§ 1 What is Industrial Automation?

1.1 Definition of Several Basic Terms
1.2 Degree of Automation and Computer Deployment
1.3 Automation of Technical Products and Technical Plants
1.4 Components of an Industrial Automation System
1.5 Levels of Process Management and Automation Functions
1.6 Technical Systems
1.7 Graphical representation of Technical Processes
1.8 Effects of Industrial Automation on People, Society and Environment
Chapter 1 - Learning targets

- to know what Industrial Automation is
- to understand what a real-time system is
- to know what is meant by the „degree of automation“
- to recognize the different kinds of computer deployment
- to be able to differ between product automation and plant automation
- to know the components of an industrial automation system
- to know the different levels of an industrial automation system and their requirements
- to be able to classify processes in technical systems
- to know the different kinds of graphical representation of technical processes
- to become aware of the responsibility of an automation engineer
# § 1 What is Industrial Automation?

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</table>
Definition 1: A technical process is a process during which material, energy or information is altered in its state. This modification of state can imply the transition from an initial state to a final state.

Technical process means flow of material, energy or information.
### Examples

<table>
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<th>Initial State</th>
<th>Technical Process</th>
<th>Technical System</th>
<th>Final State</th>
</tr>
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<td>Low ambient temperature</td>
<td>Heating of a house</td>
<td>Oil-fueled heating system</td>
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</tr>
<tr>
<td>Dirty laundry</td>
<td>Washing process</td>
<td>Washing machine</td>
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<tr>
<td>Unsorted parcels</td>
<td>Transportation and distribution processes</td>
<td>Parcel distribution system</td>
<td>Parcels sorted by destinations</td>
</tr>
<tr>
<td>Energy of fossil or nuclear fuels</td>
<td>Energy transformation and energy generation processes</td>
<td>Power plant</td>
<td>Electric energy</td>
</tr>
<tr>
<td>Parts to be stored</td>
<td>Storage process</td>
<td>High bay warehouse</td>
<td>Parts compiled for commissions</td>
</tr>
<tr>
<td>Train at location A</td>
<td>Traffic process</td>
<td>Train</td>
<td>Train at location B</td>
</tr>
<tr>
<td>Monomere substance</td>
<td>Chemical reaction</td>
<td>Chemical reactor</td>
<td>Polymeric substance</td>
</tr>
<tr>
<td>Untested device</td>
<td>Test process</td>
<td>Test laboratory</td>
<td>Tested device</td>
</tr>
<tr>
<td>Parts without a drill-hole</td>
<td>Drilling process</td>
<td>Drilling machine</td>
<td>Parts with drill-hole</td>
</tr>
<tr>
<td>Pollutants</td>
<td>Pollution monitoring</td>
<td>System for air pollution monitoring</td>
<td>Information on pollution concentrations are indicated in monitoring center</td>
</tr>
</tbody>
</table>
1.1 Definition of Several Basic Terms

**Definition 2: DIN 66201**

A process is the entirety of all interacting processes within a system that transforms and stores material, energy or information. A **technical process** is a process in which its physical parameters are recorded and influenced by **technical means**.

- from simple to highly complex **washing machine, power plant**
- different partial processes are combined to an overall process **car with automotive electronics**
Technical system with technical process

Technical System
(device,machine or technical plant)

material, energy or information inflow
actuating signals
measured signals
material, energy or information outflow

process input
process output
process influencing information
process outcome information

the technical process runs on technical system
1.1 Definition of Several Basic Terms

Example

- technical plant: chemical reactor
- technical process: 3 sub-processes (fill, reaction, empty)
1.1 Definition of Several Basic Terms

**Industrial automation**

= process + automation

- cigarette vending machine
- ticket vending machine

- office automation,
- traffic automation,
- railway automation,
- industrial automation

**automat** = independently operating technical systems

**automation** = to enable machines, installations and facilities to operate independently
1.1 Definition of Several Basic Terms

**Industrial automation**

= the automation of a technical process

**Industrial automation system**

= technical system with technical process  
  + computer and communication system  
  + process operators
1.1 Definition of Several Basic Terms

**Structure of an industrial automation system**

- **People** (process operators) for managing and operating the technical process as well as intervening in exceptional situations.

- **Technical system** (technical product or technical plant), in which a technical process takes place.

- **Computer and communication system** consisting of e.g., programmable logic controllers (PLC), industrials PCs, micro controllers, bus systems, etc.

- Signals to the technical process.

- Signals from the technical process.

- Process influence.

- Process outcome.
### Industrial automation system

- Goal is the automation of operations in the technical process with the help of appropriate information processing units
- Human operators only place requests on the operating results

### Process control system

- Goal is the management of the procedure of the technical process by human operators, supported by the automation of individual operations
- Managing refers to controlling and regulating

### Process computer sciences

- Goal is an automation software system
- Real-time system

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1.1 Definition of Several Basic Terms

**Definition: Real-time operation (DIN 44300)**

Real-time operation is the operation of a computer system, in which programs required for the handling of incoming data are in constant operation so that the processing results are available within a given period of time. This data may appear according to a random time distribution or at regular intervals.

**Features of a real-time system**

- Hardware/software system
- Data reception, data processing, data delivery to the process within a given time interval
- External events
- Processing priority

*Real-time system allows real-time operation*
## Requirements on real-time systems

- **Timeliness**
  - reaction right on time

  - not too soon, not too late

- **Simultaneousness**
  - simultaneous reaction to various events

  - parallel processes

- **Dependability**
  - reliable, safe, available

  - important reason for purchase

- **Predictability**
  - all reactions must be predictable and deterministic

  - comprehensible in case errors occur
Industrial automation system as real-time systems

1. Definition of Several Basic Terms

- computer and communication system
- technical process in a technical plant
- sensor signals
- control signals
- external influences
- time

operating personnel

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1.1 Definition of Several Basic Terms

**Features**

Processors applicable in a process automation system are freely programmable digital processors (computers) that have to show mainly 3 features:

- Compliance of real-time operation requirements, that are: recording, processing and output of process data in a timely manner
- Possibilities for input/output of process signals (directly or via a communication system) for process connection
- Processing of numbers, characters and **bits**

In 60th and 70th years specific „process computers“
- Antiquated term, because differences have disappeared
§ 1 What is Industrial Automation?

1.1 Definition of several basic terms

1.2 **Degree of automation and computer deployment**

1.3 Automation of technical products and technical plants

1.4 Components of an industrial automation system

1.5 Levels of process management and automation functions

1.6 Technical systems

1.7 Graphical representation of technical processes

1.8 Effects of industrial automation on people, society and environment
Degree of automation

The sense and benefit of an automation depends on the technical process (accessible / inaccessible) and the general conditions (economically reasonable / senseless). The degree of automation describes the extend of the processes included in the automation.

**bandwidth:** from zero up to fully automated operation

**Caution!** - Also with fully automated operation the human being can make interventions (set point default or malfunction)

Types of operation

- Off-line operation (operation with indirect process connection) with the lowest degree of automation
- On-line / open-loop operation (open on-line operation) for a medium degree of automation
- On-line / closed-loop operation (closed on-line operation) for a high degree of automation
1.2 Degree of automation and computer deployment

Operation without computer use

- General management
- Orders
- Process management applications
- Operation protocol
- Operation accounting
- Control and regulation devices
- Manual device
- Display device and graphical recorder

No automation

Technical plant
1.2 Degree of automation and computer deployment

Off-line operation (indirectly connected operation)

- Low degree of automation, no connection to the technical process
- Off-line operation (indirectly connected operation)
- Input, operation modes instructions
- General management orders
- Operation protocol input
- Process management instructions
- Process personnel
- Display and graphical recorder
- Technical plant
On-line/ open-loop operation of a computer system

medium degree of automation, data acquisition from the technical process

open-loop

on-line
On-line-/ closed-loop operation of a computer system

- High degree of automation, data recording and influence of the technical process
- Operation management and control
- On-line and closed-loop operation of a computer system
- Computer and communication system
- Technical plant
- Emergency control
- Emergency instruments
- Operation protocol
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</table>
Product automation

industrial automation systems, in which the technical process takes place within a device or within a single machine

Plant automation

industrial automation systems, in which the technical process is composed of single partial processes that take place on greater, often geographically wide spread plants
### Examples

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<tr>
<th>Examples of products in product automation</th>
<th>Examples of technical plants in plant automation</th>
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<tr>
<td>heating systems</td>
<td>power plants (steam generators, turbines, generators)</td>
</tr>
<tr>
<td>washing machines</td>
<td>energy grid</td>
</tr>
<tr>
<td>sewing machines</td>
<td>high bay warehouse</td>
</tr>
<tr>
<td>kitchen appliances (e.g., dish washer, microwave, etc.)</td>
<td>parcel distribution installations</td>
</tr>
<tr>
<td>TVs, radios</td>
<td>chemical reactors</td>
</tr>
<tr>
<td>cameras</td>
<td>process engineering installations</td>
</tr>
<tr>
<td>alarm systems</td>
<td>steel production plants</td>
</tr>
<tr>
<td>toys</td>
<td>milling installations</td>
</tr>
<tr>
<td>navigation systems</td>
<td>railway traffic system (long distance trains, commuter railways, metros)</td>
</tr>
<tr>
<td>answering machines</td>
<td>traffic light installations</td>
</tr>
<tr>
<td>musical instruments</td>
<td>gas supply installations</td>
</tr>
<tr>
<td>machine tools</td>
<td>purification and water plants</td>
</tr>
<tr>
<td>measuring devices</td>
<td>building system installations</td>
</tr>
<tr>
<td>automobiles with sub-systems: motor control, ABS, distance warning system, route planning, etc.</td>
<td>laboratories and test fields</td>
</tr>
<tr>
<td></td>
<td>environmental measurement installations</td>
</tr>
<tr>
<td></td>
<td>etc.</td>
</tr>
</tbody>
</table>
### Characteristic criteria regarding product automation

- Technical process in a device or machine (embedded systems)
- Dedicated automation functions
- Automation computer in the form of a micro controller or PLC
- Few sensors and actuators
- Degree of automation 100%, on-line/closed-loop operation
- High quantities (serial or mass products)
- Engineering and software costs of inferior importance since they are distributed among large unit numbers
Structure with simple product automation

example:
- kitchen appliance
Example of a simple product automation (chalkboard writing)
1.3 Automation of technical products and technical plants

Structure with complex product automation

- User or operator
- Microcontroller
- Bus-system
- Microcontroller 1
- Microcontroller 2
- Microcontroller n
- Subsystem 1
- Subsystem 2
- Subsystem n

Example: automotive electronics
Characteristic criteria regarding plant automation

Technical process in an industrial plant, often geographically wide spread

Extensive and complex automation functions

PLCs, PCs and process control systems are used as automation computer systems

Large number of sensors and actuators

Medium to high degree of automation

Unique system

Engineering and software costs are critical for overall costs
Structure for a larger technical plant

- **level 1**: Field bus
  - Sub-system

- **level 2**: Pant bus
  - PLC
  - ... (repeated)

- **level 3**: Factory bus
  - Master computer
  - PC
  - ... (repeated)

The diagram illustrates the hierarchical structure of automation for a larger technical plant, with various levels and components interconnected through different buses (field bus, pant bus, factory bus) and communication protocols (monitoring, operating, protocolling).
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1.4 Components of an industrial automation system

Overview

- technical components of an industrial automation system
  - technical system to be automated (automation object)
    - technical product
    - technical plant
  - facilities necessary for automation (automation system)
    - communication system
      - communication system close to the process (field bus)
        - bus system for the communication between automation computers
      - automation computer system
        - hardwired individual devices
        - facilities for user-process communication
    - interface to the technical process: sensors and actuators
    - facilities necessary for automation (automation system)
1.4 Components of an industrial automation system

**Sensors**
- Acquisition of information on the progression of process variables
- Sensors, detection devices, measuring devices
- Conversion into electrical or optical signals

  **examples:** temperature, pressure, velocity

**Actuators**
- Conversion of control information in order to influence process variables
- Actuators (correcting element)

  **examples:** relays, magnets, servomotors
Communication system in product automation

Simple products

- few sensors and actuators
- short line distances

Complex products

- communication between subsystems via bus system
- examples: CAN bus, Interbus-S
Communication system in plant automation

- Many sensors and actuators, geographically distributed
- Many automation computers, geographically distributed

Communication tasks on several levels

- Factory bus
- Plant bus (process bus)
- Field bus
Different forms of automation computers

- Programmable logic controller (PLC)
- Micro controller
- Personal computer (PC)
- Process control system
1.4 Components of an industrial automation system

**Automation software system**

- Set of all programs necessary for the execution of automation tasks, including their documentation

- Differentiation between executive and organizational/administrational tasks

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**Executive programs** (application software)

- input measured values
- calculation of control variables

**Organizing and administrating programs** (operating software or system software)

- software device drivers
- operating system
1.4 Components of an industrial automation system

**Application software**
- Programs for acquisition of process variables
- Programs for process monitoring
- Programs for process control
- Programs for process regulation
- Programs for process optimization and management
- Programs for process safety and security

**System software**
- Programs for organizing of application programs
- Programs for managing peripheral devices
- Programs for organizing data traffic with external memories
- Programs for the dialogue between human and computer
- Compilation programs
- Run-time programs

**Operating system**
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Model of levels in the management of a technical process

- **Levels of hierarchy**
  - Strategic level
  - Dispositive level
  - Tactical level
  - Operative level

- **Levels of distribution**
  - Long-term distribution policy
  - Distribution planning
  - Distribution tactics
  - Sales

- **Levels of a company**
  - Business management level
  - Production and operation management level
  - Process control level
  - Level of measuring, controlling, and regulating process variables (process variable level)
  - Technical process in a technical system

Field of action → Market → Technical process in a technical system
Time requirements on the different levels

- **Business management level:** Effects ranging between months-years
- **Production and operation management level:** Effects ranging between days-weeks-months
- **Process control level:** Effects ranging between minutes-hours
- **Process variable level:** Effects ranging between microseconds-seconds
Automation functions

Levels of a company

- business management level
- production and operation management level
- process control level
- process variable level
- field level

Automation functions

- cost analysis, statistical evaluations
- work sequence planning, capacity optimization, evaluation of process results
- process monitoring, start-up and shut-down, malfunction handling, process guidance, process security
- measuring, controlling, manipulating, regulating interlocking, emergency handling of process variables, shut-down, protection
- recording and influencing process variables with sensors and actuators
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Types of occurring process variables (1)

- Process variables, that are allocated to the course of physical state-variables with a continuous or piecewise continuous range of values
  example: temperatures in a heating system

- Process variables, that are allocated to certain discrete process states
  - physical variables with a continuous range of values that characterize the process states
  - binary process variables that are allocated to state transitions i.e., to events that cause the change of state

example: switch setting: 0/off - 1/on
Types of occurring process variables (2)

- Process variables that are allocated to individually identifiable objects
  - physical variables with a continuous range of values
    example: temperature of a slab in a clogging mill,
    size of a part in a store
  - non-physical variables
    example: type, design, application, depot number
Definition of three process types in technical systems

- continuous processes

- sequential processes, discrete event type processes

- object-oriented processes

Caution! - a clear distinction is not always possible!

example: transportation as a continuous and object-oriented process
### Continuous processes in technical systems

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>processes containing time-dependent continuous process variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process variables</td>
<td>physical variables with a (at least piecewise) continuous range of values</td>
</tr>
<tr>
<td>Examples</td>
<td>generation processes, transformation processes, movements, etc.</td>
</tr>
<tr>
<td>Mathematic models</td>
<td>differential equations (time as an independent variable), transfer functions</td>
</tr>
</tbody>
</table>
## Sequential processes in technical systems

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>processes containing sequences of different, distinguishable process states</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process variables</td>
<td>binary signals that cause or indicate discrete process states as well as continuous physical variables allocated to process states</td>
</tr>
<tr>
<td>Examples</td>
<td>sequences of process states during start-up or shut-down of a turbine, sequence of states during the operation of an elevator, sequence of states during production using a machine tool</td>
</tr>
<tr>
<td>Models</td>
<td>flow charts, function plans according to DIN 40719, state models, Petri nets</td>
</tr>
</tbody>
</table>
Object-oriented processes in technical systems

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>processes during which individually identifiable objects are transformed, transported or stored</th>
</tr>
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<tbody>
<tr>
<td>Process variables</td>
<td>physical variables with a continuous range of values or non-physical variables (e.g., type, design, application, bay number) that are allocated to the objects, as well as binary variables, that cause or indicate state changes of objects</td>
</tr>
<tr>
<td>Examples</td>
<td>processes during the manufacturing of parts, traffic processes, storage processes, information processes in computers</td>
</tr>
<tr>
<td>Models</td>
<td>simulation models, queue-models, state models, Petri nets, OO-models</td>
</tr>
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</table>
Classification methods

Classification according to the kind of...

- transformed or transported medium
  material related processes, energy related processes, information related processes

- effect
  generation processes, distribution processes, storage processes

- material-related transformation
  chemical processes, production processes

- dominating process type
  flow processes (continuous), successive processes (sequential), piece-related processes (object-related)
Assignment of technical production processes to process types

<table>
<thead>
<tr>
<th>Technical processes</th>
<th>Process types</th>
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<tbody>
<tr>
<td>Energy-related processes</td>
<td>continuous processes, sequential processes</td>
</tr>
<tr>
<td>chemical processes</td>
<td>continuous processes, sequential processes</td>
</tr>
<tr>
<td>production processes</td>
<td>continuous processes, sequential processes, object-related processes</td>
</tr>
<tr>
<td>material-handling processes</td>
<td>continuous processes, sequential processes, object-related processes</td>
</tr>
</tbody>
</table>

Technical processes can contain processes of different types, on the other hand a process in turn can be a technical process.
Examples:

- Generation of electric energy in a turbo generator
  - continuous process
  - sequential process (start-up sequence of plant)

- Batch processes
  - single process steps are continuous processes
  - sequence of steps is a sequential process

- Manufacturing a swivel
  - transportation of the machine’s parts is an object-related process
  - manufacturing process consists of a sequence of steps (“mount part”, “drive machine to position “ etc.), thus it is a sequential process
  - cutting process is a continuous process
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<td><strong>Graphical representation of technical processes</strong></td>
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Flowchart

- Similar to block diagrams used in control engineering
- Processes and process steps are represented as rectangles
- Arrows represent the information or material flow
- Bundles of connections are shown as double lines with arrow

Example:

![Flowchart Diagram]

- **additive**
- **crush**
- **raw material**
- **dissolve**
- **solvent**
- **reaction**
- **intermediate product**
- **separate**
- **final product**
1.7 Graphical representation of technical processes

**Information/material-oriented representation**

- Information/materials as circles
- Processes/functions as linking arrows

Example:

- additive
- crushed
- reaction
- separation
- material
- dissolved
- reaction
- separation
- solvent
- final product
- dissolve
- dissolve
Phase model representation

- Mixture of flowchart and information/material-oriented representation

Example:
Examples for the flowchart representation

Simple flow chart:

- Additive: 350 kg/h
- Raw material: 800 kg/h
- Solvent: 1000 kg/h

Process flow chart:

- Heating steam: 3 bar
- Heating steam: 108°C
- Final product: 1450 kg/h
- Depot

1 bar
20°C
1 bar
20°C
Pipes and instrumentation flow diagram
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### Intentional (positive) effects

- **Simplified and more convenient operation**
  - automation of a washing machine
  - automation of a heating system

- **Production of better, cheaper products of equal quality with lowered production costs**
  - automation of chemical production processes

- **Reduction of hazards to people**
  - ABS system
  - traffic system automation (like inductive train security, automatic barrier close)

- **Better, more humane working conditions**
  - automation of painting or foundry work

- **Securing jobs through higher competitiveness**
  - use of robots in automobile manufacturing
Unintentional (negative) effects

- Redundancy of workers may lead to unemployment
  - use of robots in manufacturing

- Restructuring of jobs due to changes in work flow and fields of work
  - lower/higher qualified jobs
  - drop of ancillary tasks
  - increase of jobs in the service sector

- Reduction of human relationships
  - introduction of ticket vending machines and information systems

- Increase of stress and reduction of relaxing tasks
  - automation of testing systems

- Overtaxing in difficult situations
  - safety-critical decision in a nuclear power plant
Industrial automation has effects on:

- people
- society
- environment
- energy and resources

The automation engineer is responsible for the effects of industrial automation!

Direct, immediate responsibility

- damages in industrial automation systems designed by him
- violations of generally accepted guidelines and regulations (regulations of the VDE, etc.)
- safety of automation systems

Indirect, collateral responsibility

- unintentional side effects

Dilemma: trade-off between benefits and damage
Question referring to Chapter 1.1

In addition to the correctness of the data the timeliness of data is of high relevance in industrial automation. Which of the following statements do you agree?

- Early data is bad data
- Late data is bad data
- As fast as possible data is correct data
- Precise data is bad data
- No data is bad data

Answer
Question referring to Chapter 1.3

A company wants to automate the production of refrigerators. For this purpose, a new production line shall be constructed. In this production line, the coolant will be filled in and the rear will be screwed to the case.

Which kind of automation system is this?

Answer

The given system is a plant automation system. The production process (assembly line) shall be automated and not the product itself.
Question referring to Chapter 1.4

For the control computer of a production line of refrigerators (described in the last question) the company received two offers:

- „ordinary“ PC 3000,- €
- industrial PC with the same performance 5000,- €

Which computer would you choose?
Give reasons for your choice and explain the difference in price.

Answer

There is no difference in the performance range of the two computers. The main difference between an „ordinary“ PC and an industrial PC is that the industrial PC is especially built to endure the higher stress in industrial environments (temperature variations, EMI, vibrations, etc.)

In this case, therefore, the choice would be an industrial PC.
Question referring to Chapter 1.6

The IAS modular production system is shown below. Which kind of processes do you identify in this system?

Answer

- **Sequential processes**: (all individual assembly stations are passed through sequentially)
- **Object-related processes**: (all work steps are done at the barrels)
- **Continuous processes**: (e.g. transportation)
Crosswords to Chapter 1

1. REALTIME

2. SYSTEM

3. OBJECTORIENTED

4. F

5. TEL

6. ROW

7. SIMULTANEOUSNESS

8. TECHNICALPROCESS

9. CONTROLLEVEL

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## Crosswords to Chapter 1

### Across

3. Denomination of systems which have to be in synchrony with activities happening in an external system. (4,4,6)
5. Process type of manufacturing of parts. (6,8)
7. Simultaneous reaction to various events (16)
9. Process in which the physical parameters are recorded and influenced by technical means. (9,7)
10. Automation technical analog to "tactical level". (7,7,5)

### Down

1. Device used to influence process variables. (8)
2. Term describing the extent in which a process is automated. (6,2,10)
4. Graphical representation of technical processes, similar to block diagram. (9)
6. Reaction to an event right on time (10)
8. Device used to measure process variables. (6)