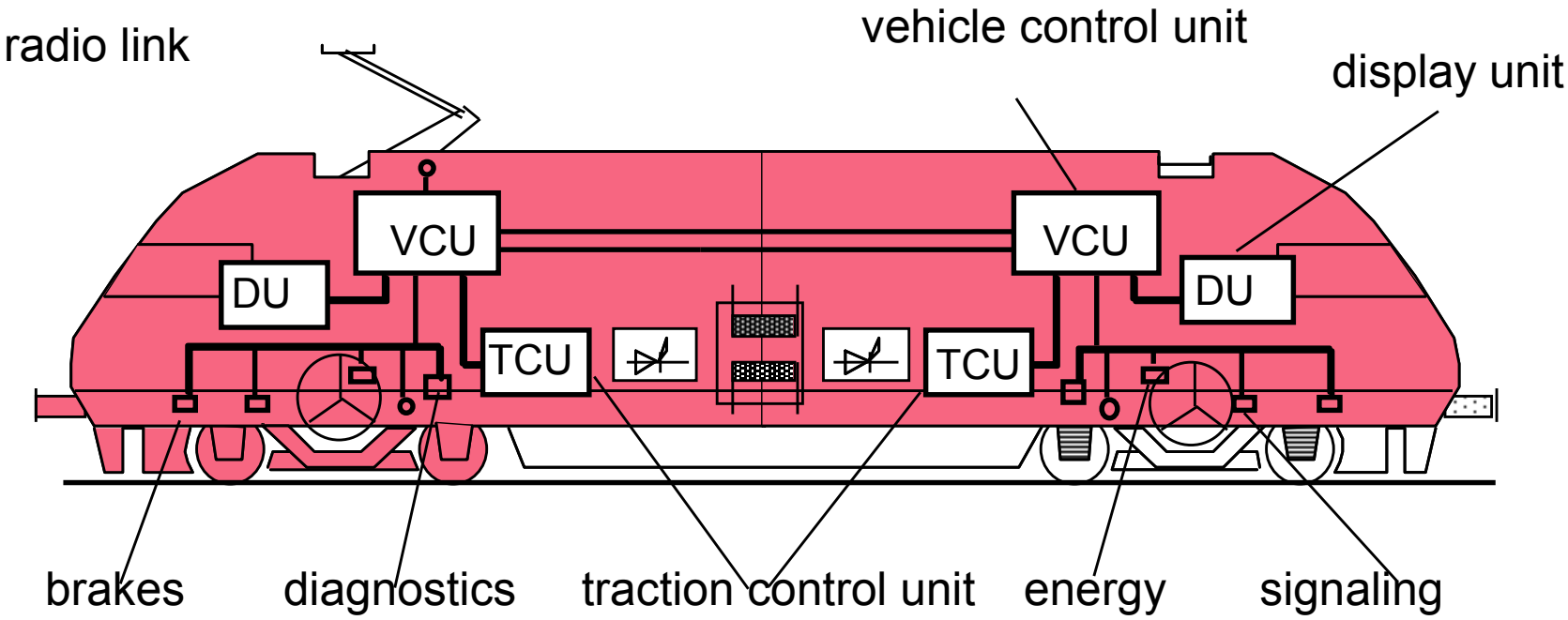
Examples of Automated Plants

Cars

traditional: appliances control (windows, seats, radio,..)
motor control (exhaust regulations)
critical new applications: ABS and EPS, brake-by-wire, steer-by-wire (“X-by-wire”)
increased safety ?
extreme price squeezing
2001 US model: 19% of the price is electronics, tendency: +10% per year.

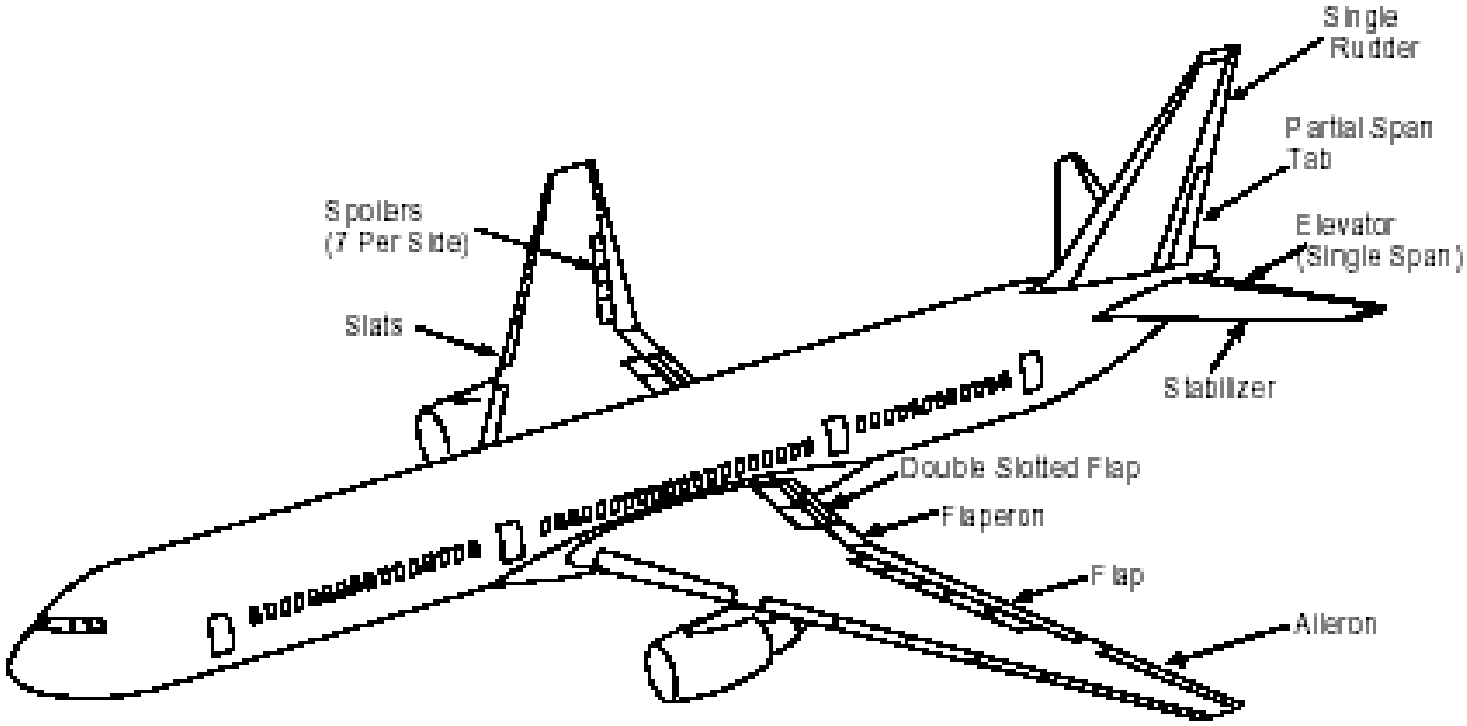
Rail vehicles

there are more than 20 interconnected computers on a Lok 2000 (SBB 460)



Benefits: reduce operation costs, faster diagnostics, better energy management, automatic train control.

Airplanes

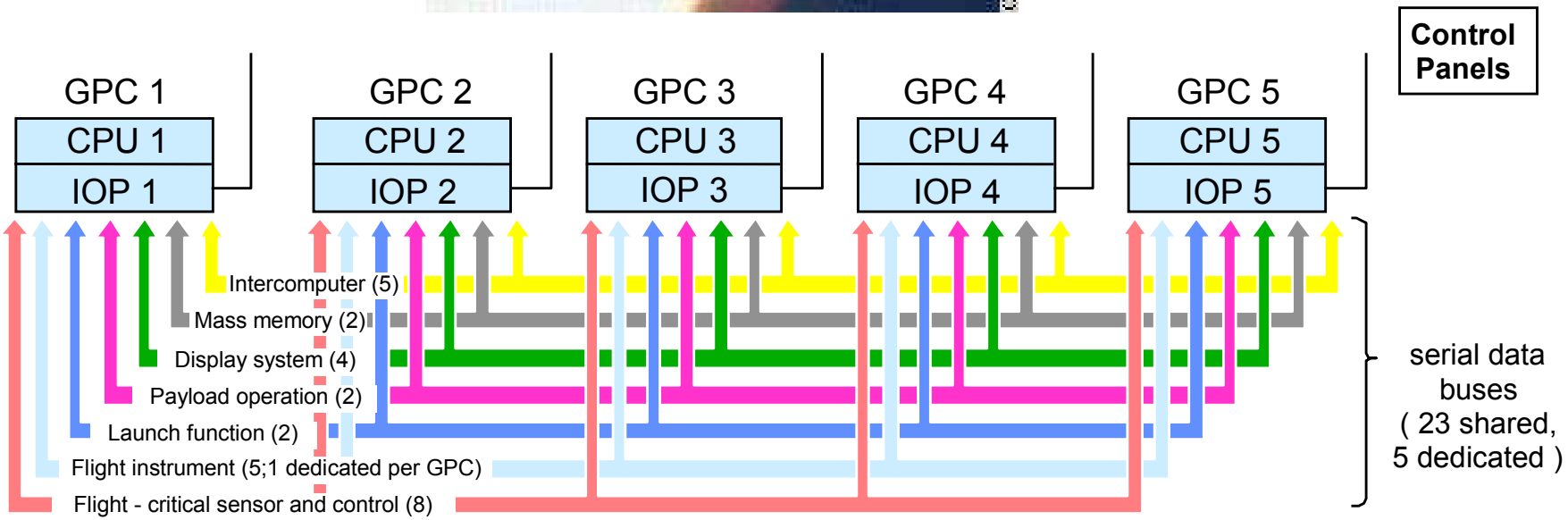


777 FLIGHT CONTROL SURFACES

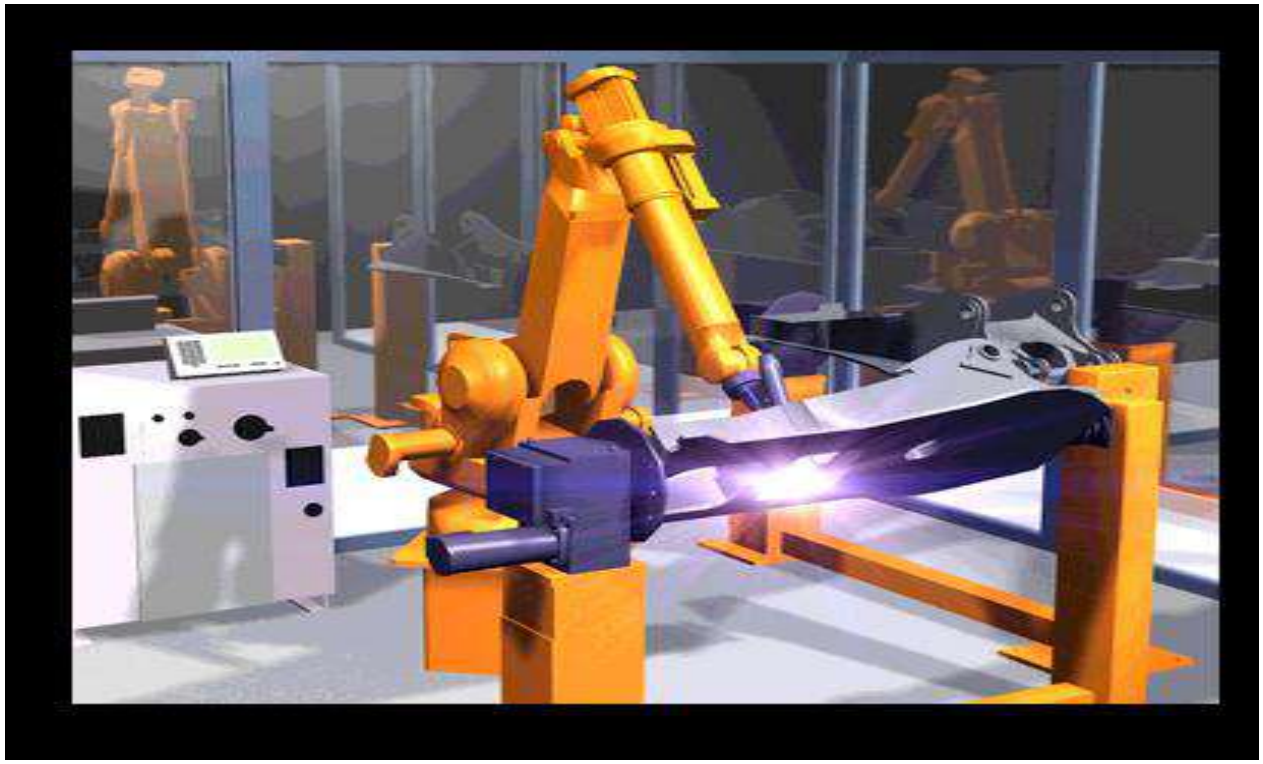
"avionics":
flight control (safe envelope, autopilot, "engineer")
flight management
flight recording (black boxes, turbine FATC)
diagnostics
"fly-by-wire"

high reliability

Launch vehicles

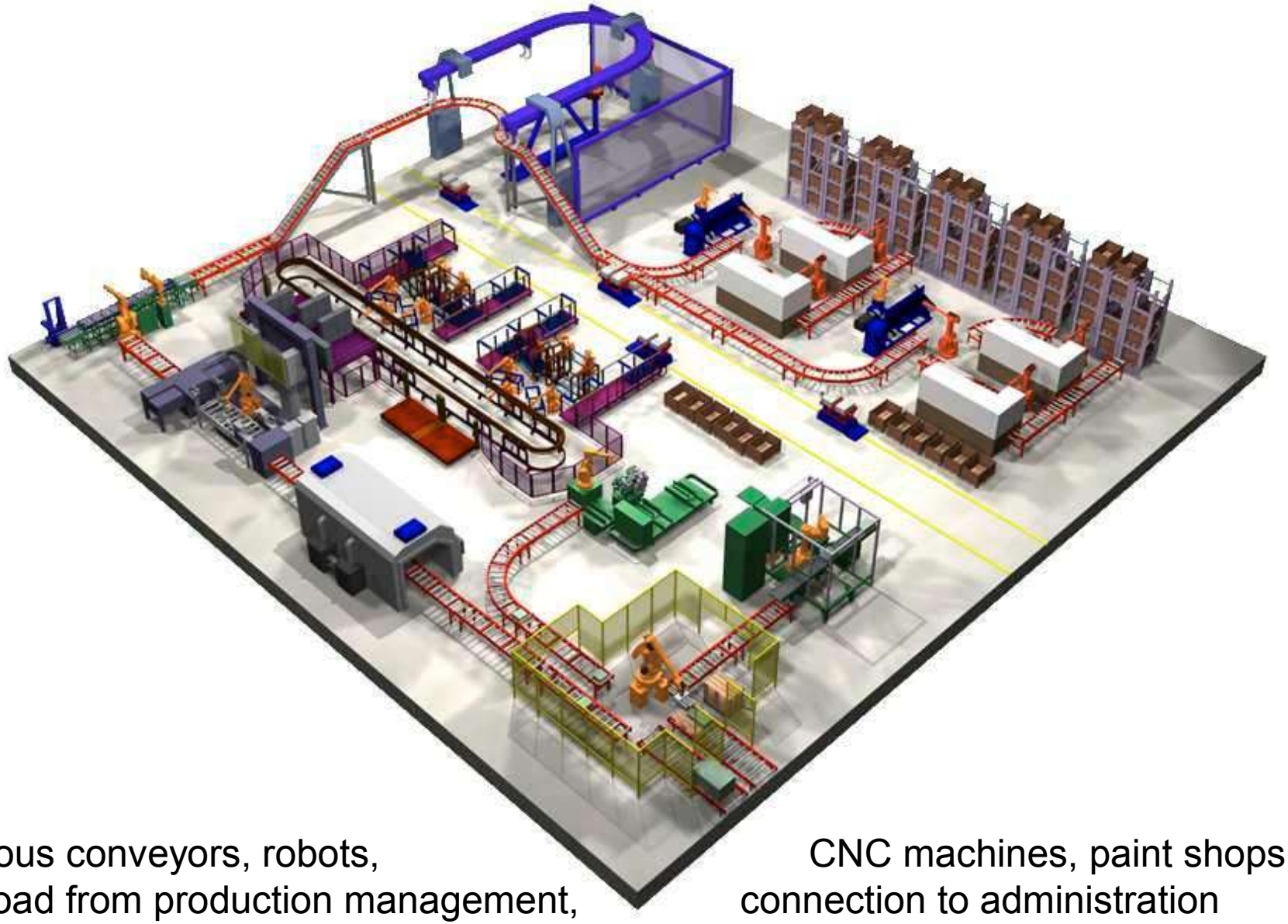


Robots



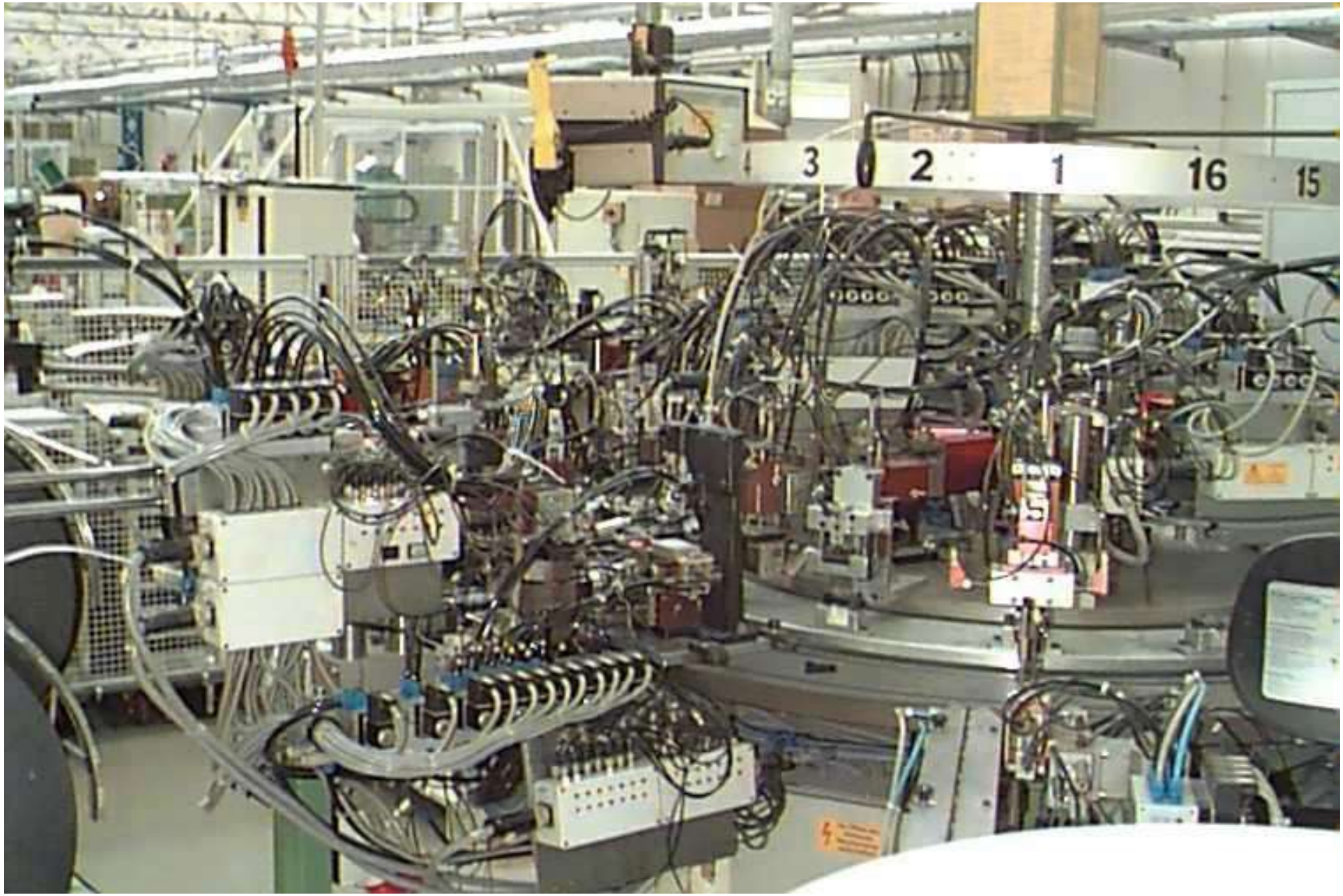
extension limited to 2-3 m (portal robots 10-20m)
frequent reprogramming for new tasks, tooling
simple embedded computer, hierarchical control

Flexible Automation



numerous conveyors, robots, CNC machines, paint shops, logistics.
Download from production management, connection to administration

Manufacturing



Oil & Gas, petrochemicals

"upstream": from the earth to the refinery
down-sea control

special requirement: high pressure, saltwater, inaccessibility
explosive environment with gas.

distribution

special requirement: environmental protection

"downstream": from the oil to derived products

special requirement: extreme explosive environment

Switzerland: Colombey, Cressier

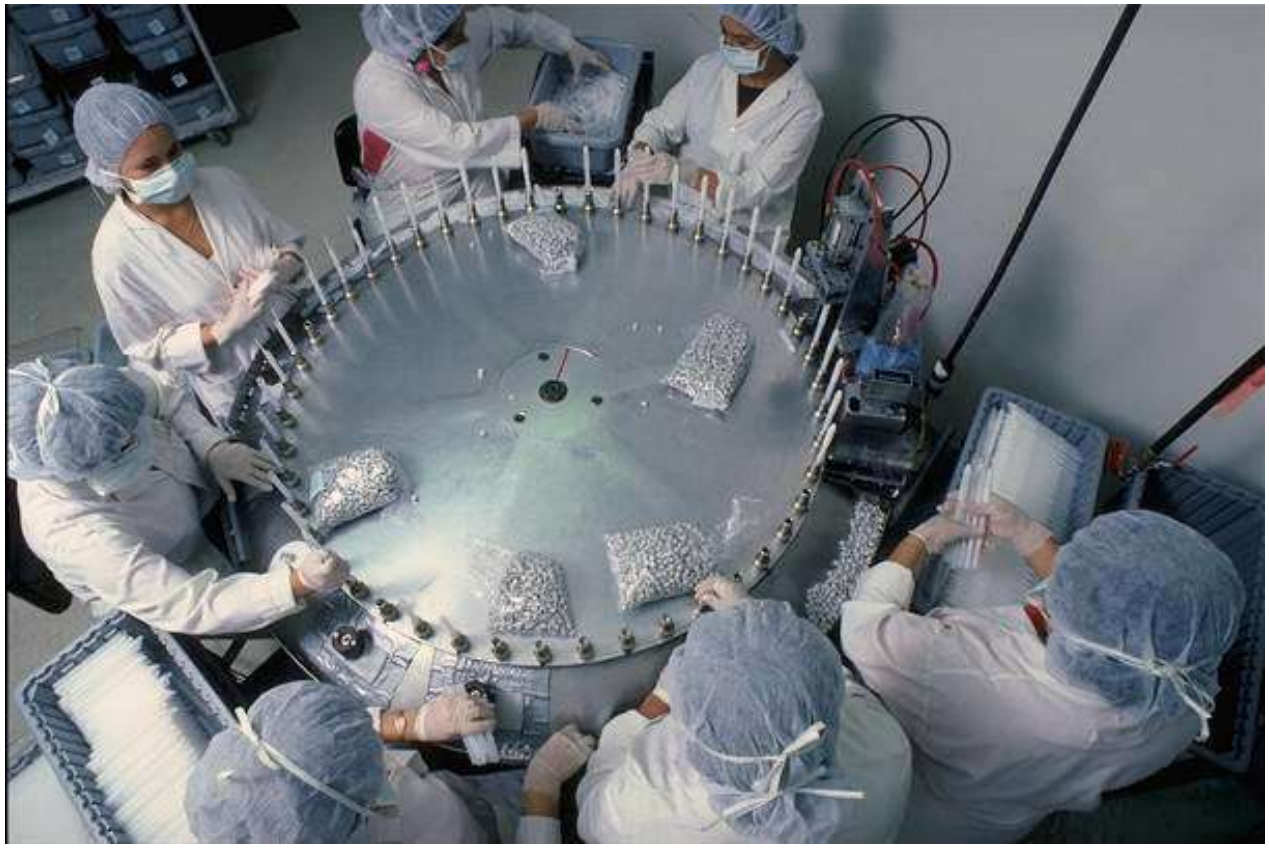
Chemical industry

logistics,
local control of reactors

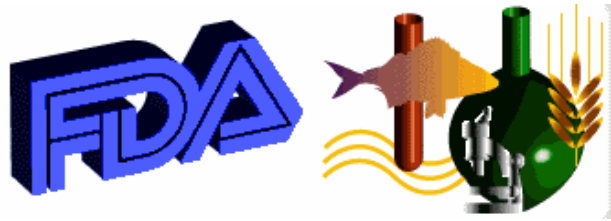
e.g. LONZA

Characterized by batches of products, reuse of production reactors for different product types (after cleaning).

Pharmaceutical Industry

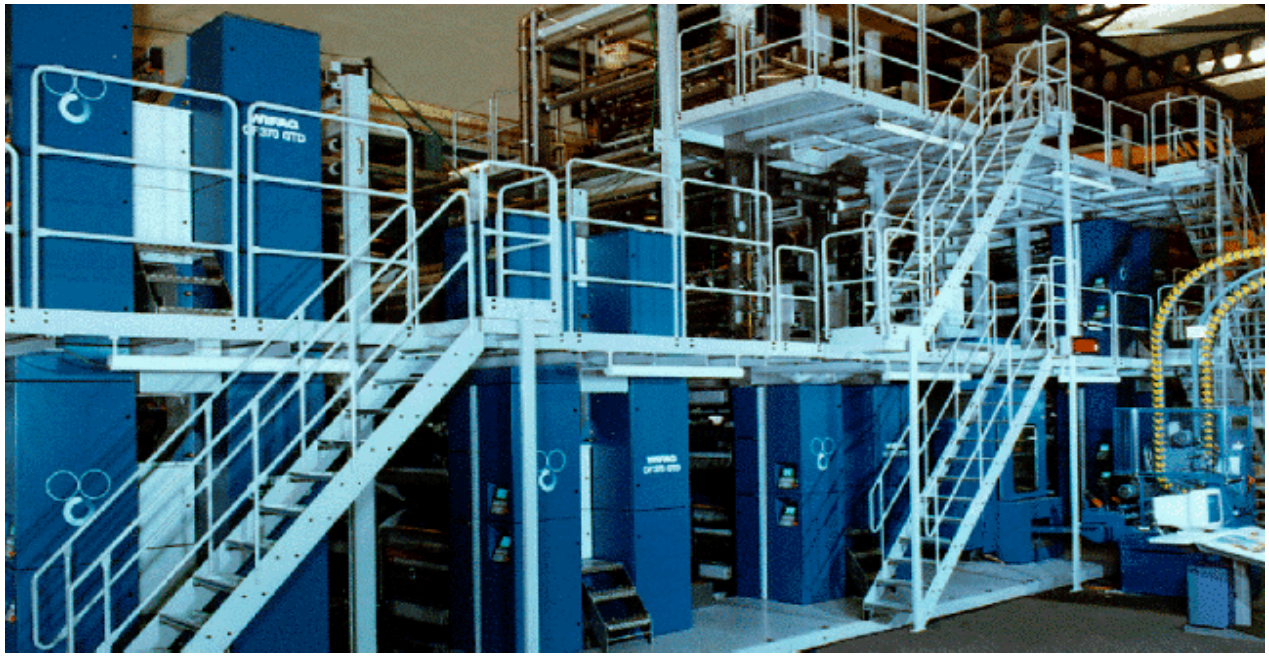


Inventory
Recipe management
Packaging
Sampling
Tracking & tracing
Comply with government rules:



Typical of batch processes.

Printing machines



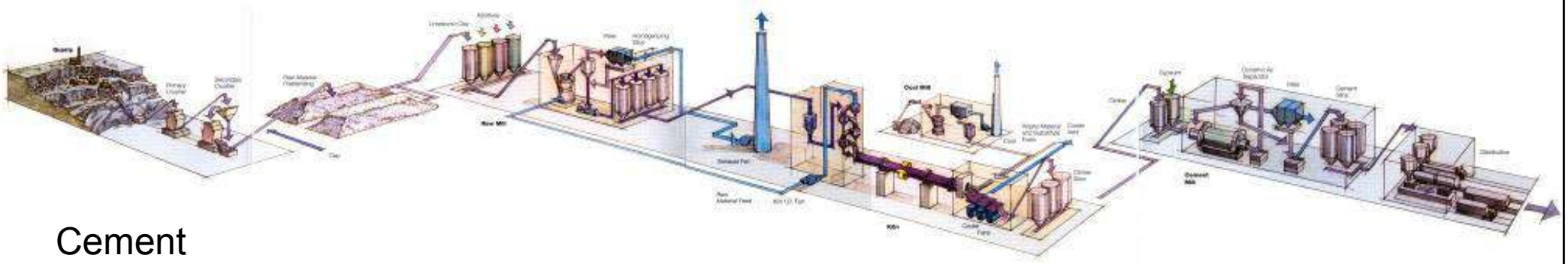
tasks of control system:

- motor control (synchronisation of the printing cylinders)
- ink and water control
- paper web control (reelstands (Rollenwechsler, bobines), web tension, emergency knife)
- interface to operator (commands, alarms)
- production preparation and statistics - up to the press room

very high requirements on availability: two hours delay and the production is lost.

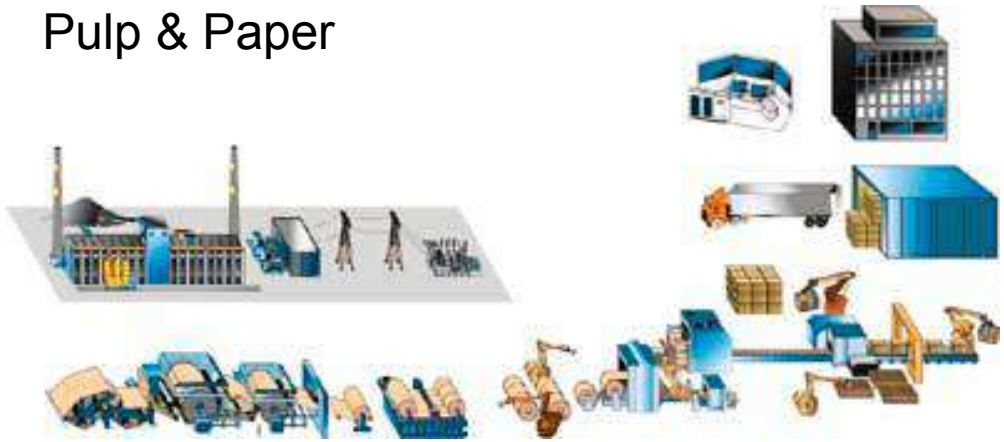
Process Industry

Process Industry = *industries de transformation*, Verfahrenstechnik
(one of the many meanings of “process”)



Cement

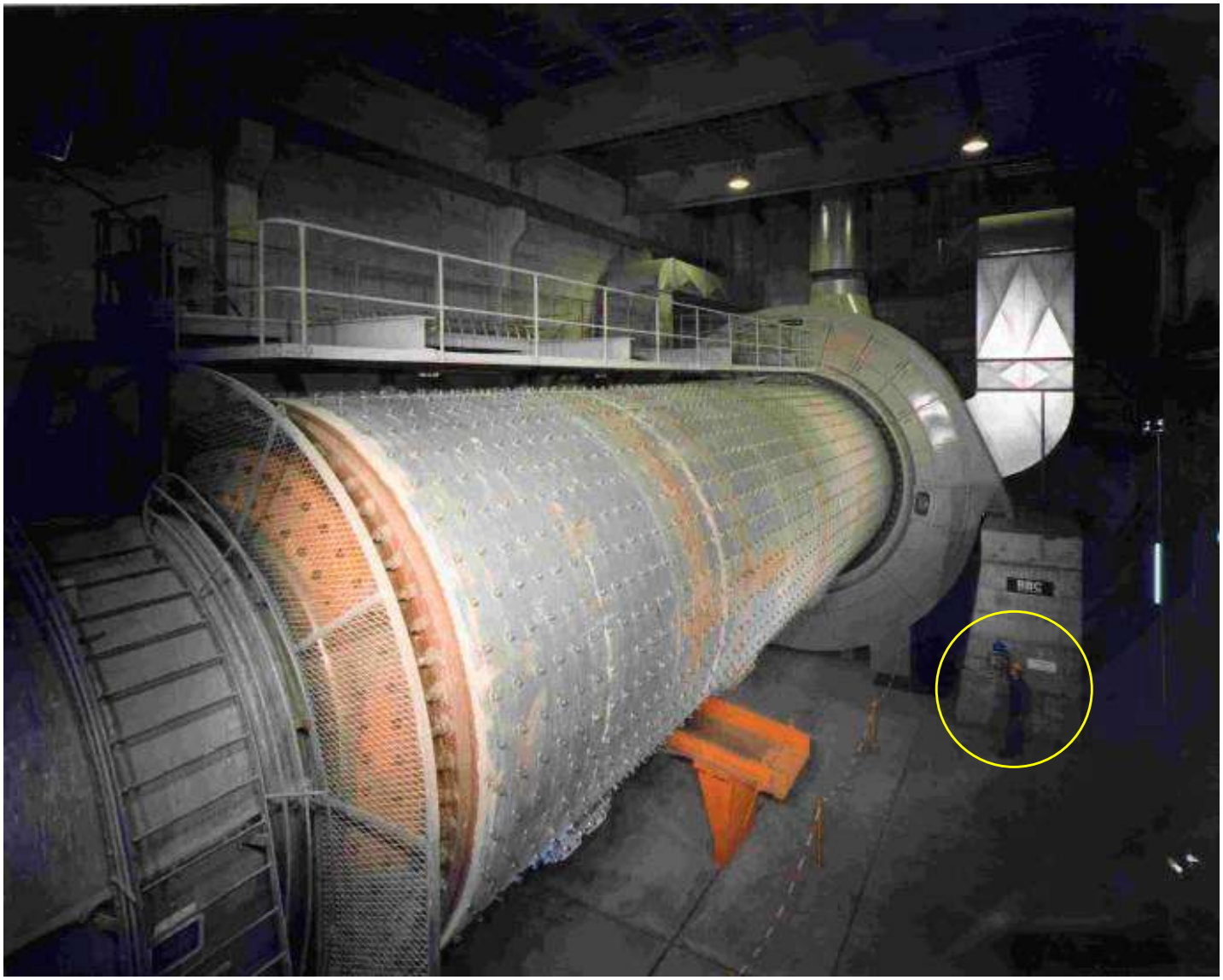
Pulp & Paper



Metals and Minerals
Glass production
Chemical ….

Continuous flow of materials, often 24 hours a day

Cement Works



The rotating oven is the heart of the cement process: the grinded kiln is burnt and comes out as chunks later reduced to powder.

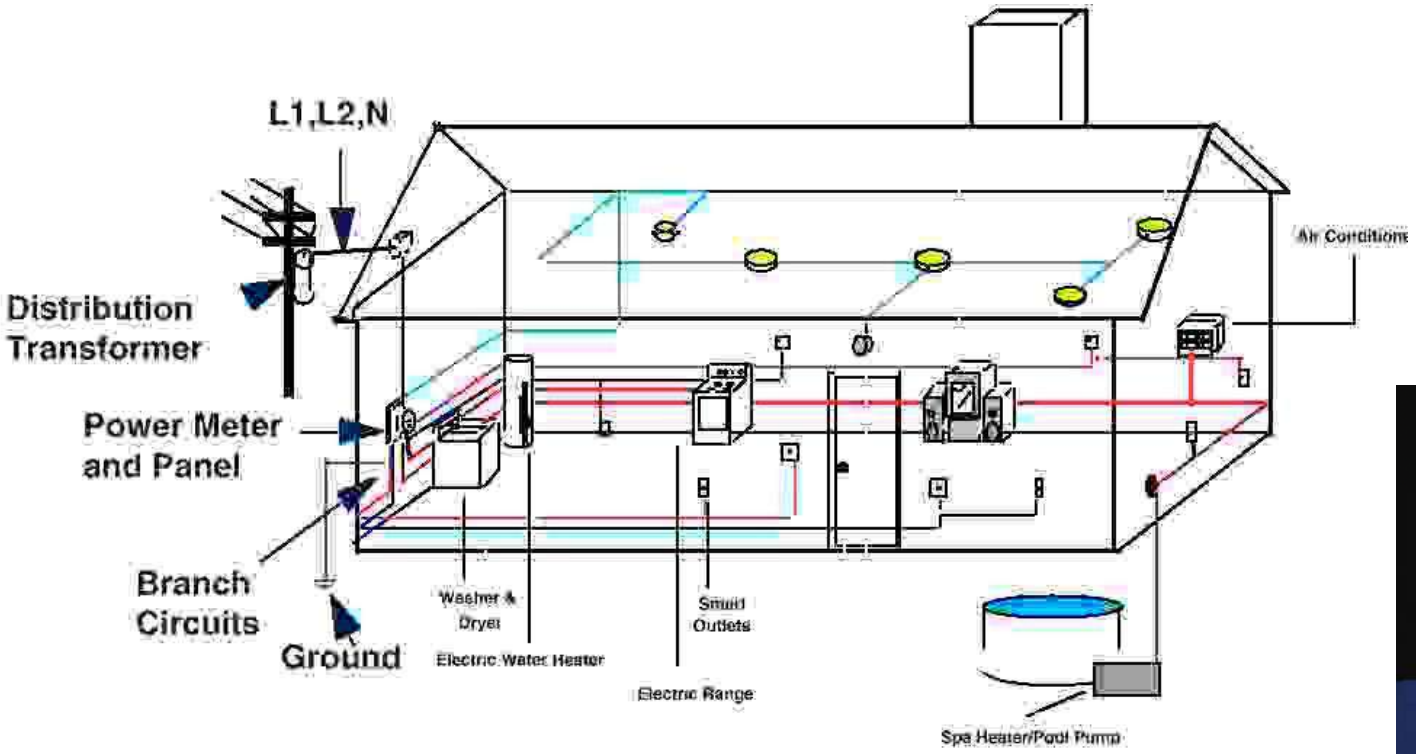
Control tasks: Oven rotation and temperature control fuel supply, silos, transport belts, grinding mills, pollution monitoring, quality supervision, filler stations,...

Switzerland is leading nation in Europe (Holcim, Jura, …)

Mining

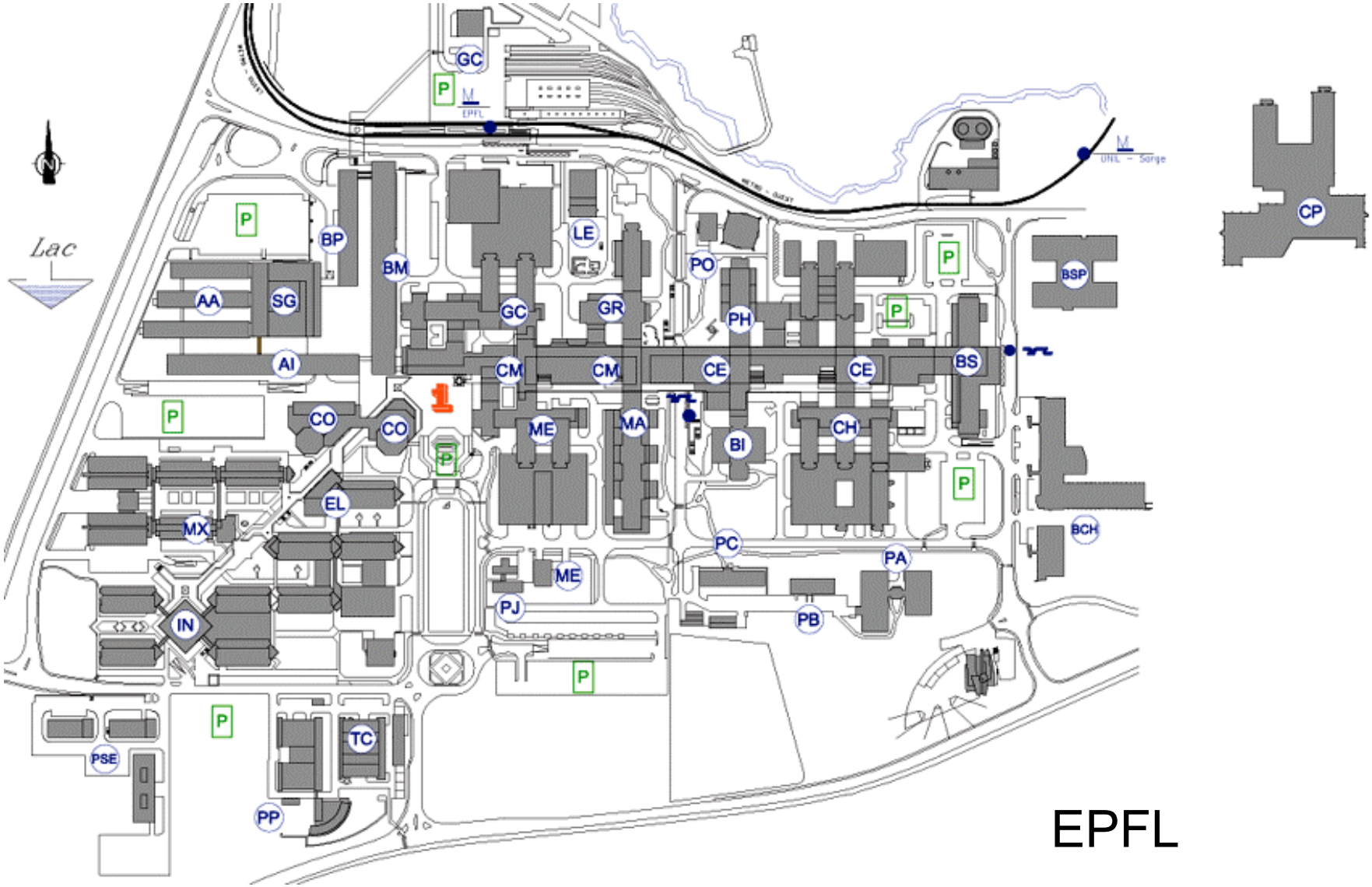
Building Automation

basics: fire, intrusion, climate, energy management
HVAC = Heat, Ventilation and Cooling = air conditioning



visitors, meeting rooms, catering,….
low price tag

Automation of Building Groups



EPFL

Airports

International Airport Oslo
(Public Buildings)

A reliable system, 365 days a year

Features

- Terminal building, tower and security area, parking and traffic area
- Number of gates: 34 with bridge connection, 16 remote buildings
- Building area: 180'000 m²
- 12 mio.passengers per year

Technical solution

- 3 DESIGO management stations
- 1000 plant graphics
- 8500 HVAC points
- Integration of fire alarm (Eltec)
- Integration of electrical controls based on EIB
- Remote management via TCP/IP link over the airport IT network

large building automation system:
fire,
security access,
energy,
lighting,
air conditioning,
communications,
traffic control

Traffic control

fire
intrusion
energy
water
ventilation
pollution monitoring
cameras
light control
traffic jams prevention,....

(Tunnel Letten near Zurich)

Warehouses

extreme dependency on the availability of the control system

Connection to
* supply chain management,
* order fulfilment
* customer relationship and
* commercial accounting (SAP)

Harbours

from ship planning
to crane manipulation
and stock control

Power plants

raw materials supply
primary process (steam, wind)
personal, plant and neighbourhood safety
environmental impact
generation process (voltage/frequency)
energy distribution (substation)

24 / 365 availability

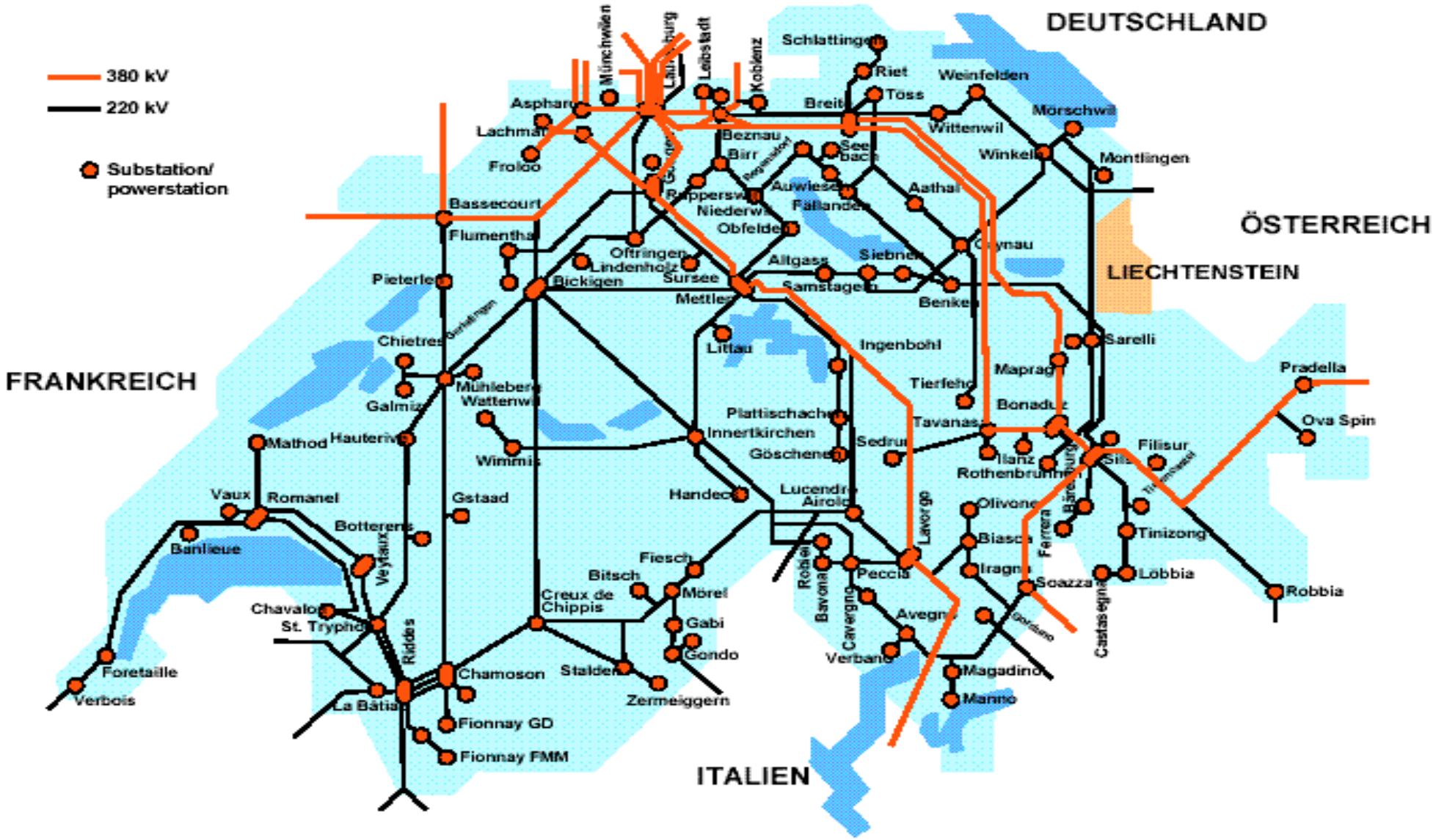
Waste treatment, incinerators

raw material supply
burning process
smoke cleaning
environmental control
co-generation process (steam, heat)
ash analysis
ash disposal

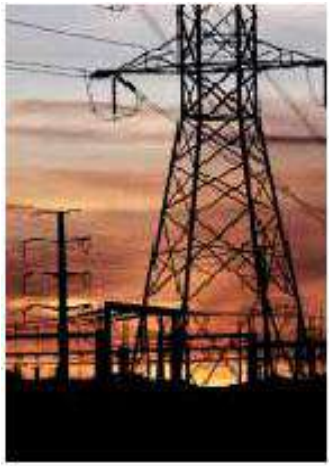
Water treatment

manage pumps, tanks, chemical composition, filters, movers,...

Swiss electricity interconnection network



Power transmission network



Huge number of "points" (power plants, transformers, breakers, substations) lying 2km to 2000 km apart.
All time-critical operations executed locally in the substations and power generation units.

Assessment

1) describe some of the typical processes…

2) what is the process industry ?

3) what does upstream / downstream means ?

4) what is the task of a control system in an interconnection network ?

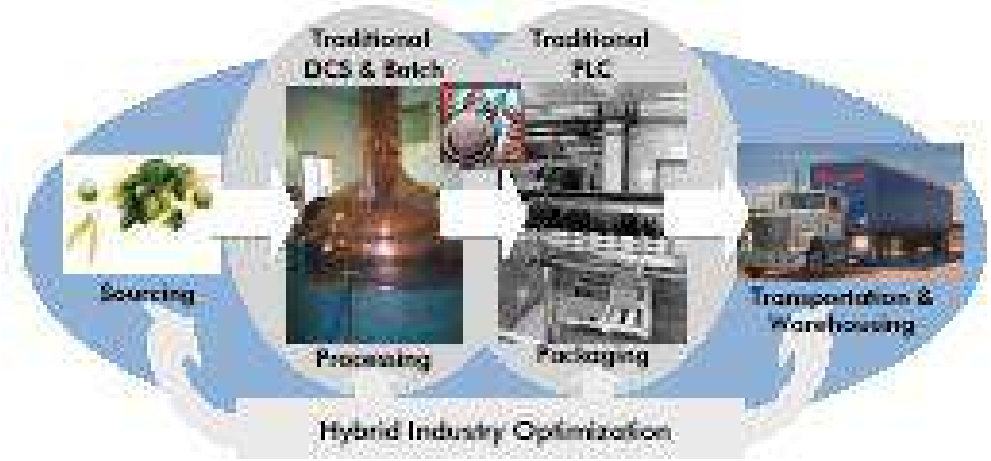
5) which computer functions do you know in a car and which are to come ?

6) draw an electricity network and show where data processing takes place and to which purpose

7) in the EPFL buildings, identify the automation components and their function.

8) what are the functions of the control computers in a locomotive ?

Industrial Automation
Automation Industrielle
Industrielle Automation



1.3 Types of Plants and Control
Systèmes contrôlés et contrôle
Strecken und Steuerungen

Prof. Dr. H. Kirrmann
ABB Research Center, Baden, Switzerland

1.3 Contents

Plant types

In spite of wide diversity of applications, the principles of automation are similar.

There are a few basic types of plants and the same control system hardware and basic software is shared by most applications.

Distinction is often question of a point of view, profession-specific vocabulary and marketing.

Control Tasks

measure - command - control

mesure - commande - régulation - conduite

messen - steuern - regeln - leiten

Conduite: l'ensemble des mesures qui permettent d'influencer l'état d'un processus dans un but fixé.

Leiten - die Gesamtheit aller Massnahmen, die einen im Sinne festgelegter Ziele erwünschten Ablauf eines Prozesse bewirken (DIN 19222)

Function of computers in control systems

open-loop functions

- Data acquisition and pre-processing
- Data transfer between plant and operator
- Display the plant state
- Logging and history recording
- Simulation and training
- Process optimization algorithms

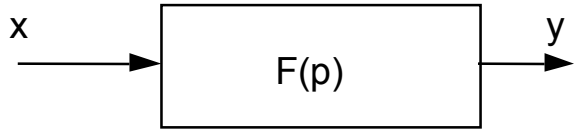
closed-loop functions

- Protection and interlocking*
- Regulation
- Process-driven sequential control

Interlocking*: prevent dangerous actions, such as all lights on green at a crossing

Continuous plants

Examples: Drives, Ovens, Chemical Reactors



Continuous plants (processes) have states that can be described by a continuous (analog) variable (temperature, voltage, speed,...)

Between plant input and plant output, there exists a fixed relation which can be described by a continuous model (transfer function).

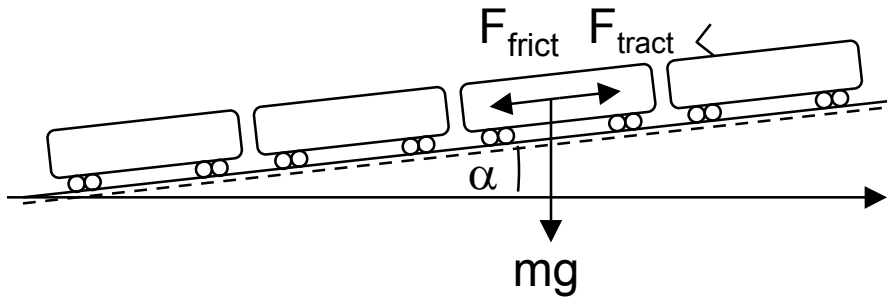
Continuous plants are mostly reversible and monotone:
This is the condition necessary to control them, i.e. impose the value of their output.

The transfer function may be described by a differential equation, simplified to a Laplace or a z-transform when the system is linear.

The principal control task in relation with a continuous process is its *regulation* (maintain the state at a determined level)

Example: modeling a train

Train:



$$\frac{dx}{dt} = v$$

$$\frac{dv}{dt} = \frac{1}{m\rho}(F_{tract} - mg\sin(\alpha) - m\frac{K_c}{radius} - C_x v^2 - C_f v)$$

mass of the train plus contribution of rotating parts (wheels and rotors)

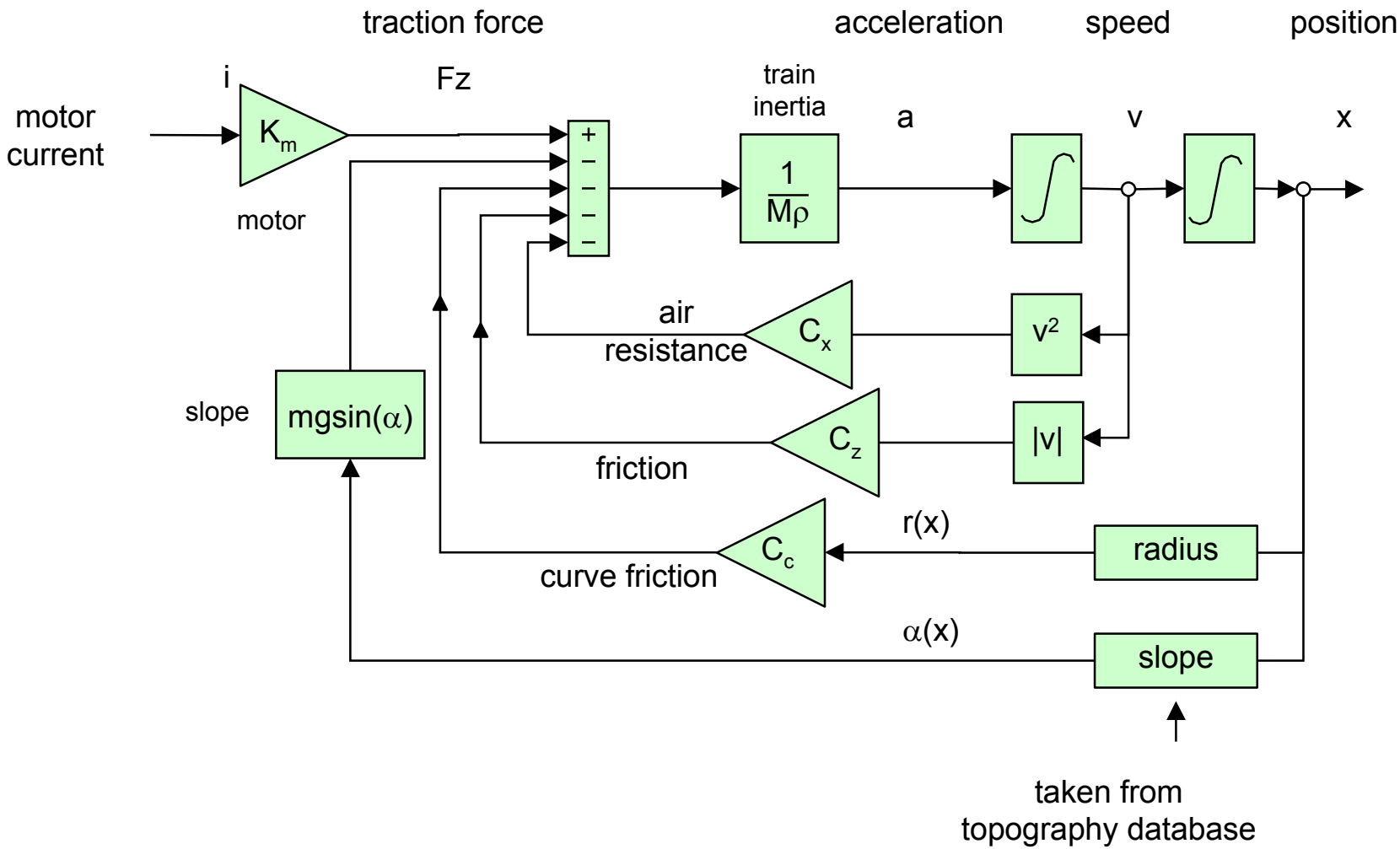
slope

curve friction

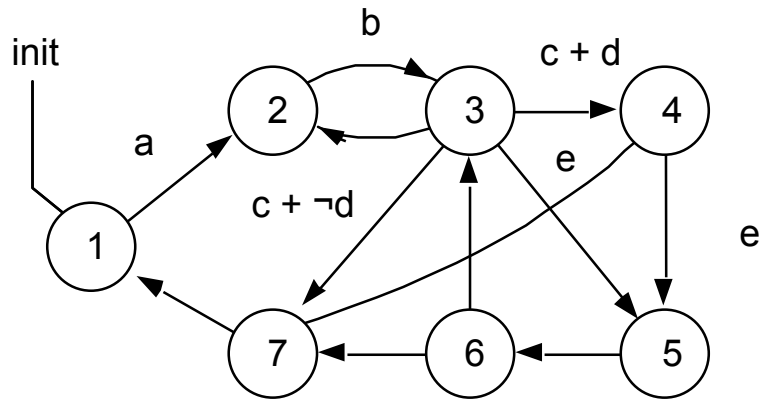
air friction

mechanical friction

Modeling: the train as block diagram



Discrete plants



A discrete plant is modeled by well-defined, exhaustive and non-overlapping states, and by abrupt transitions from one state to the next caused by events.

Discrete plants are mainly reversible, but not monotone:
the removal of the stimulus which caused a state transition will not necessarily bring the plant back to the previous state.

Example: a lift will not go back to the previous floor when releasing the button that called it.

Going back to a previous state may require transit through several other states.

Discrete plants are described by Finite State Machines, Petri Net, State transition tables Grafcet, SDL or Sequential Function Chart diagrams.

The main task of a control system in relation with discrete plants is their command.

Continuous and batch processes

Continuous process

(*processus continus*, kontinuierliche Prozesse)

continuous flow of material or energy

e.g. motor control, cement, glass, paper production,
rolling mill for wires, plate or profiles,
printing: 23 m/s, steel wire 90 m/s

Main task: regulation

Batch process

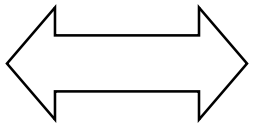
(processus de charge (par lots), Stückgutprozesse*)*

discrete processes with handling of individual elements

e.g. Numerical Controlled machine, packing machines,
Bottle-filling, manufacturing, pharmaceutical and chemical processes.

Main task: command

Discrete and continuous worlds



discrete control

continuous control

Mixed plants

In reality, all plants consist of discrete and of continuous processes.

Example 1: Motor Control of a cable-car with speed control and stop at stations

Example 2: A bottle-filling line is in principle a continuous process, but each step consists of a sequence of operations

All parts must de described individually.

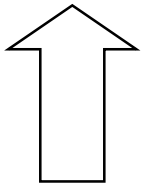
Processes can be described as continuous within a discrete state or as non-linear, continuous process.

Example: Time-triggered set-point of an oven temperature.

Mixed Plants are the normal case - a question of point of view.

All processes have some continuous and some discrete behavior

Accent depends on industrial process



discrete

Automotive Manufacturing

Electronics

Machinery

Textiles

Pharmaceuticals

Fine Chemical

Food & Beverage

Metals & Mining

Water & Waste

Pulp & Paper

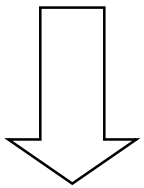
Vehicles

Petrochemicals

Oil & Gas

Electrical Power

continuous



source: ARC

The main categories in industry

industry distinguishes the following categories of applications:

"process control": continuous processes, associated with fluids, for instance sewage water treatment, petrochemical process, cement…

"batch control": semi-continuous processes, associated with individual products, for instance chemical, pharmaceutical, brewery…

"manufacturing": discrete processes, associated with transformation of parts, e.g. automobile industry, bottle-filling, packaging

Assessment

What is open loop and what closed loop control ?

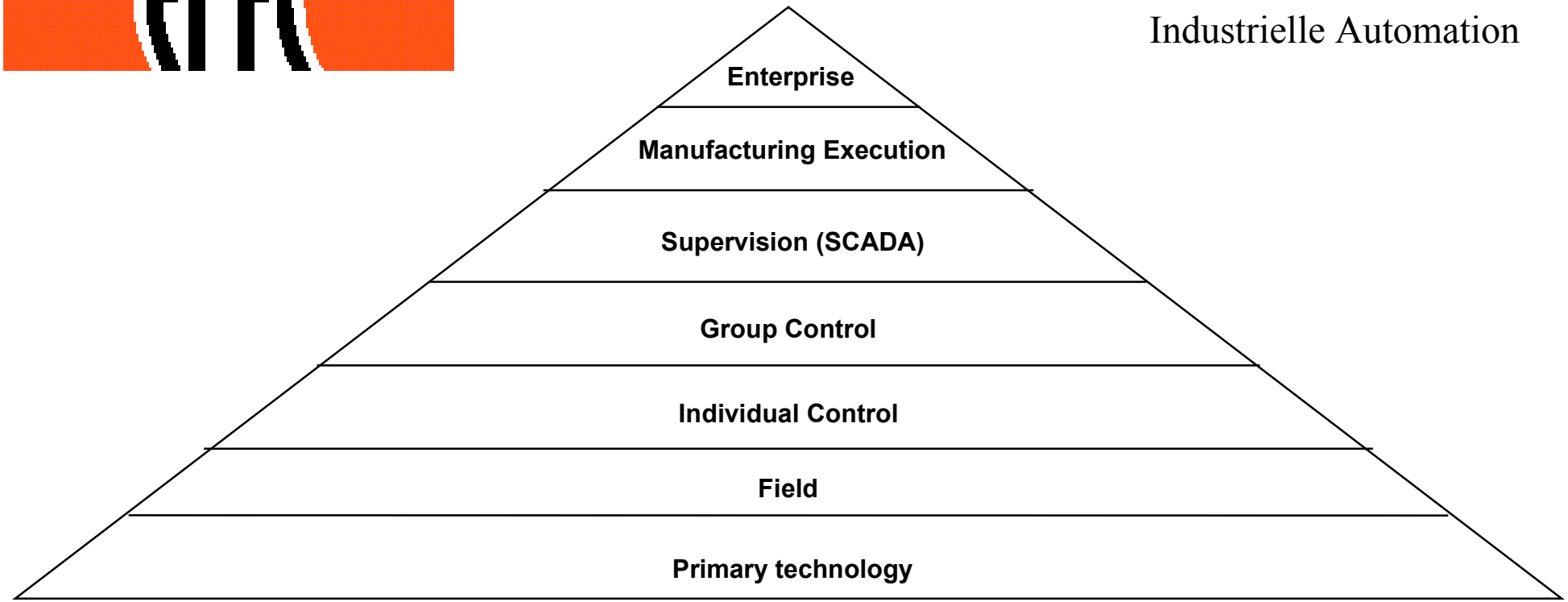
What is the difference between continuous and discrete processes ?

What is the difference between a discrete and a batch process ?

What is the main task of a controller in a discrete process, in a continuous process ?


EPFL

Industrial Automation
Automation Industrielle
Industrielle Automation



1.4 Automation Hierarchy
Hiérarchie de l'automation
Leitsystem-Hierarchie

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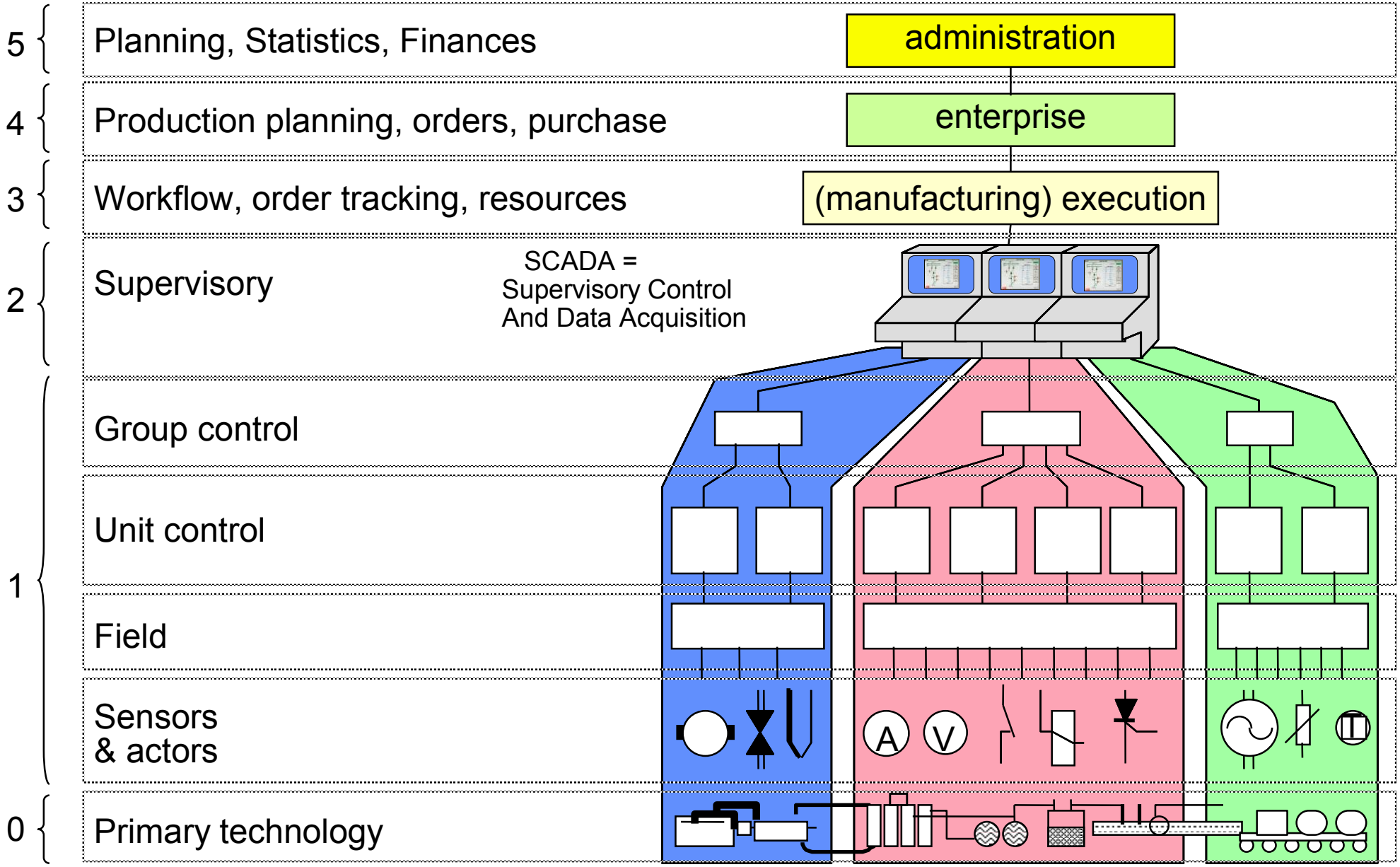
1.4 Contents

Automation System Structure

Although applications differ widely, there is little difference in the overall architecture of their control systems.

Why the control system of a power plant is not sold also for automating a brewery depends largely on small differences (e.g. explosion-proof), on regulations (e.g. Food and Drug Administration) and also tradition, customer relationship.

Large control system hierarchy (1)



Large control system hierarchy (2)

Administration	Finances, human resources, documentation, long-term planning
Enterprise	Set production goals, plans enterprise and resources, coordinate different sites, manage orders
Manufacturing	Manages execution, resources, workflow, quality supervision, production scheduling, maintenance.
Supervision	Supervise the production and site, optimize, execute operations visualize plants, store process data, log operations, history (open loop)
Group (Area)	Controls a well-defined part of the plant (closed loop, except for intervention of an operator) • Coordinate individual subgroups • Adjust set-points and parameters • Command several units as a whole
Unit (Cell)	Control (regulation, monitoring and protection) part of a group (closed loop except for maintenance) • Measure: Sampling, scaling, processing, calibration. • Control: regulation, set-points and parameters • Command: sequencing, protection and interlocking
Field	data acquisition (Sensors & Actors*), data transmission no processing except measurement correction and built-in protection.

(*capteurs et moteurs, Messfühler & Stellglieder)

Field level

the field level is in direct
interaction with the plant's hardware
(Primary technology, *Primärtechnik*)

Group level

the group level coordinates the activities of several unit controls

the group control is often hierarchical, can be also be peer-to-peer (from group control to group control = distributed control system)

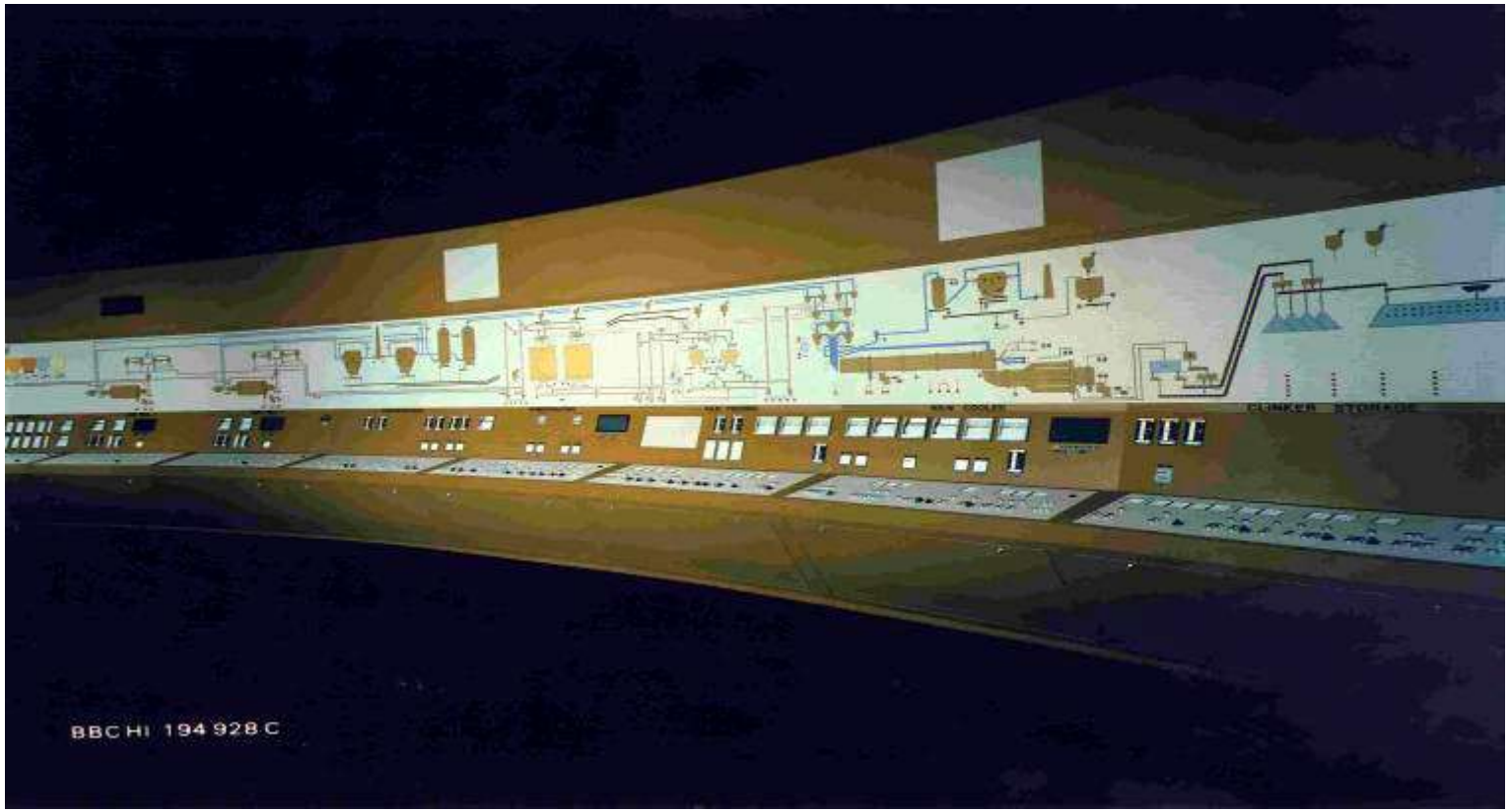
Note: "Distributed Control Systems" (DCS) commonly refers to a hardware and software infrastructure to perform Process Automation

Local human interface at group level

sometimes,
the group level has its own man-machine interface for local operation control
(here: cement packaging)

also for maintenance:
console / emergency panel

Supervisory level: Man-machine interface

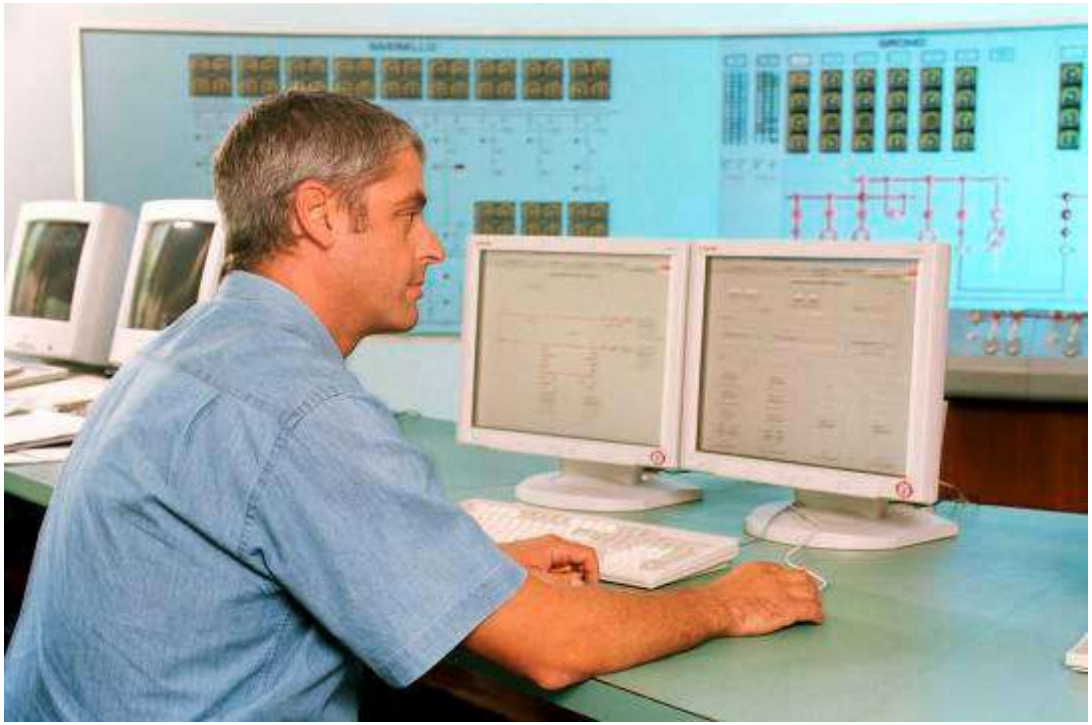


control room
(mimic wall)
1970s...

formerly, all instruments were directly wired to the control room

Supervisory level: SCADA

(SCADA = Supervisory Control and Data Acquisition)



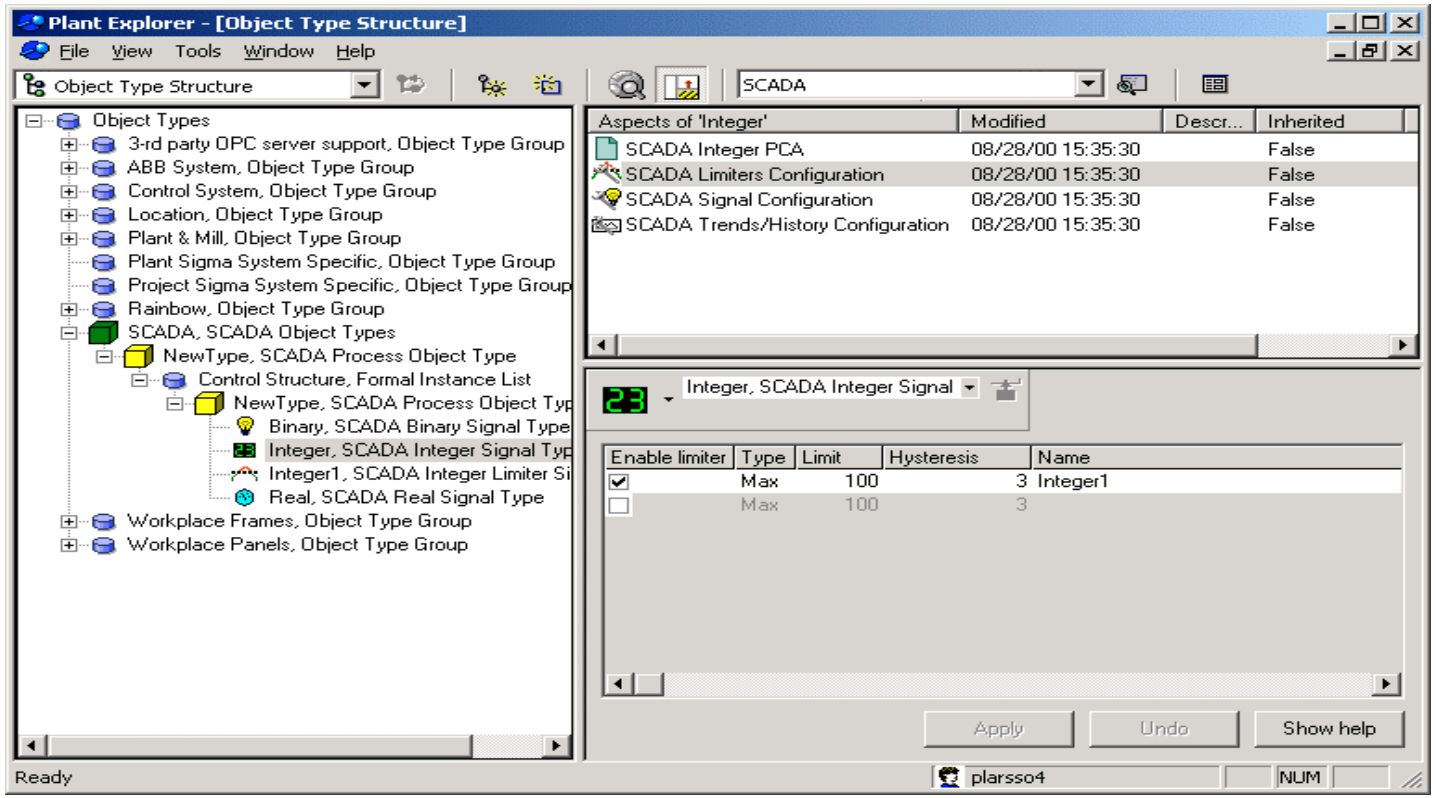
- displays the current state of the process (**visualization**)
- display the alarms and events (**alarm log, logbook**)
- display the trends (**historians**) and analyse them
- display handbooks, data sheets, inventory, expert system (**documentation**)
- allows communication and data synchronization with other centres

Plant management

- store the plant and product data for further processing in a secure way (historian), allowing to track processes and trace products
  -> **Plant Information Management System (PIMS**)

- make predictions on the future behaviour of the processes and in particular about the maintenance of the equipment, track KPI (key performance indicators)
-> **Asset Optimisation (AO**)

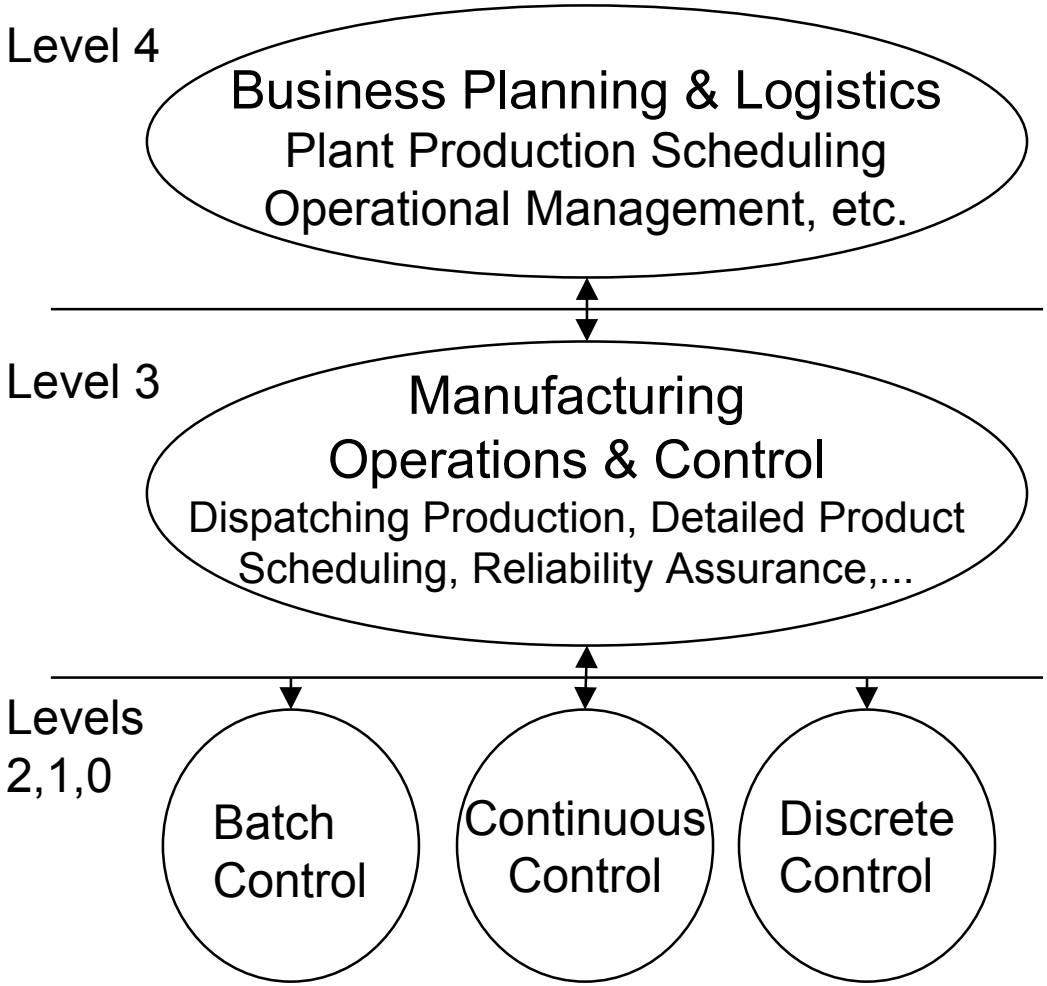
Engineering workplace



The engineering workplace manages the control system, not the plant.
The engineer can configure the networks and devices, load the software, assign authorizations, troubleshoot the control system,...

ANSI/ISA 95 standard

the ANS/ISA standard 95 defines terminology and good practices



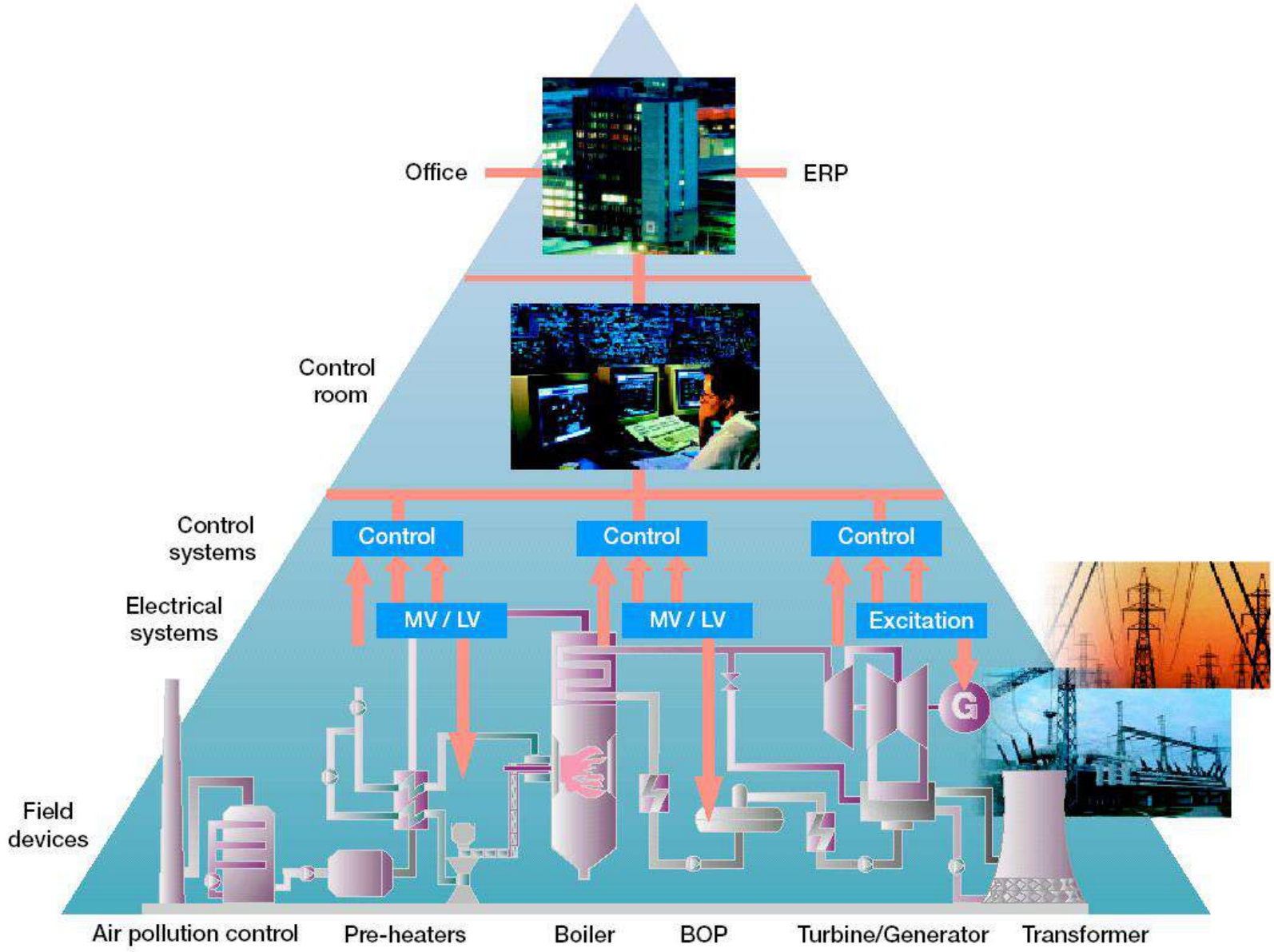
Enterprise Resource Planning

Manufacturing Execution System

Control & Command System

Source: ANSI/ISA–95.00.01–2000

Example: Power plant

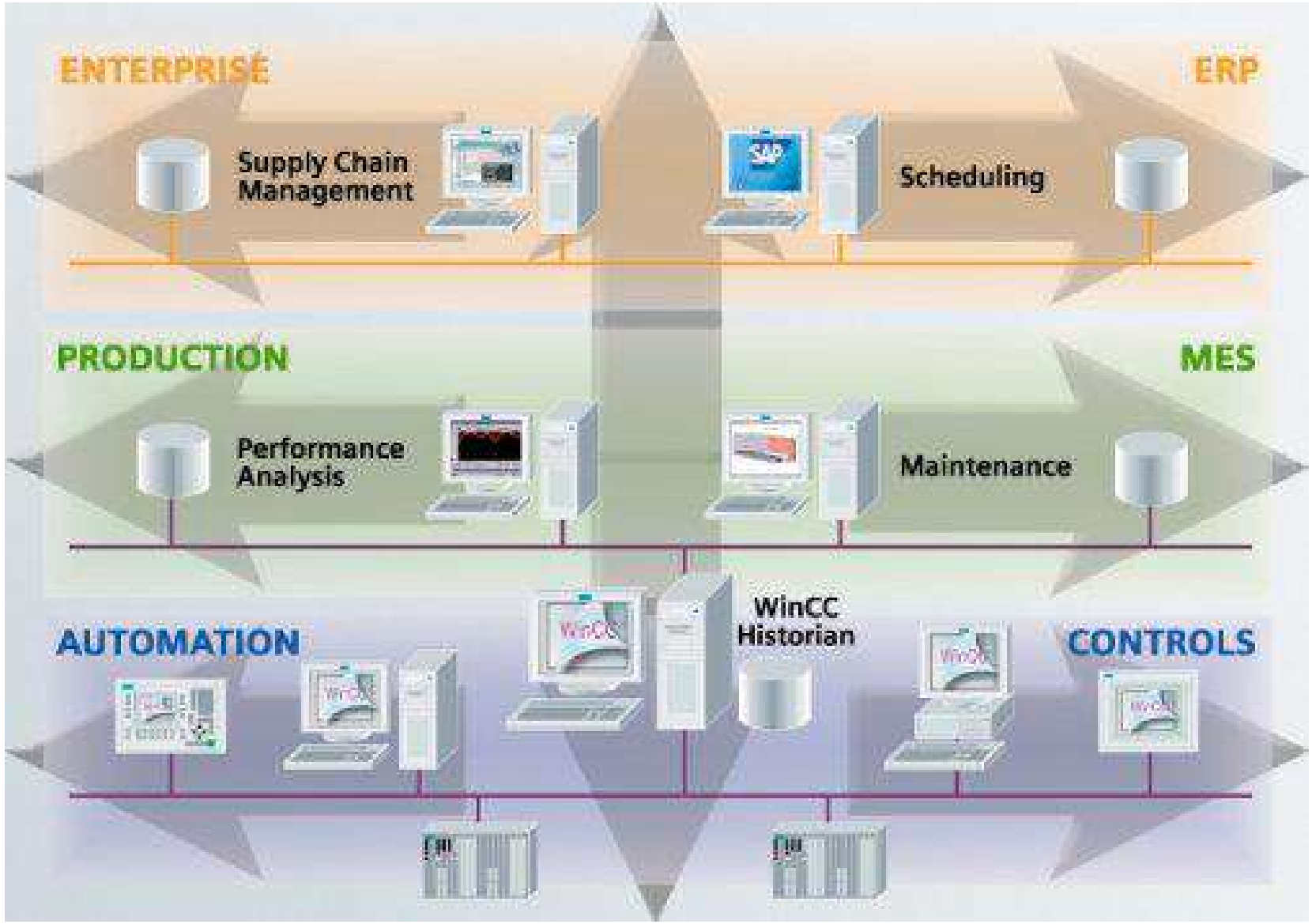


Example: Siemens WinCC (Generic)

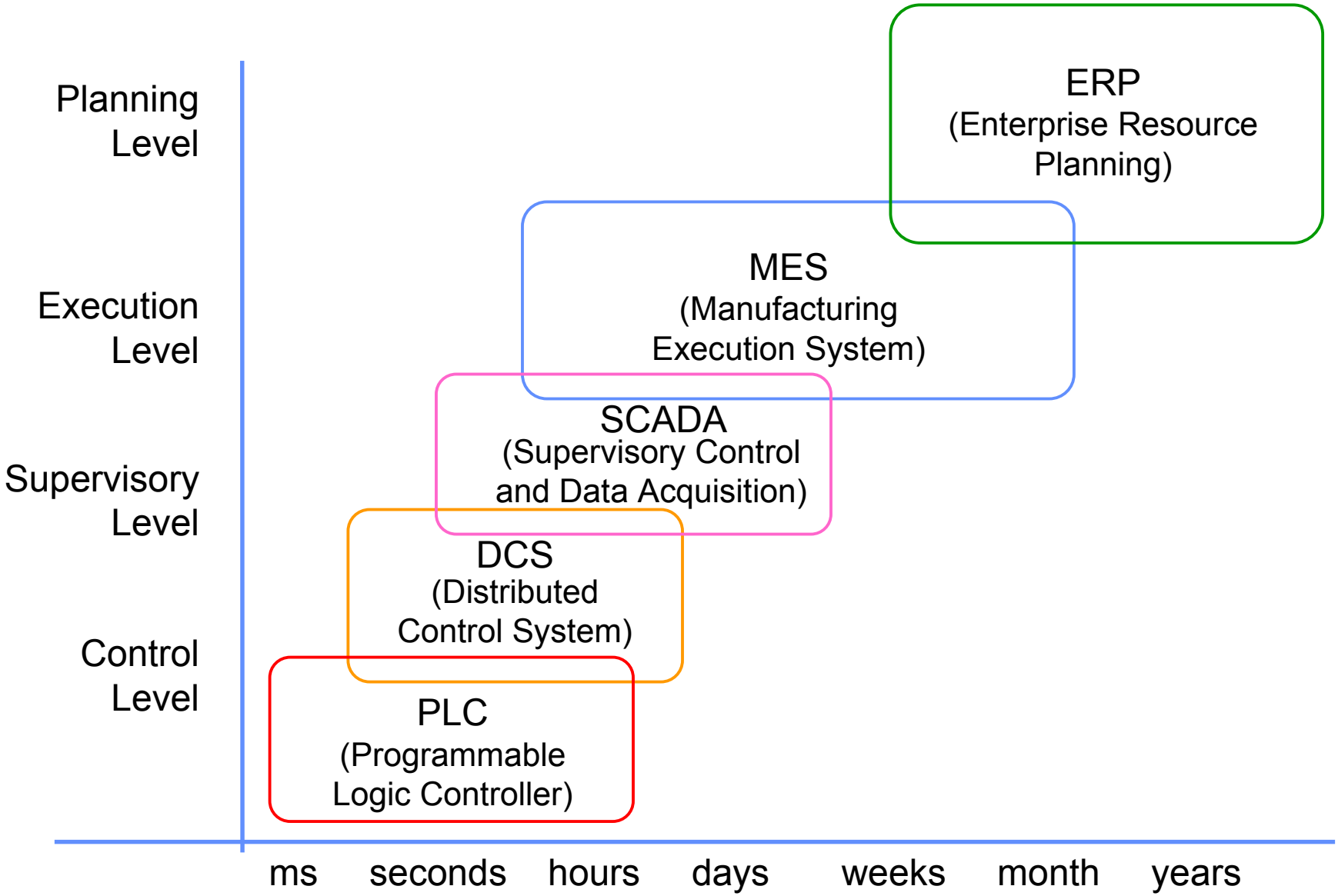
Unternehmens-leitebene

Betriebs-leitebene

Prozess-leitebene



Response time and hierarchical level



Data Quantity & Quality and Hierarchical Level

Higher Levels

When ascending the control hierarchy, data are reduced:
higher level data are created (e.g. summary information)
Processing and decisions becomes more complicated (requires using models).
Timing requirements are slackened. Historical data are stored

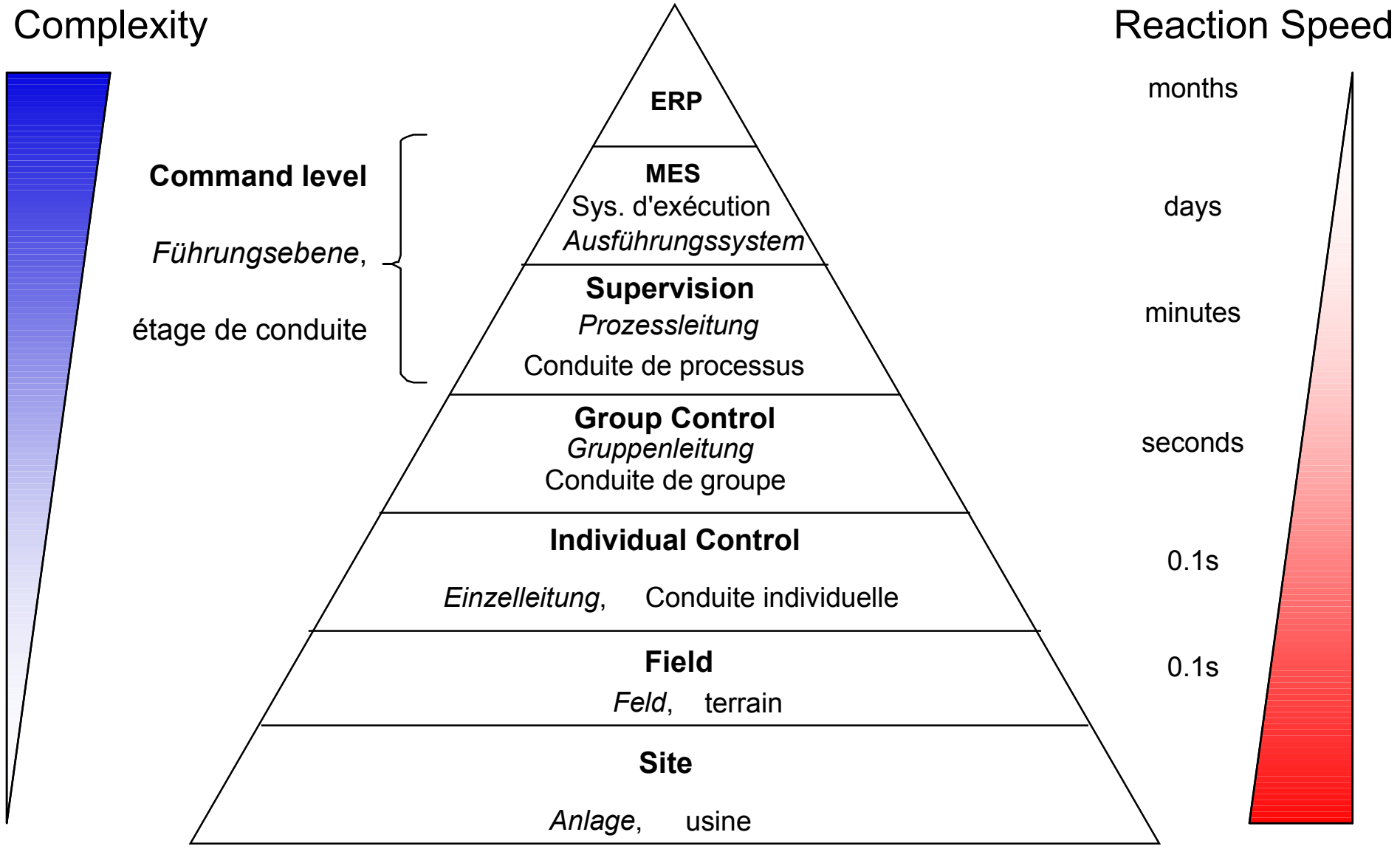
SCADA level

Presentation of complex data to the human operator,
aid to decisions (expert system) and maintenance.
Requires a knowledge database in addition to the plant's database

Lower Levels

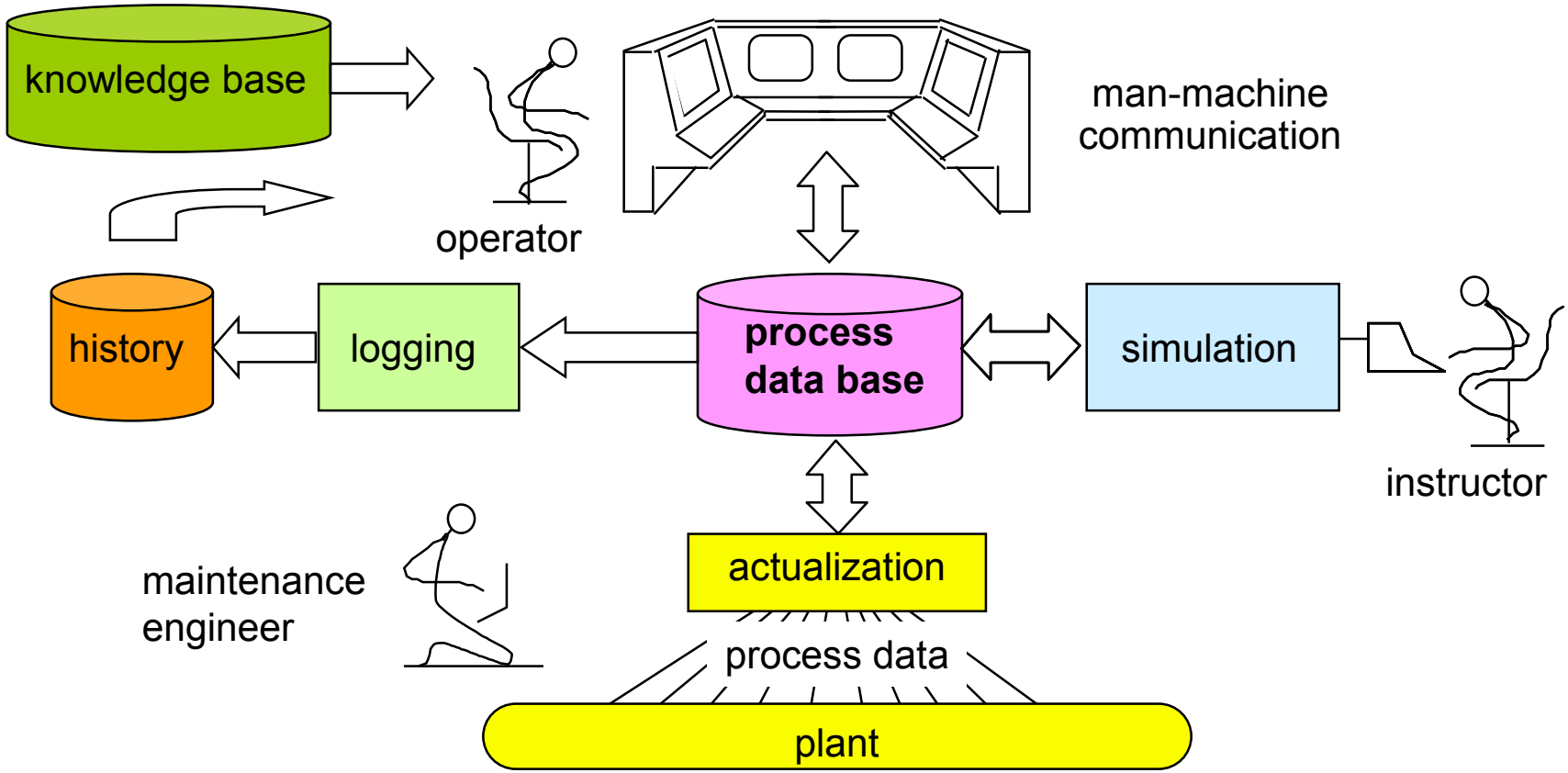
Lowest levels (closest to the plant) are most demanding in response time.
Quantity of raw data is very large.
Processing is trivial (was formerly realized in hardware).
These levels are today under computer control,
except in emergency situations, for maintenance or commissioning.

Complexity and Hierarchical level

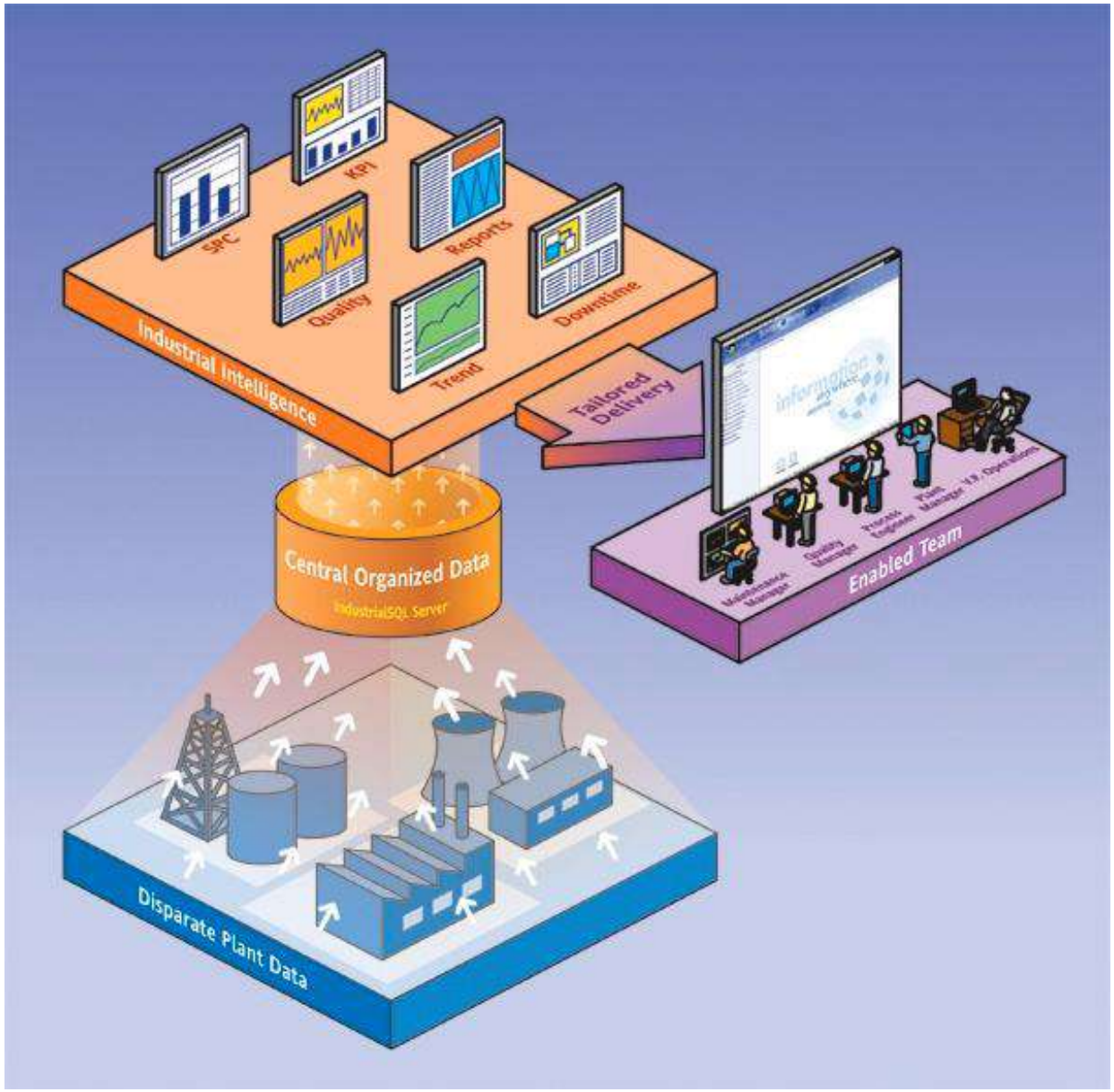


Operation and Process Data base

Consideration of human intervention breaches this hierarchy.
Normally, the operator is only concerned by the supervisory level,
but exceptionally, operators (and engineers) want to access data of the lowest levels.
The operator sees the plant through a fast data base, refreshed in background.
This database is the pivot for logging and simulation.



The process database is at the centre (example: Wonderware)



Assessment

Describe the levels of a hierarchical control system

What is the relationship between hierarchical level, the response time, data quantity and complexity ?

What does SCADA stands for ?

What is a group control used for ?

What is the role of a Manufacturing Execution System ?

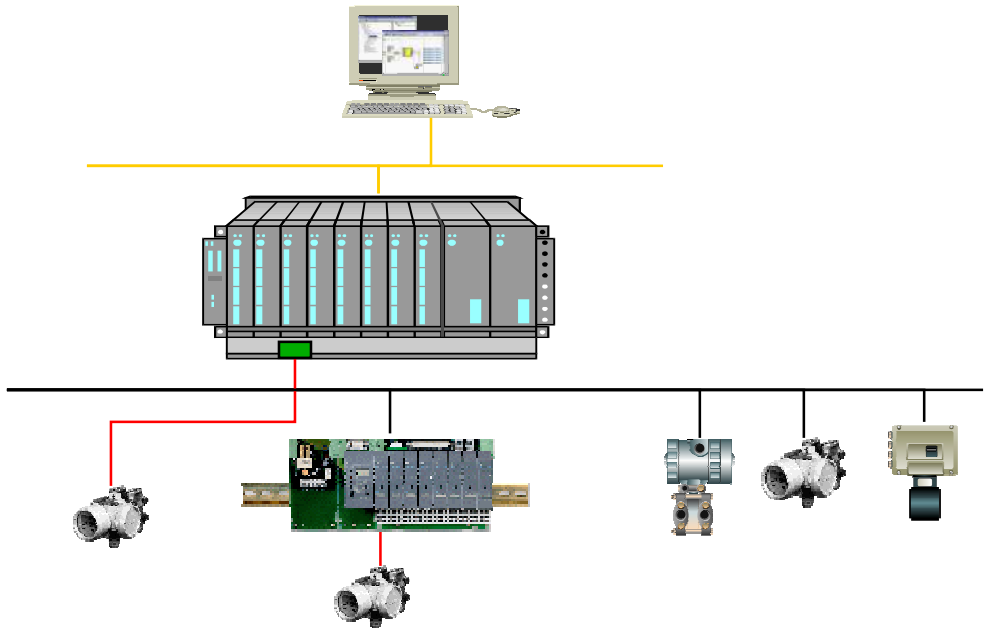
What are the three functions of the operator interface ?

What is Enterprise Resource Planning ?

What is the role of the process database ?


EPFL

Industrial Automation
Automation Industrielle
Industrielle Automation



Control System Architecture

1.5 *Architecture de Contrôle - Commande*
Leittechnik-Architektur

Prof. Dr. H. Kirrmann
ABB Research Center, Baden, Switzerland

1.5 Control System Architecture

Principle

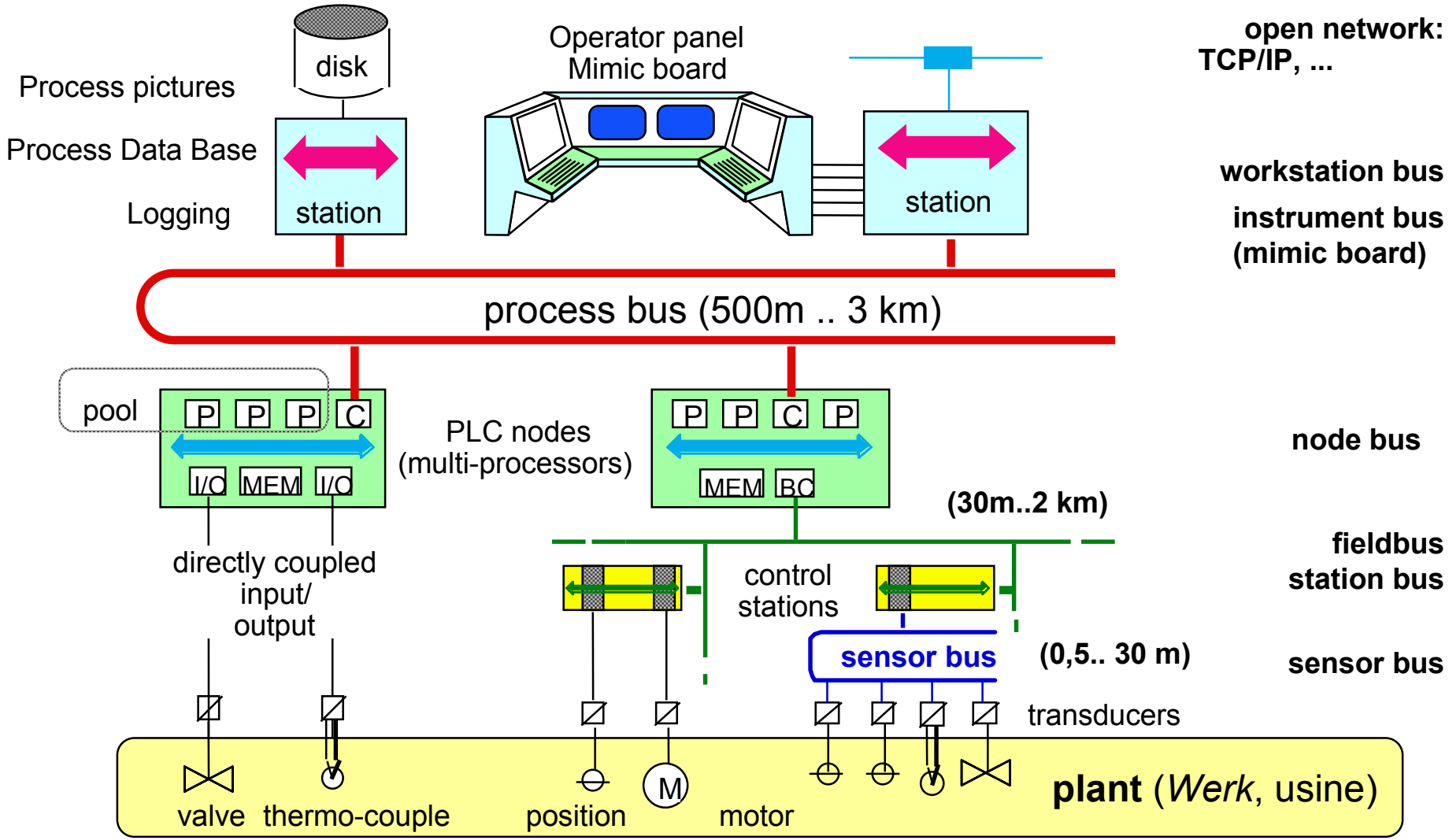
The control system has to suit the plant, not the reverse

The structure of the control system should reflects that of the plant

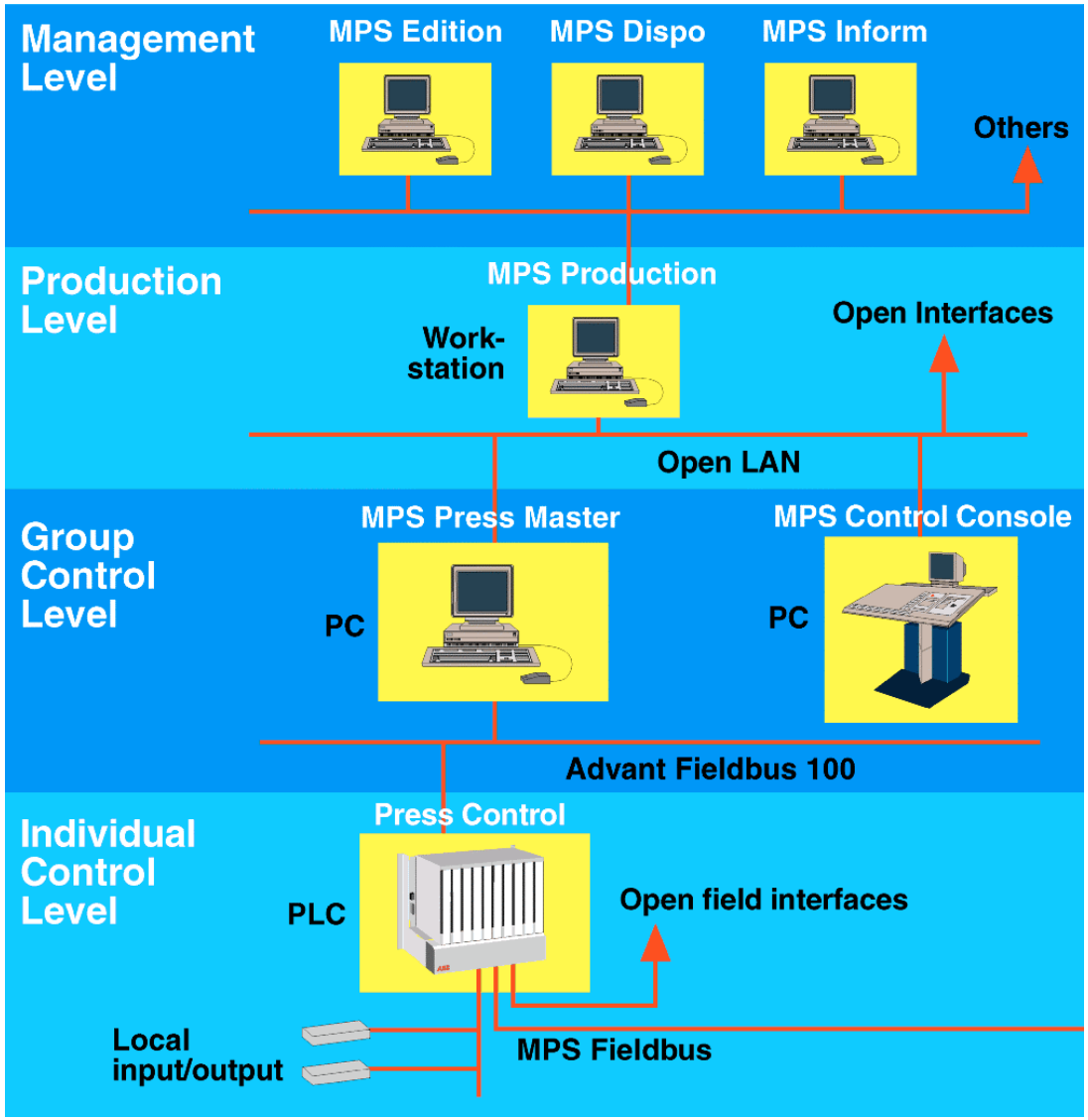
Ideally, each unit of the plant should have its own controller,
interacting with the controllers of the other, related units,
mirroring their physical interaction.

Example: Airbus: a wing is delivered with its own computers.

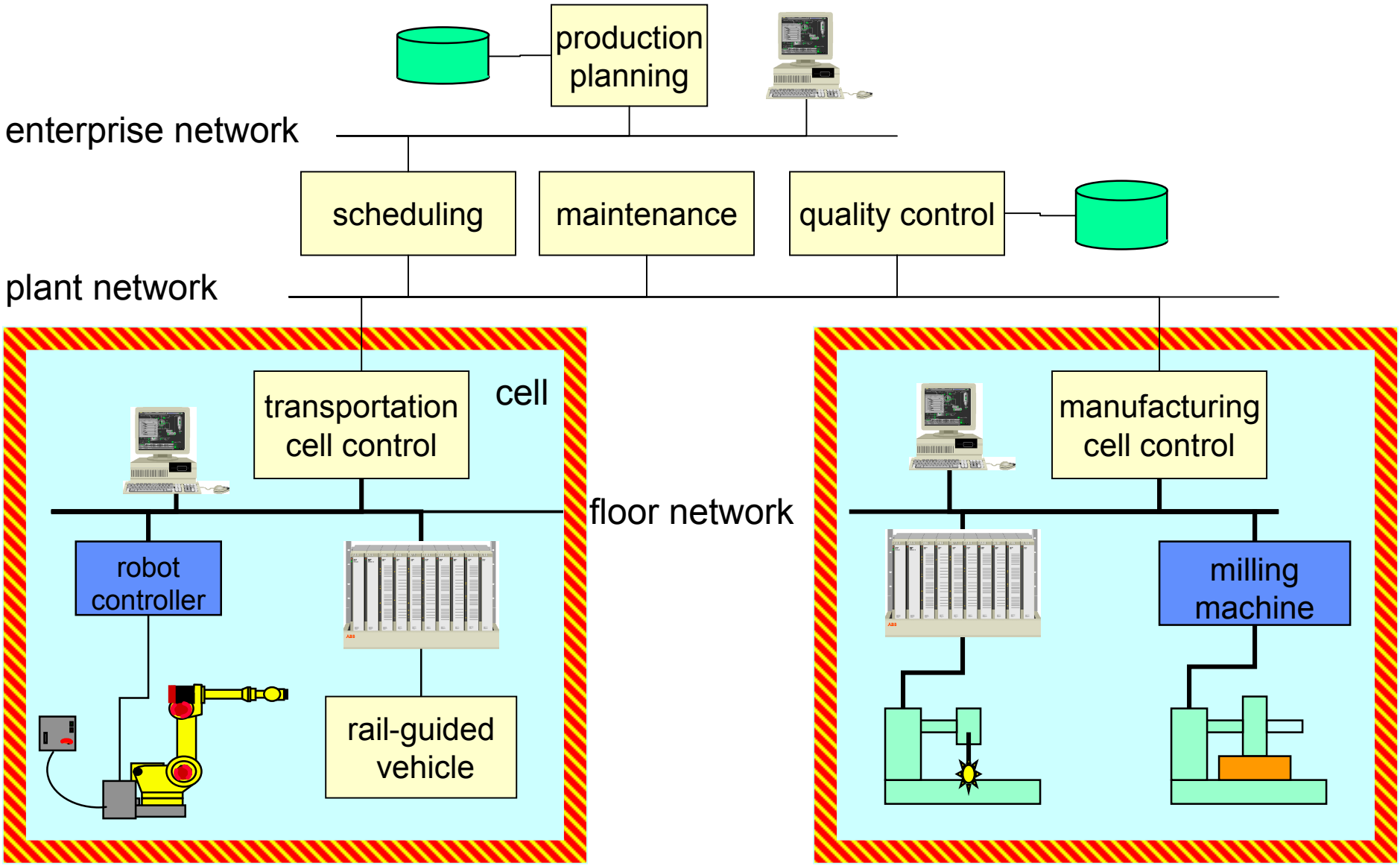
Busses and processors in industrial plants



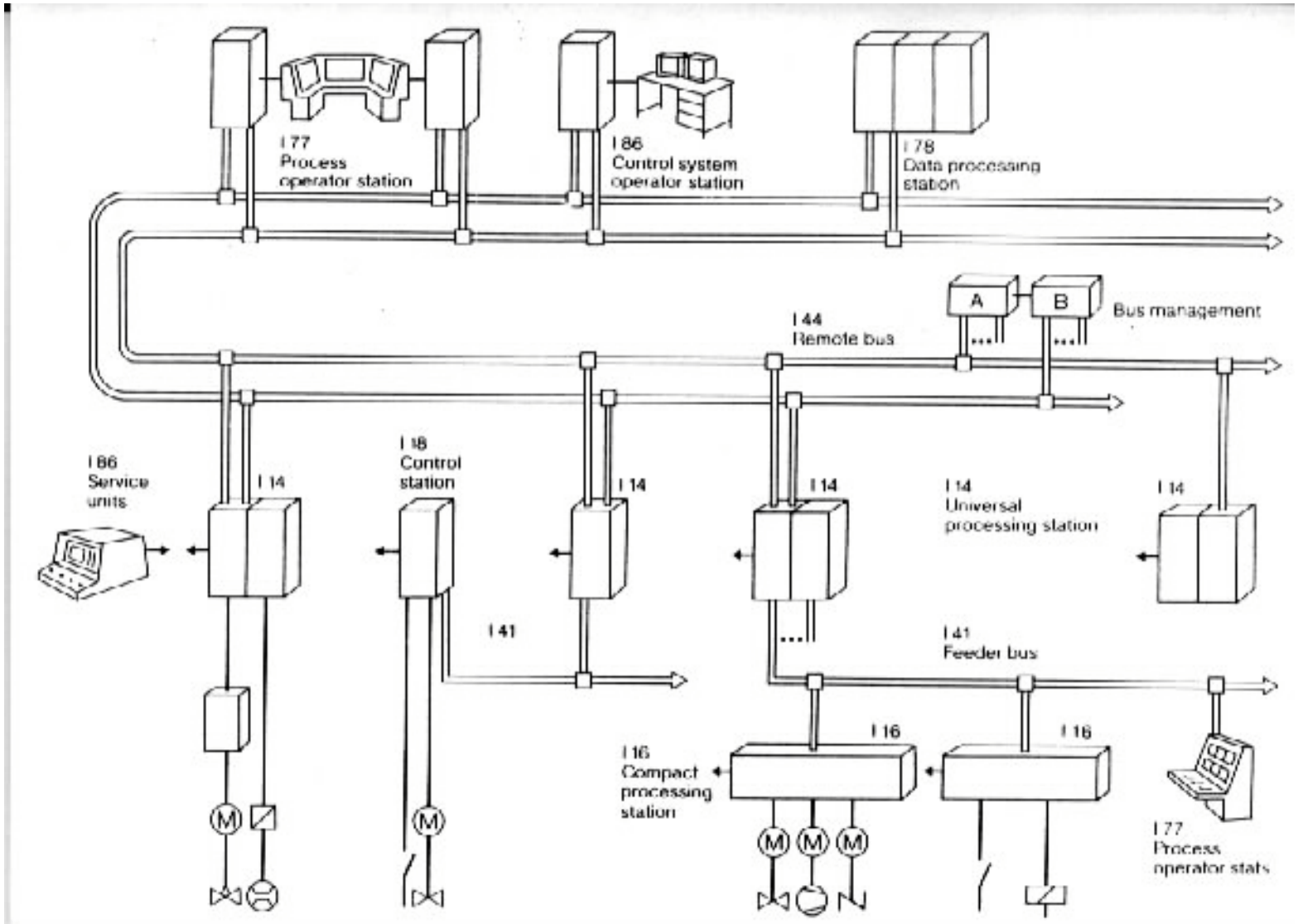
Example: Printing Architecture



Example: Production management system

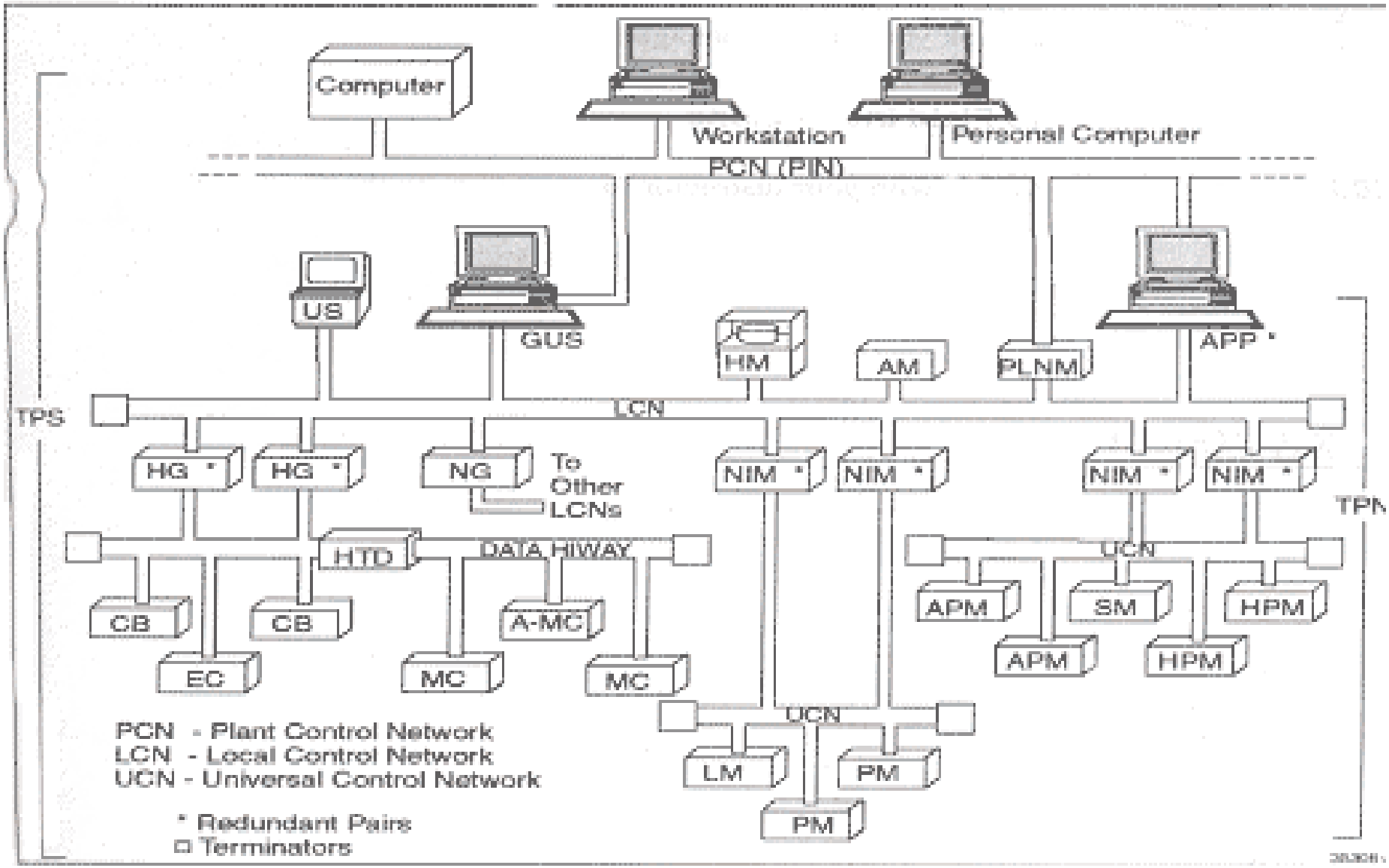


Example: Power plant control (BBC, 1980)

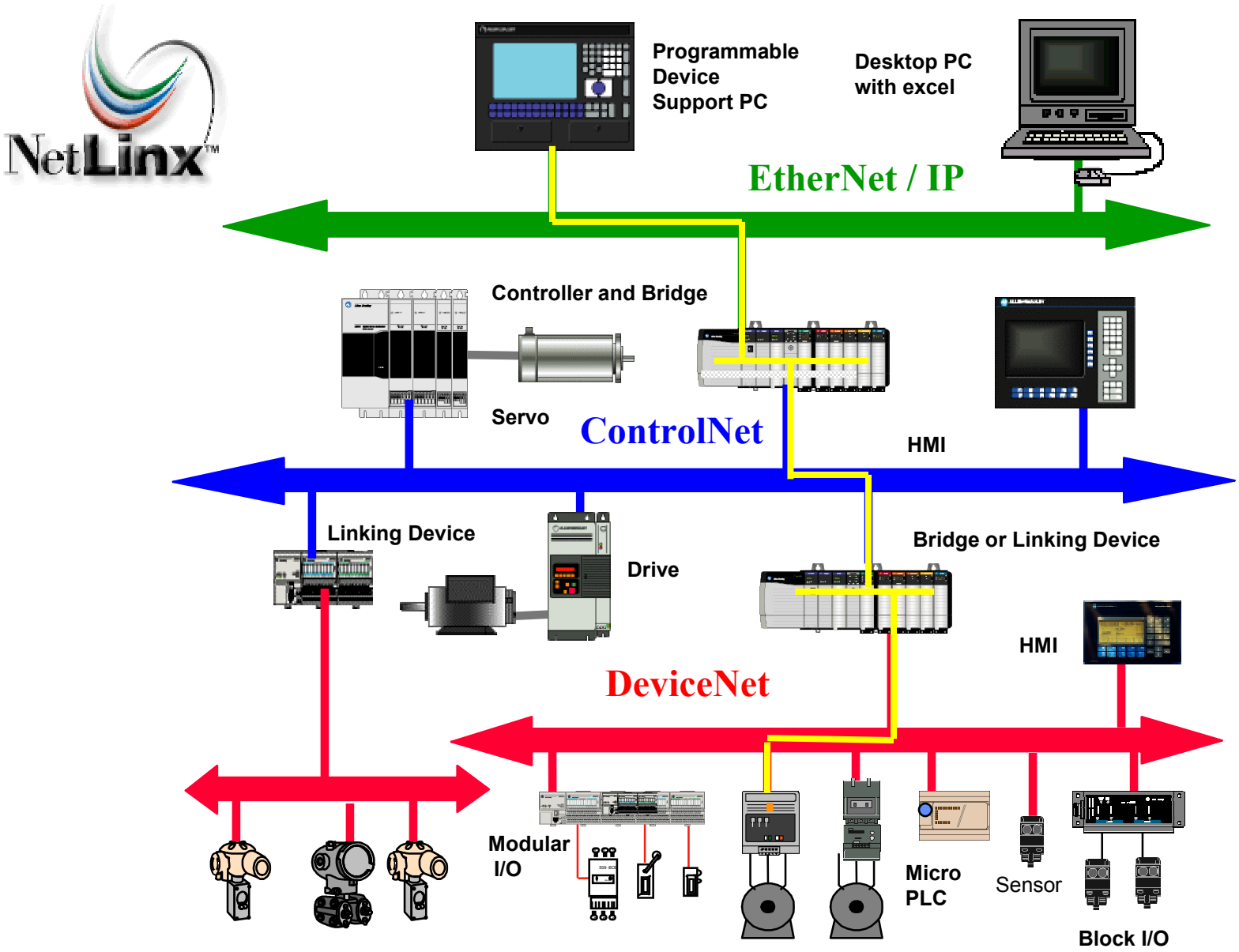


Control systems look similar

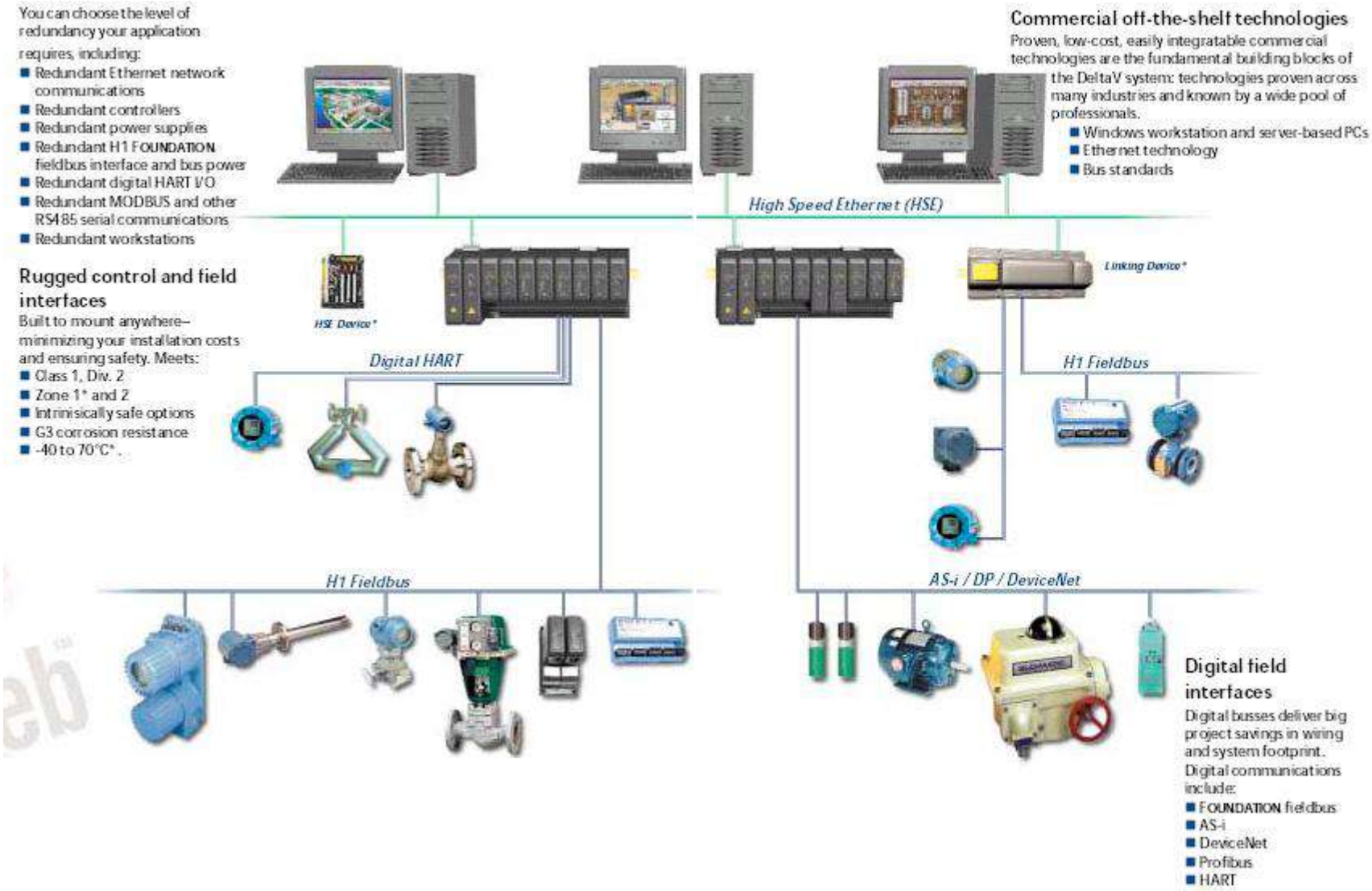
Example: Honeywell TotalPlant (2003)



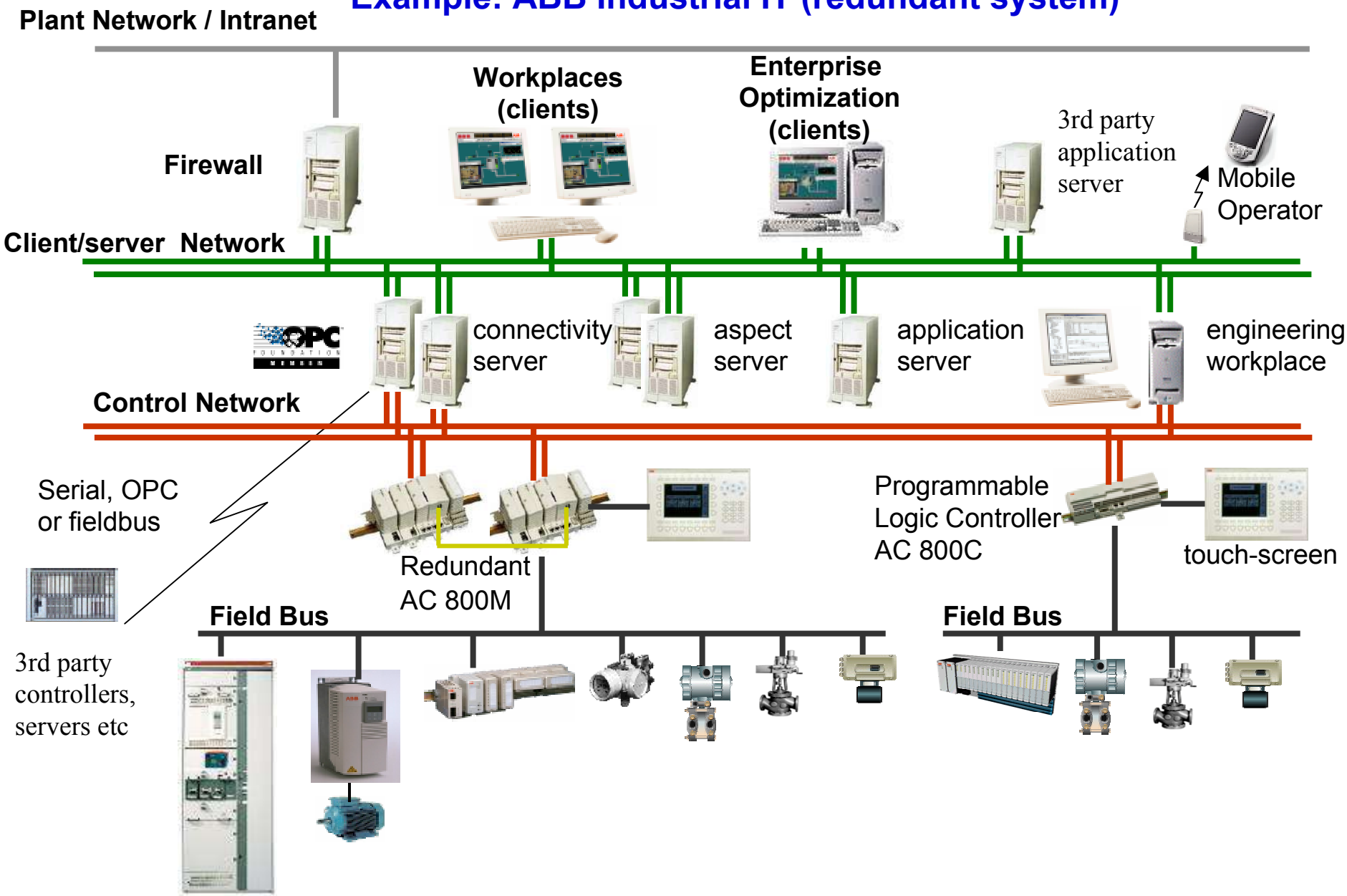
Example: Rockwell (Allen-Bradley) NetLinx



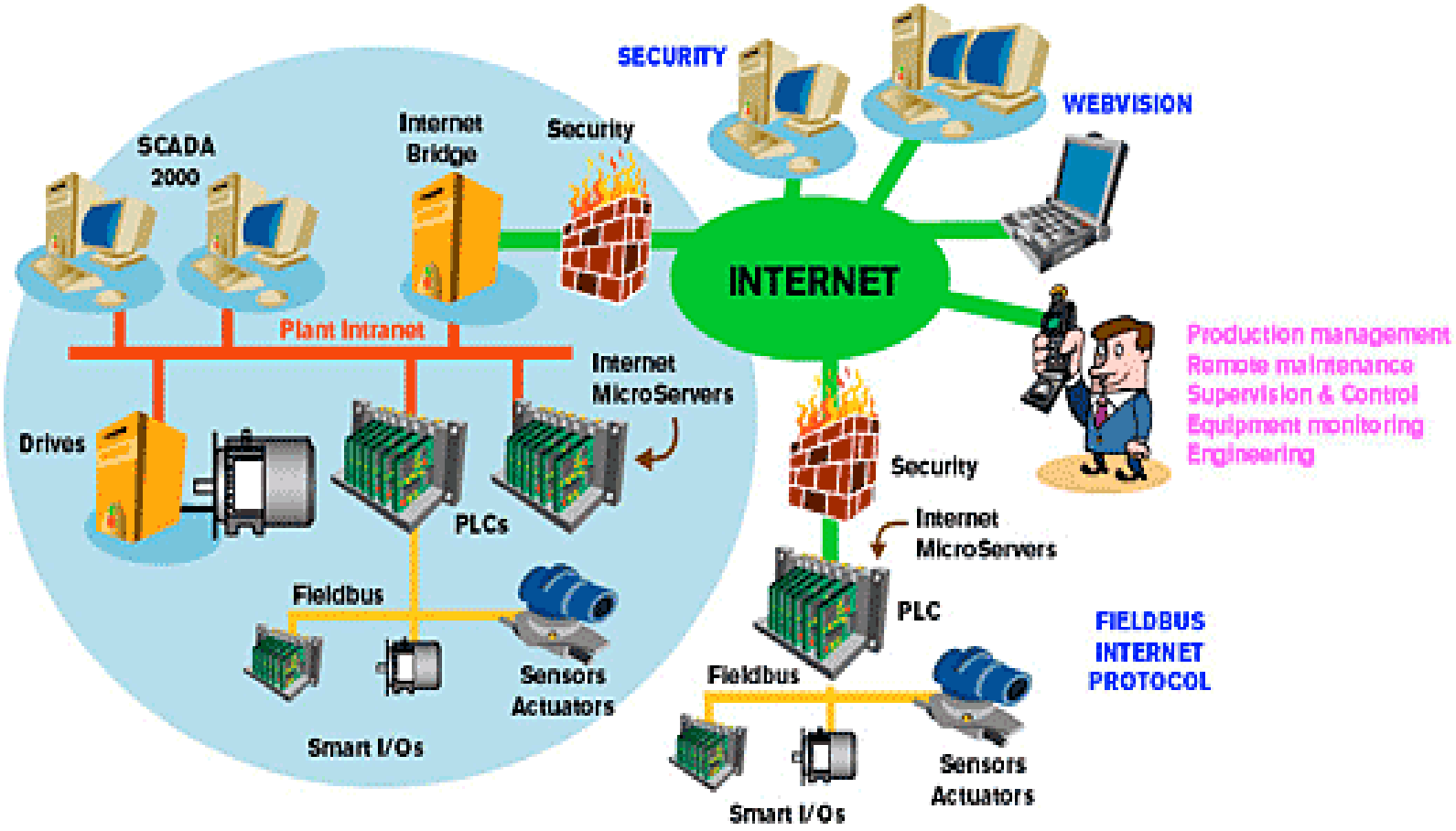
Example: Emerson's PlantWeb (Delta V)



Example: ABB Industrial IT (redundant system)

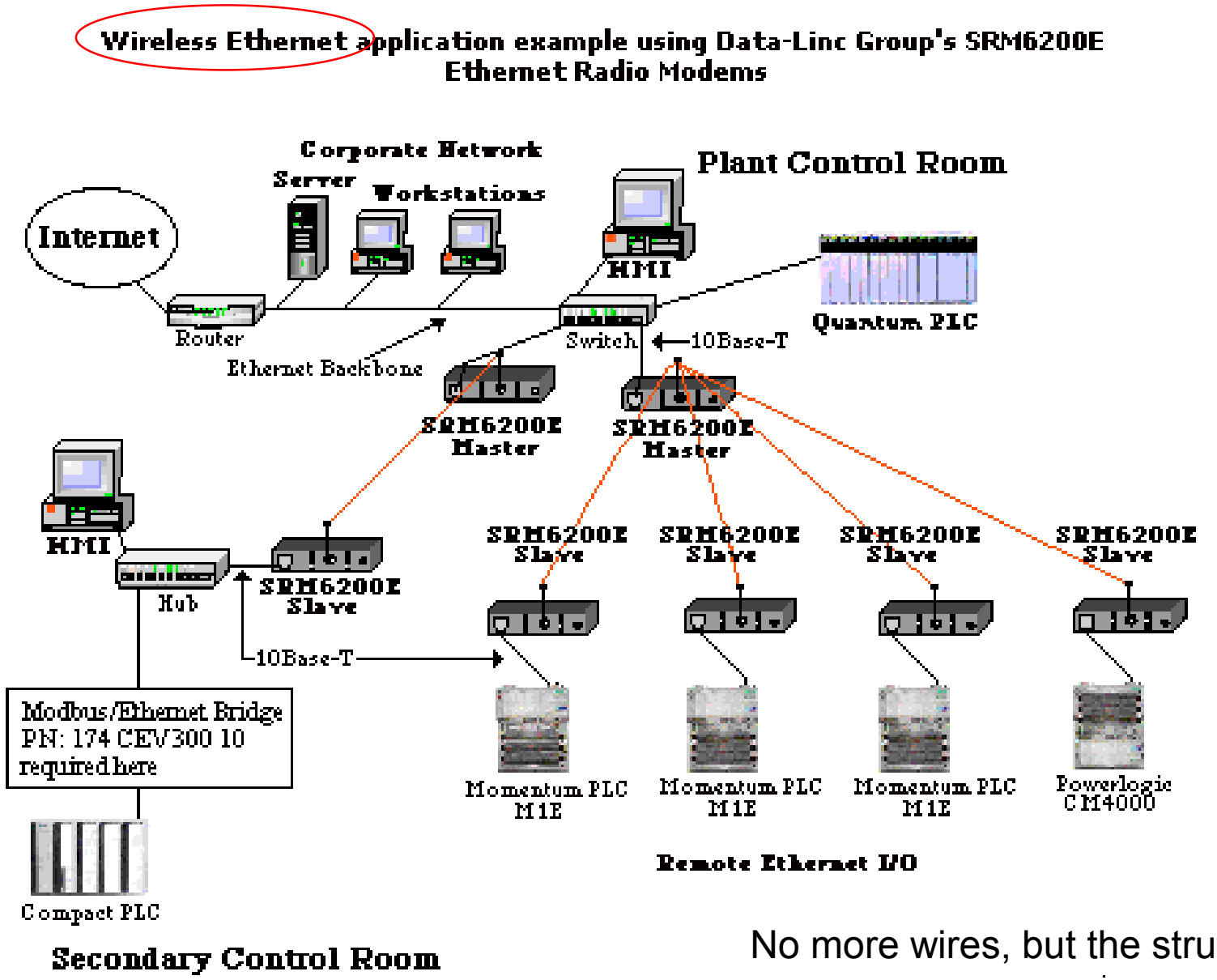


The internet dimension (example: Alstom)



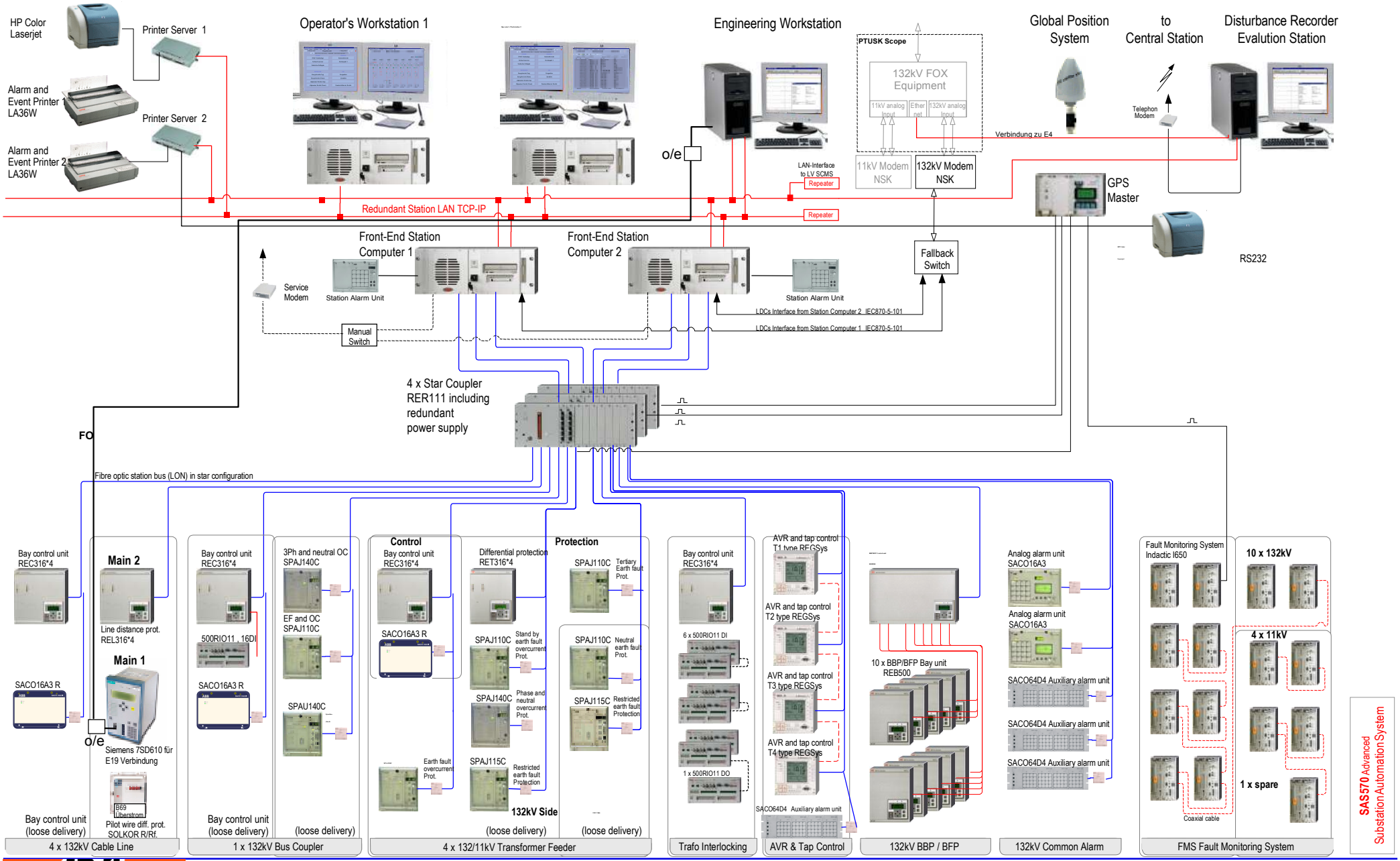
The ALSTOM e-Control Architecture

The wireless dimension (example: Schneider)

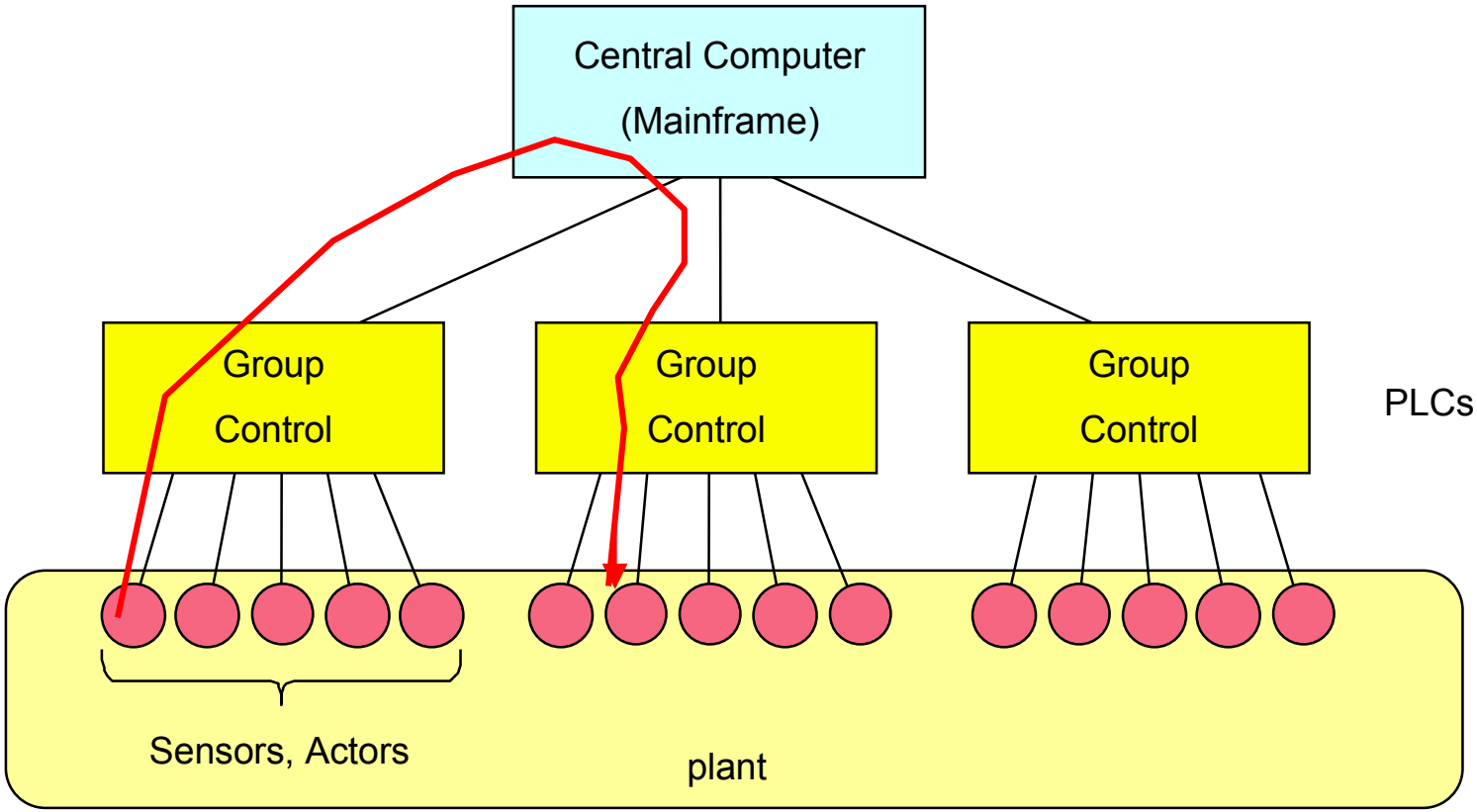


No more wires, but the structure remains

Substation project



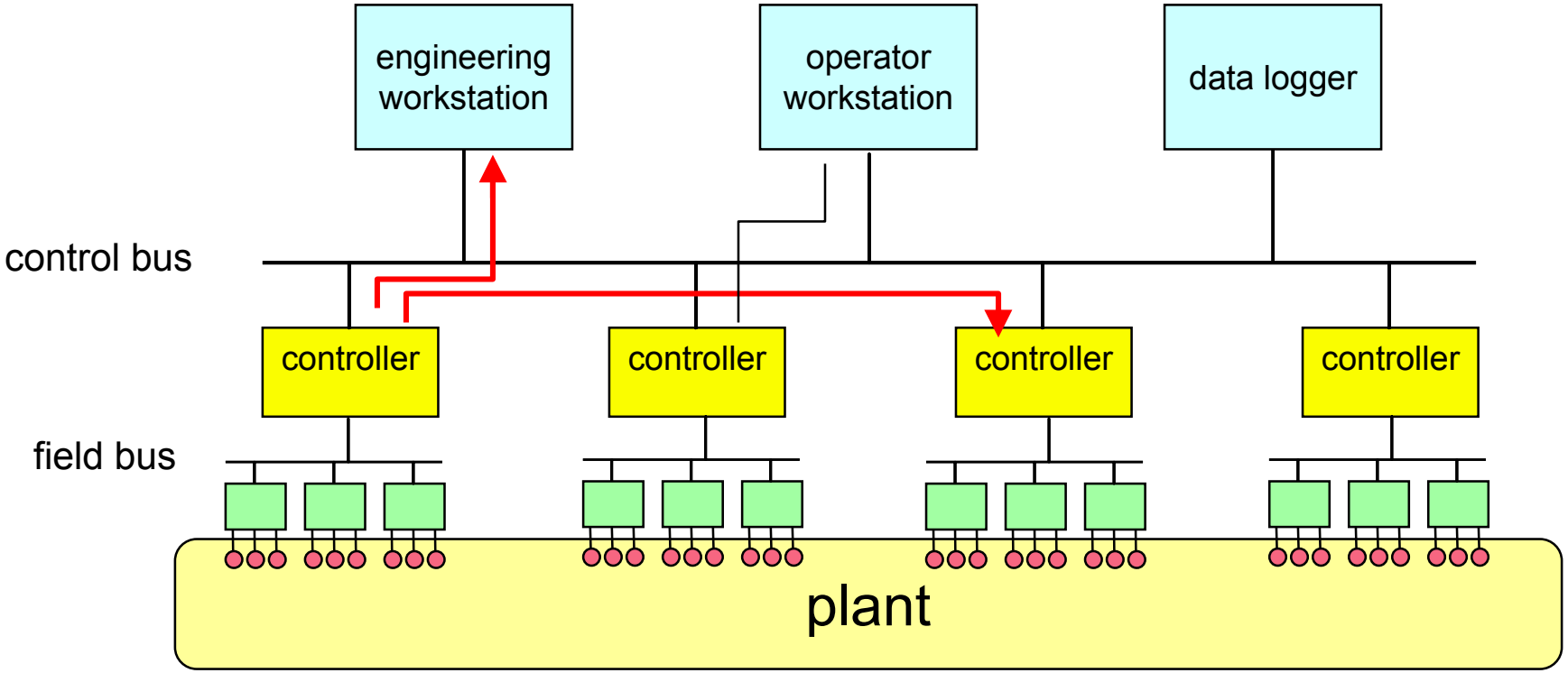
Centralized Control Architecture (classical)



Classical, hierarchical, centralized architecture.

The central computer only monitors and forwards commands to the PLCs

Decentralized Control System (DCS)



all controllers can communicate as peers (without going through a central master), restricted only by throughput and modularity considerations.

Note: Honeywell's "DCS™" stands for "Distributed Control System", it is not a decentralized control system, but a control system for the process industry.

Hierarchies are simple and traditional

but Distributed Control Systems reflects a more complex world....

Assessment

1. Draw a typical hierarchical control system showing busses and controllers

2. How does the network hierarchy relate to the plant control hierarchy ?

3. What is the difference between a centralized and a decentralized control system ?
   (can this difference be seen from the outside ?)


EPFL