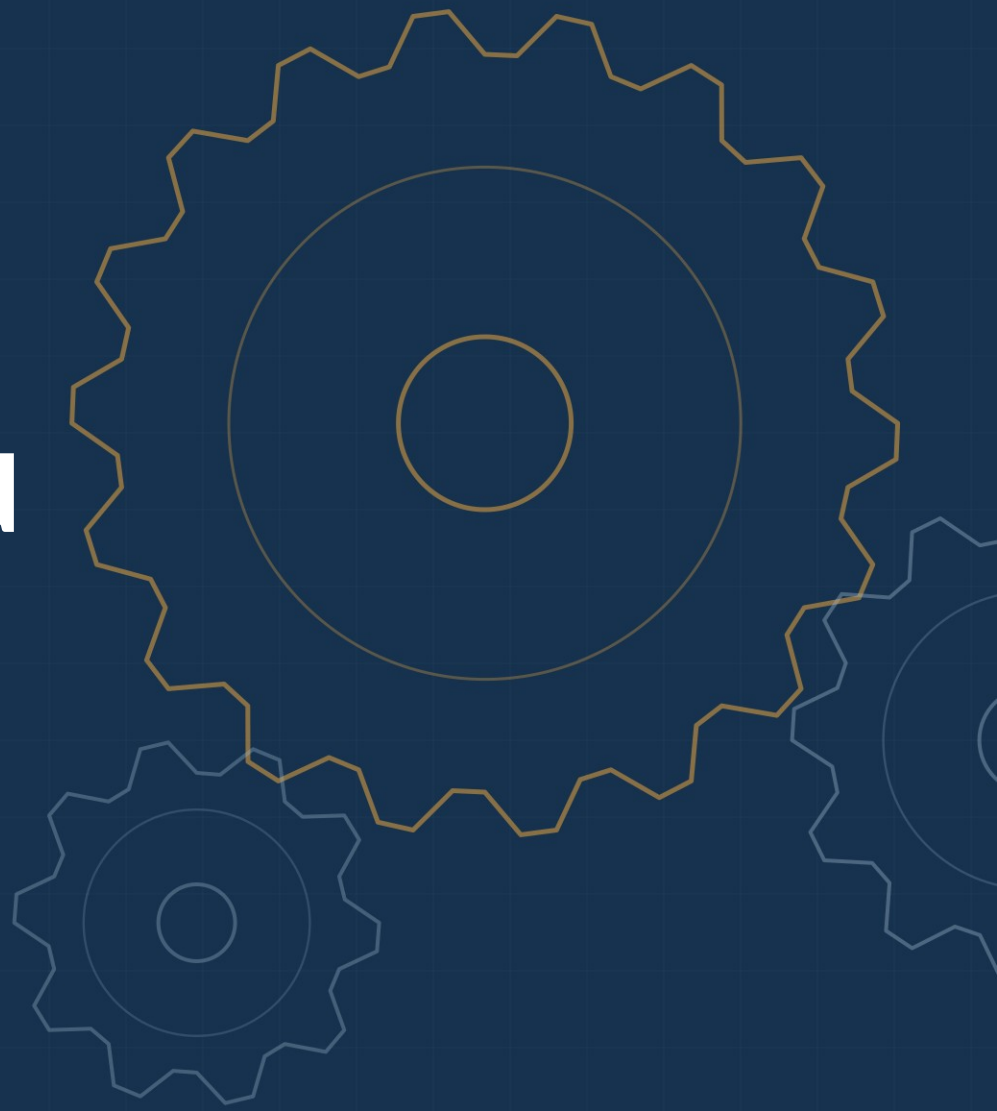
BASICS OF MACHINE OPERATION

Block 1 · Lecture 2 · 2 Dec 2026

Systems Approach and Maintenance Organisation and Strategies

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Akademia Techniczno-Artystyczna Nauk Stosowanych w Warszawie



Course plan

L1 Block 1 · 2 Dec 2026

Introduction to machine operation · Machines as technical means

L2 Block 1 · 2 Dec 2026

Systems approach · Maintenance organisation and strategies

L3 Block 2 · 9 Dec 2026

Modern maintenance · Availability, durability and wear

L4 Block 2 · 9 Dec 2026

Tribology and lubrication · Fundamentals of diagnostics

L5 Block 3 · 20 Jan 2027

Condition monitoring · Reliability fundamentals

L6 Block 3 · 20 Jan 2027

System reliability · Failure analysis and improvement

L7 Block 4 · 27 Jan 2027

Life data and maintenance logistics · Industry 4.0 · Review

Today: L2. Systems Approach and Maintenance Organisation and Strategies

RECAP

Before the break – six points

- Machines are made **to be operated** – operation is the longest life-cycle phase.
- Decide with **Life Cycle Cost**, not the purchase price.
- **Maintenance** (EN 13306) – technical, administrative and managerial actions.
- **Availability** A = MTBF / (MTBF + MTTR).
- Safety: **EN ISO 12100** and Regulation **2023/1230**.
- Three phases of wear – keep machines **out of phase III**.

TODAY

Plan for today

PART A

Systems approach to machine operation

1. The concept of a system
2. Systems thinking
3. Systems modelling
4. Human in the system and systems engineering

PART B

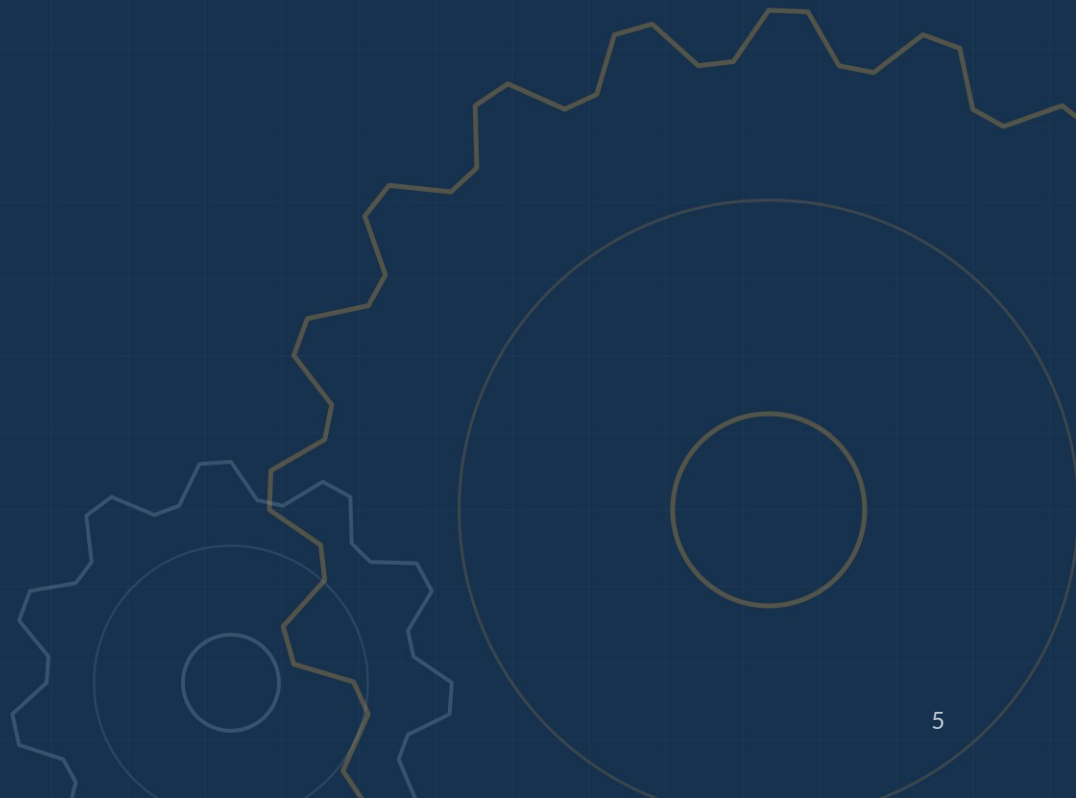
Maintenance organisation and strategies

5. Maintenance problems
6. The maintenance department
7. Maintenance strategies
8. Choosing the right strategy

01

The concept of a system

Elements, relations, environment – and the goal they serve



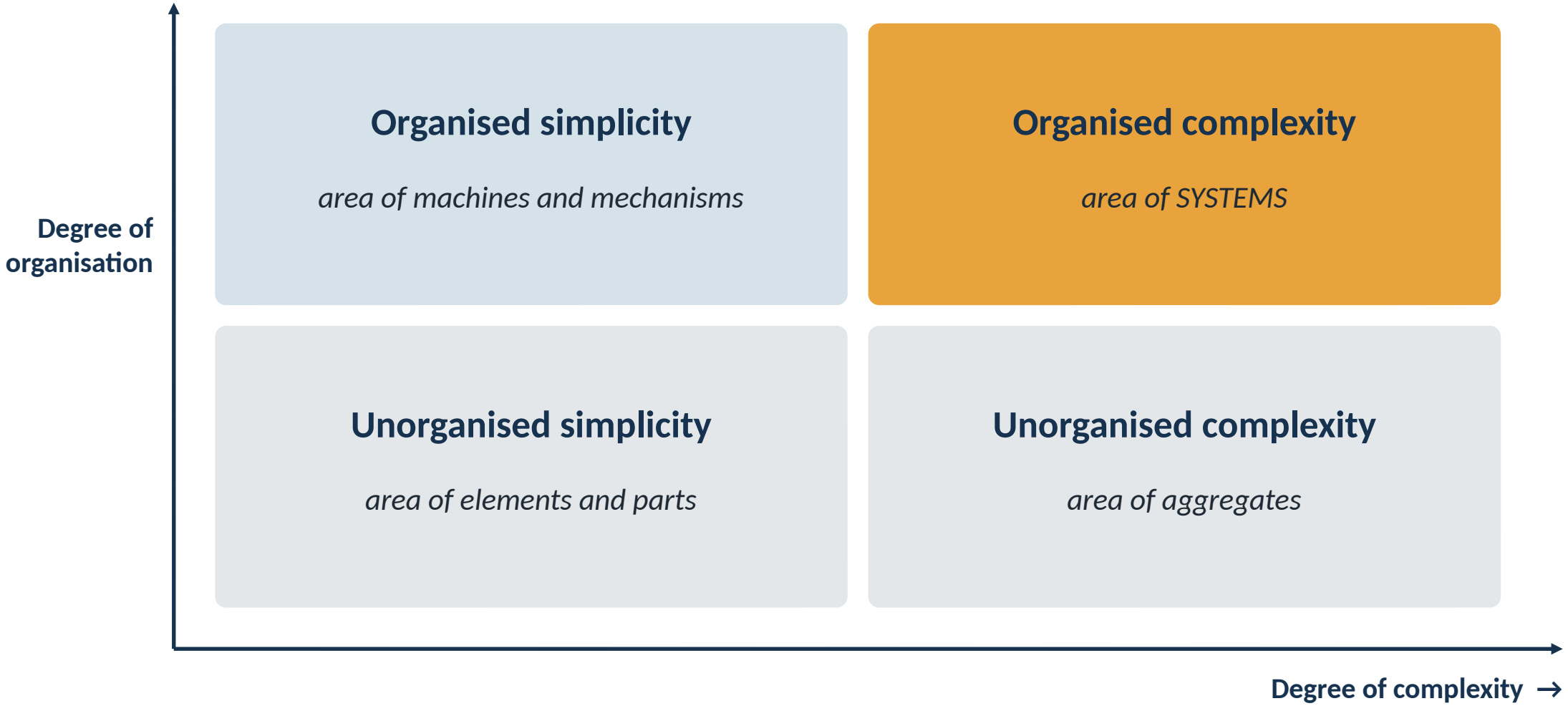
What is a system?

The word “system” is used in all sciences. Sadowski counted as many as **34 definitions**. The founder of general systems theory, **Ludwig von Bertalanffy**, defined a system as **“a set of elements in mutual interaction with each other and with the environment”**.

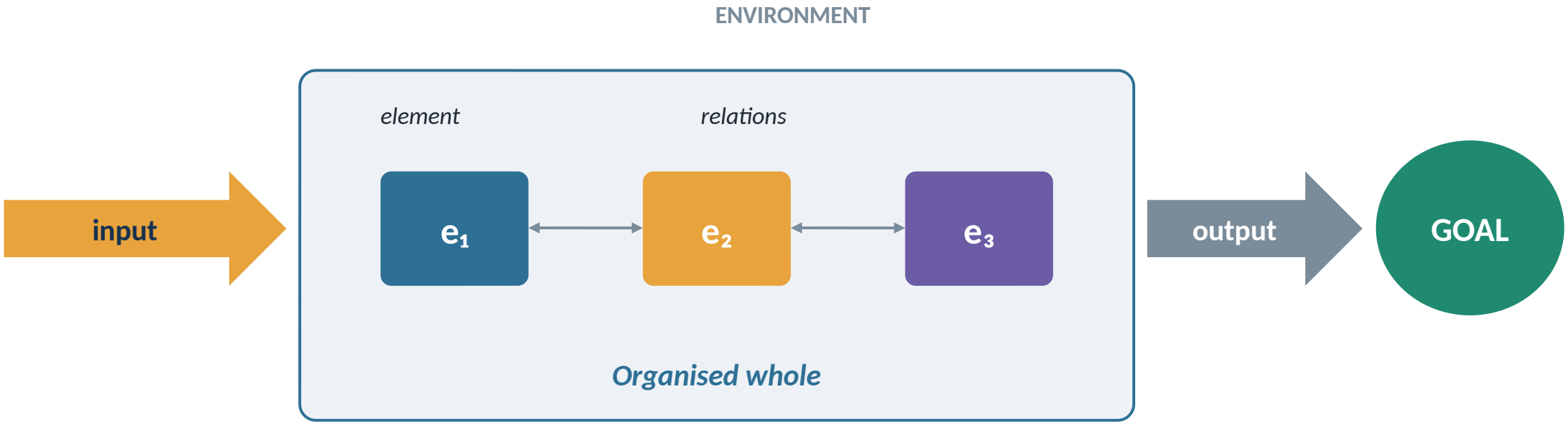
> A system is a set of material or abstract objects, separated from the environment, connected by relations that create a structure.
>
> — *S. Pabis*

The minimum: **elements** + **relations (structure)** + **separation from the environment**

Where do systems belong?



The cybernetic model of a system



To call something a system, we need **at least three elements** working together to reach a **goal**. The influence of the environment on the system is the **input**; the influence of the system on the environment is the **output**.

The whole is more than the sum of its parts

Systems show a property known as **Nernst's principle**: the whole is more than the sum of its parts – parts inside a system have different properties than when separated.

The properties of the whole (system features) are determined by:

- the properties of the elements (parts),
- the relations (system connections).

The same set of parts can form different systems if connected differently. The system also acts back on its parts – for example, it causes their **wear**.



KEY TAKEAWAY

The structure of a system determines its behaviour.

From an element to an operation system

set of elements	+	structure	=	**assembly**
set of assemblies	+	internal coordination	=	**machine**
set of machines	+	task	=	**system**

A system made of sets is divided into **subsystems**; a higher-level system is a **supersystem**.

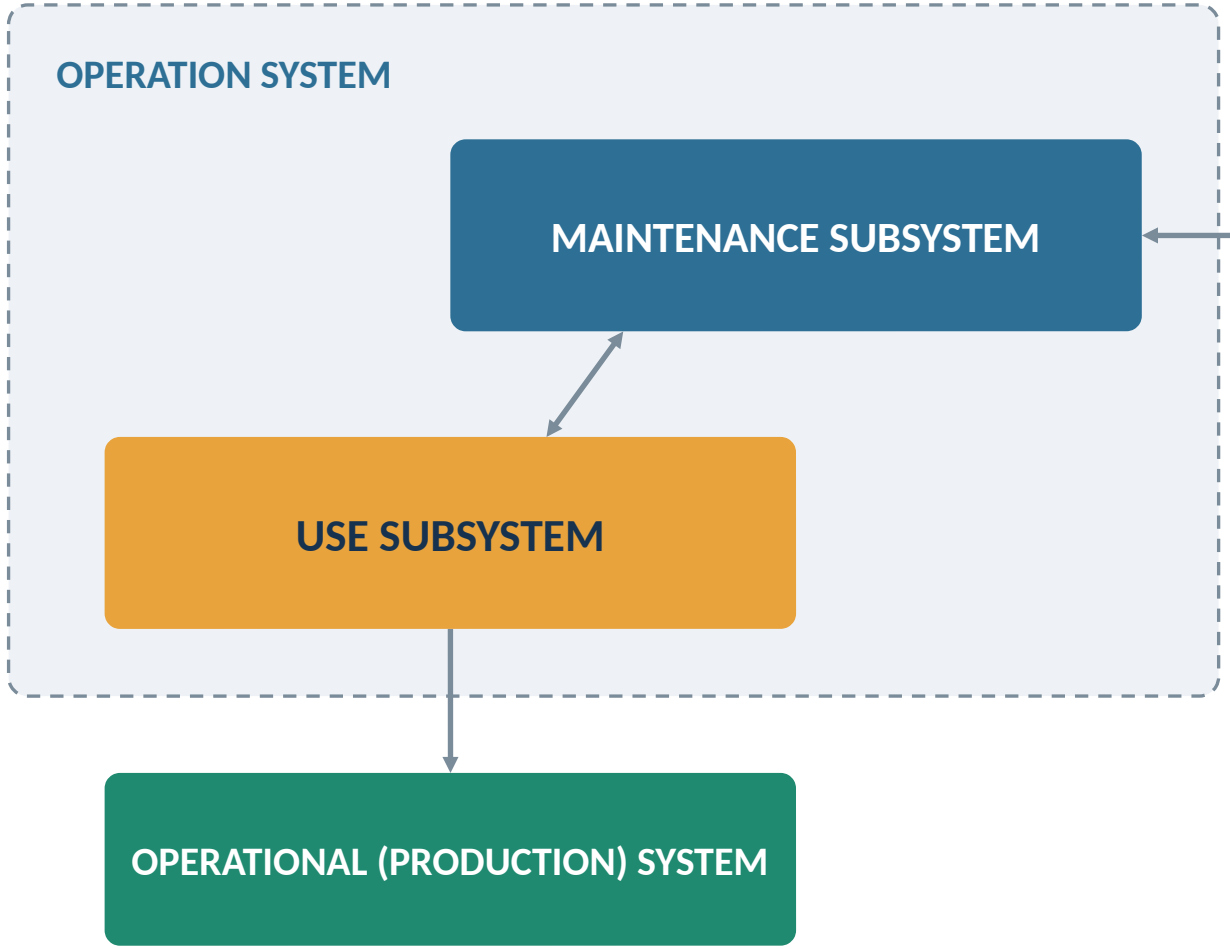
From the engineering point of view, **the operation system is the set of all elementary operation arrangements of a machine**, ordered by co-usefulness or interdependence.

Every machine has two elementary arrangements:

Use – the use subsystem (US)

Maintenance – the maintenance subsystem (MS)

The operation system and its environment



What we treat as a system, and which subsystems we distinguish, is decided by **the person who needs it** to solve a problem.

Subsystems are usually separated by **operational states** and by **functions**.

EXAMPLE

Example: a city bus company as an operation system

Use subsystem

buses on routes, drivers, timetables – the “production” of transport

Maintenance subsystem

depot workshop, daily checks, inspections, repairs, cleaning

Supply system

fuel or electricity, spare parts, tyres, oils – from external suppliers

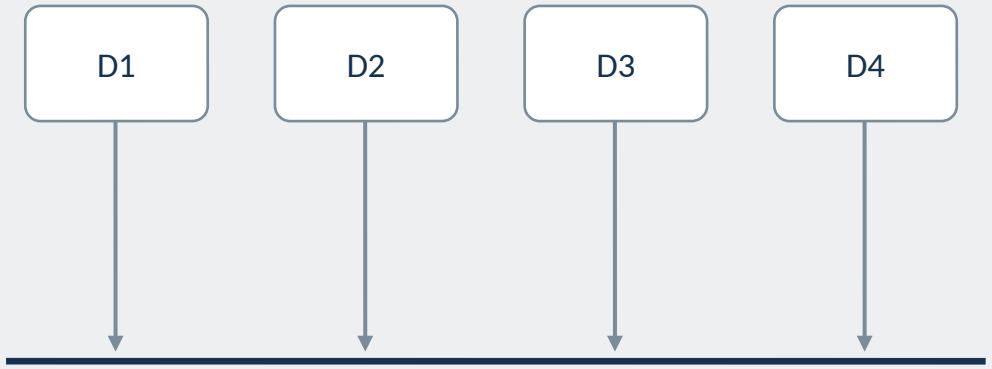
Environment and supersystem

the city (customer), passengers, traffic law, weather, technical inspection authorities

“How does it work?” – not “What is it made of?”

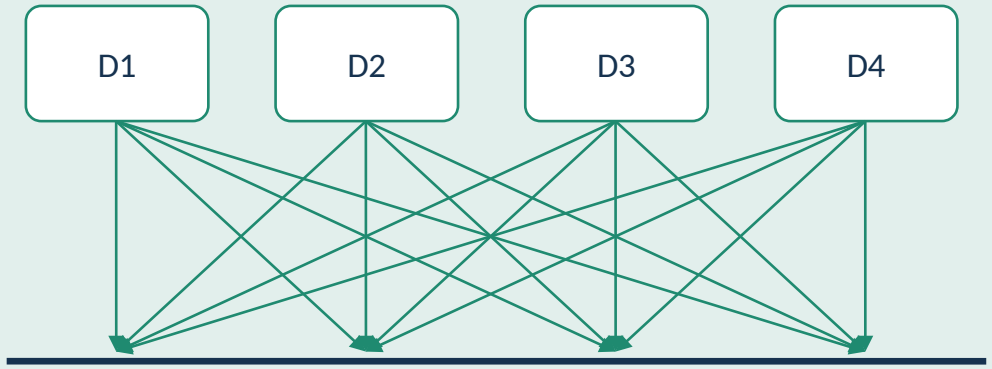
Operation science owes its simplicity to **abstracting from materials**. We ask “how does it work?”, not “what is it made of?”. Differences in materials created separate mono-disciplines that split the whole into fragments.

a) Atomistic (traditional) science



fragmented reality

b) Systems (modern) science

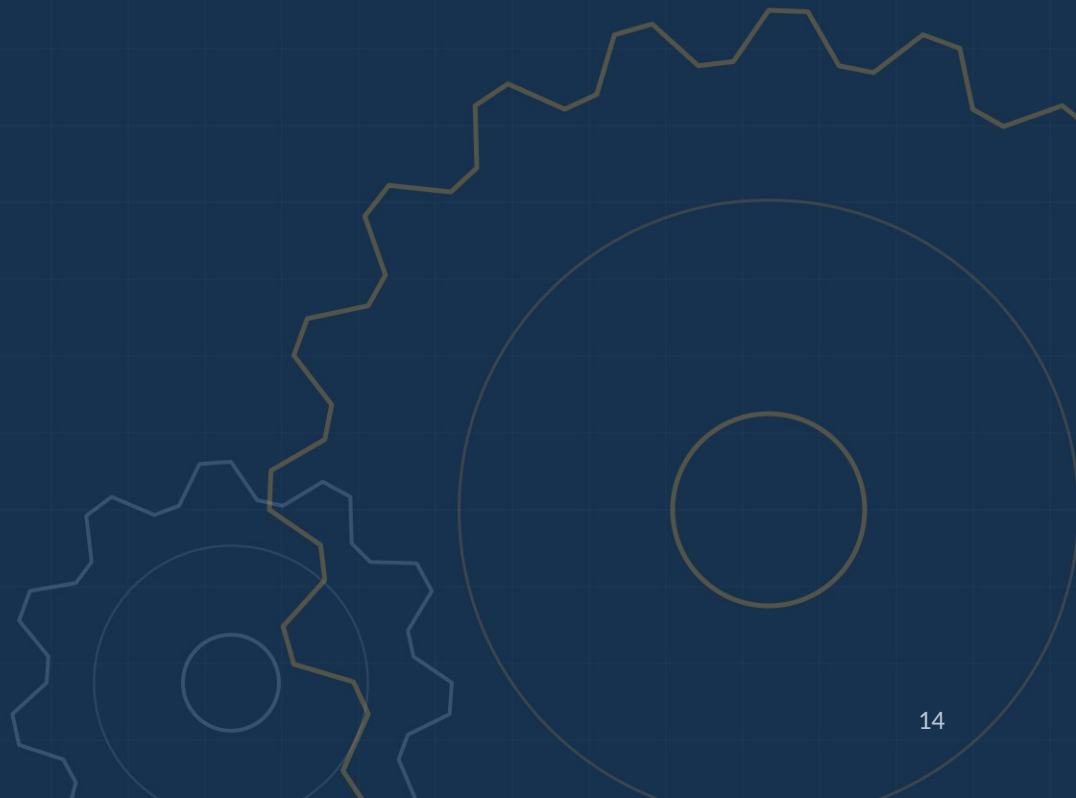


integrated reality

02

Systems thinking

Seeing the whole, the feedback loops and the hidden structures



What does it mean to think systemically?

To think systemically means **to consider the context (what is it for?)** – a context that is changing, complex and ordered, with no clear beginning or end. G. Ossimitz describes four elements:



thinking in models and the ability to build them



thinking in feedback loops



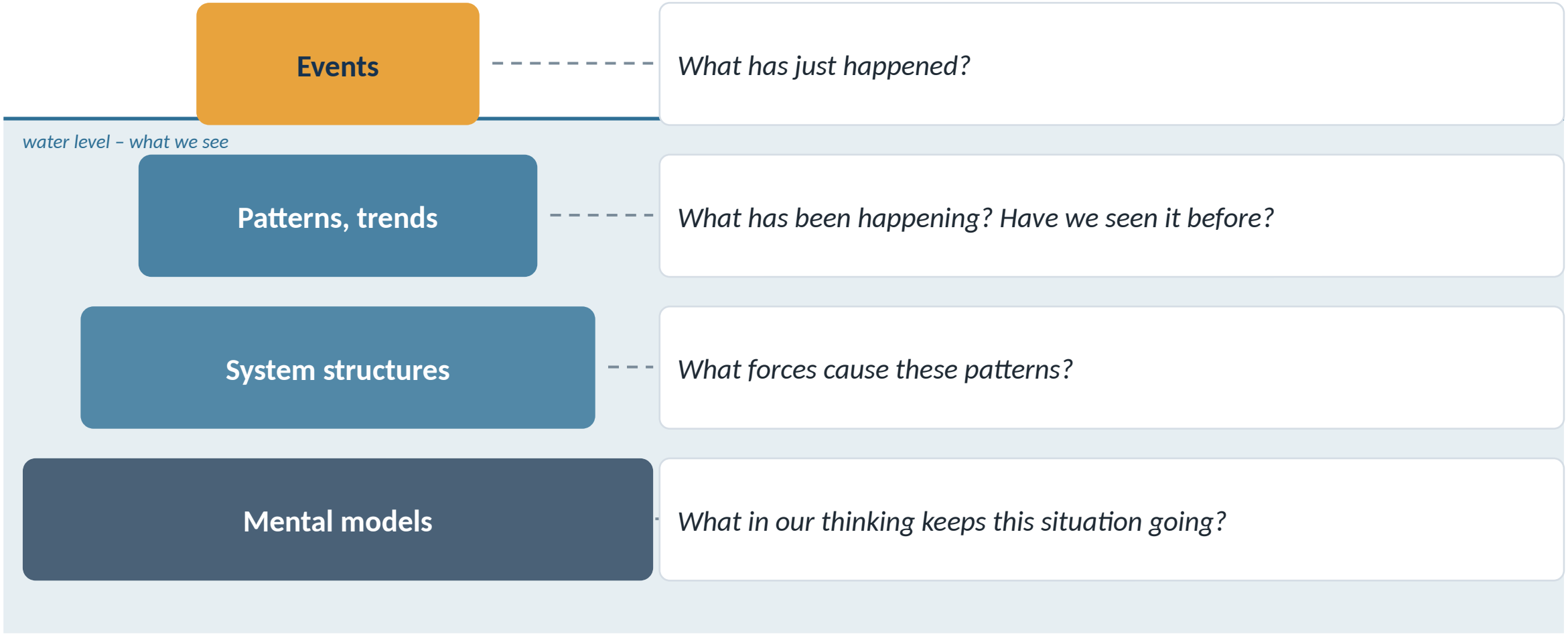
dynamic thinking – changes in time



the ability to control systems

The iceberg model of systems thinking

Most discussions stay at the tip – the events. Systems thinking goes deeper.



GROUP EXERCISE

ACTIVITY

Iceberg exercise: the packaging machine that keeps stopping

Work in groups of 3–4 for **8 minutes**. Read the facts and place each of them on one level of the iceberg: **event, pattern, structure or mental model**.

A Today the packaging machine stopped again – a jammed film roll.

B It stops two or three times every week, always on the night shift.

C Night-shift operators were never trained to adjust the film tension.

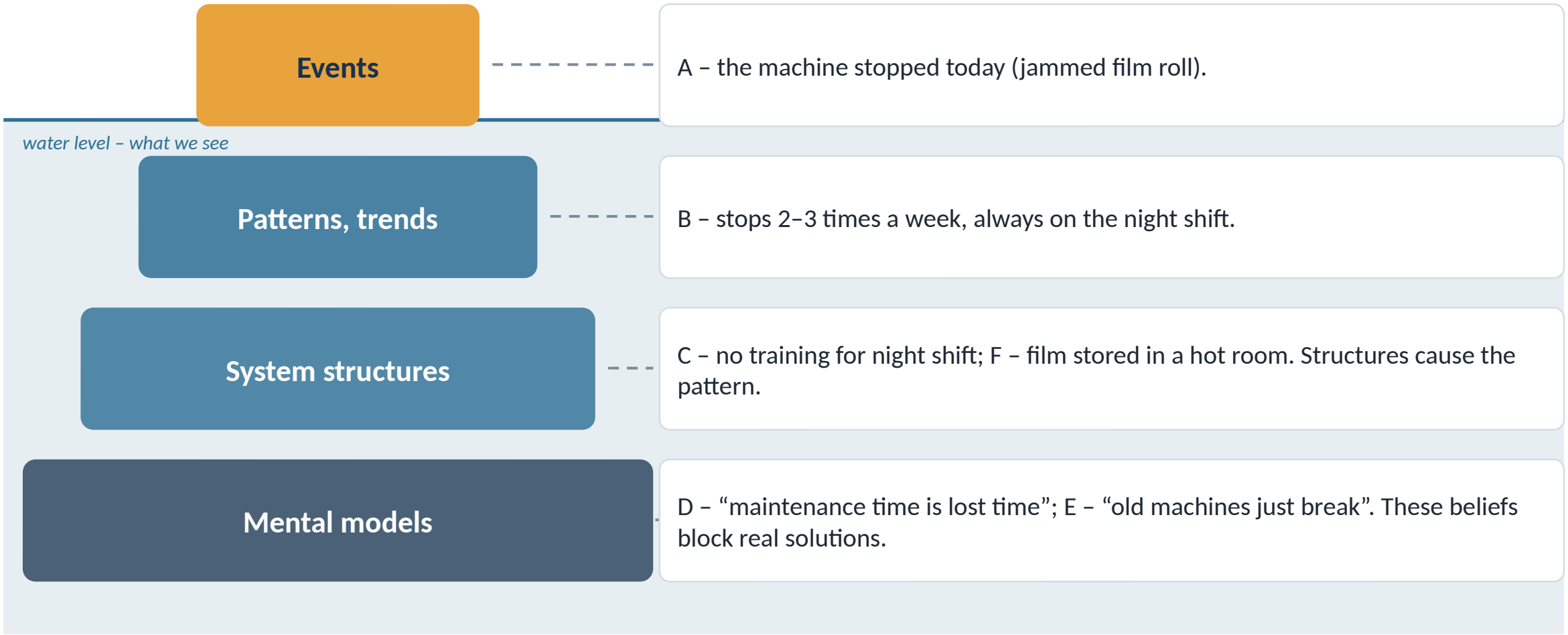
D Production managers reward output; maintenance time is seen as lost time.

E “The machine is old – that is why it breaks. Nothing can be done.”

F Spare film rolls are stored in a hot room next to the boiler.

ANSWERS

Iceberg exercise – example solution

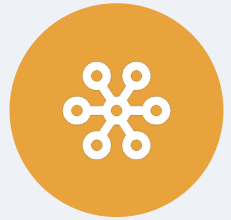


The systems paradigm – integration

In the widest sense, the systems approach is the opposite of the **Newtonian paradigm**, which saw objects as collections of independent particles. The systems paradigm is characterised by integration:

- from parts to the whole – considering the role of parts in the whole,
- from the structure of the system to the processes inside it.

The systems approach is a **principle of ordering** and a way of acting in which phenomena are treated comprehensively. Its leading idea is **rationality and the optimal achievement of goals**.



KEY TAKEAWAY

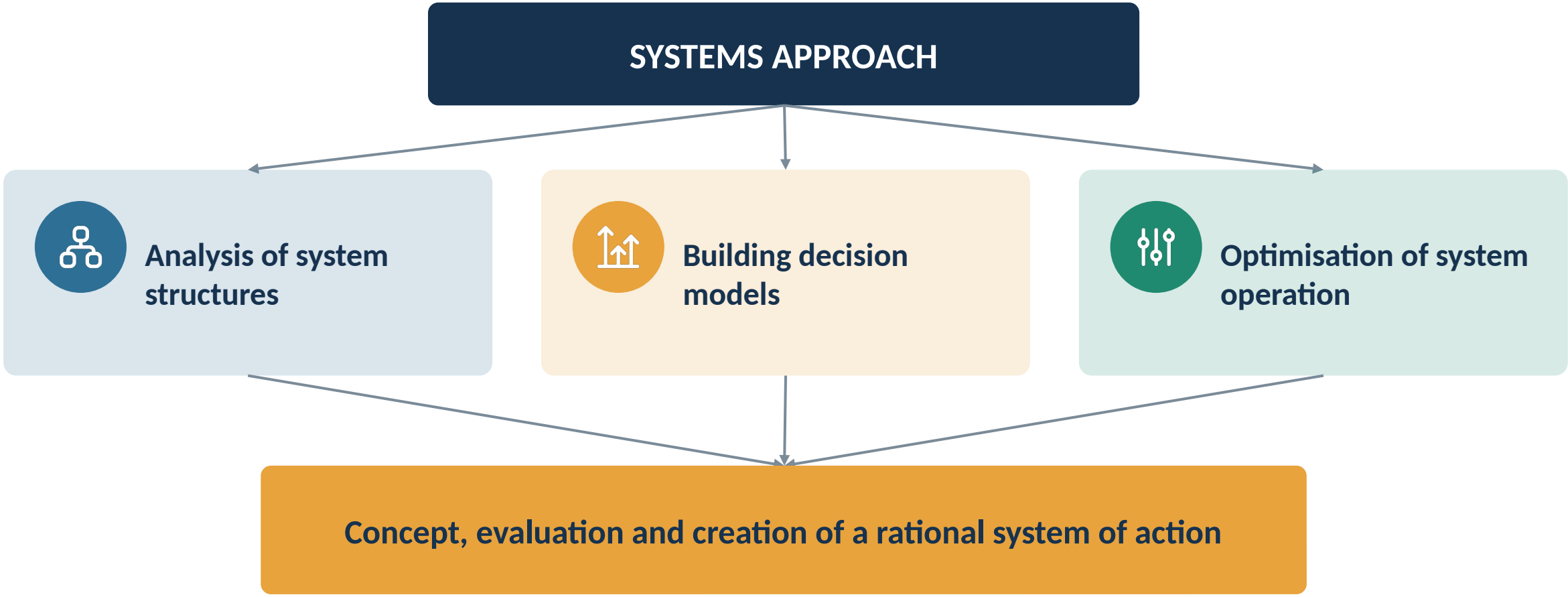
Look at the **whole**, its **structure** and its **processes** – not only at single parts.

Methodological assumptions of the systems approach

The systems method is useful for solving problems, but it requires some assumptions:

- Properties of a system result from the whole
- Everything can be connected with everything else
- Every action causes some feedback
- The structure of a system determines the results
- Results are not proportional to the effort
- A system works only as well as its weakest element
- Effects of a problem are often distant in space and time
- The most flexible part has the greatest influence on the system

Three directions of the systems approach



Internal and external structure

Structure is the basis of how a system works, so its analysis is a main direction of research. We distinguish:

Internal structure

the organisation or architecture of the system – its elements and the relations between them.

External structure

the connections between the system and its environment, described by inputs and outputs – energy, information or time relations.

Other directions: **decision models** (finding the optimal decision and the causes of wrong decisions) and **optimisation procedures** – all aiming at a system with the best operational properties.

03

Systems modelling

Black box, couplings, structures and models



Hard and soft modelling

A basic rule of the systems approach: study the object in relation to its **changing environment** (inputs and outputs), and look for **couplings** between its elements (structure analysis).

Relations can be simple parameters (e.g. machining times) or mathematical equations. They can be **deterministic** or **probabilistic**.

When we give up an exact mathematical model and use only correlation and graphical descriptions, we call it **“soft” modelling**. It is used for poorly structured, complex problems with uncertain and incomplete information.



KEY TAKEAWAY

Operation systems include **people** (anthropotechnical systems) – so **soft** modelling is often appropriate.

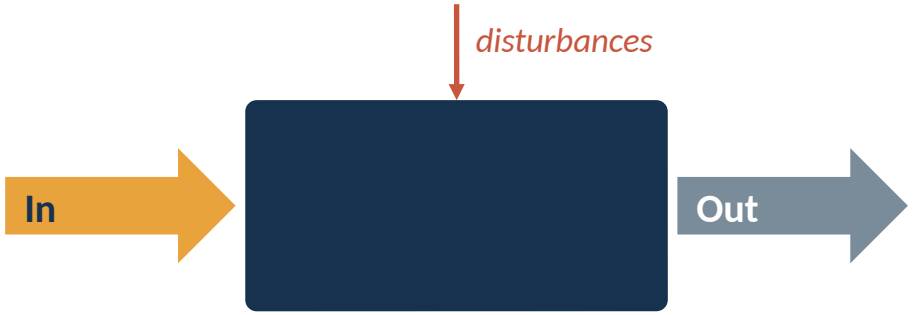
The black box model

Elementary system model

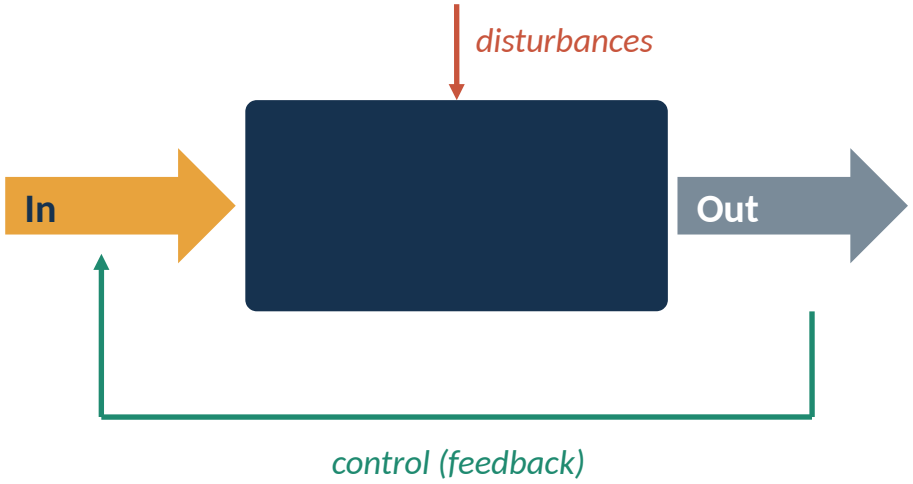


The system is described **only by its inputs and outputs** – without looking inside.

a) with disturbances



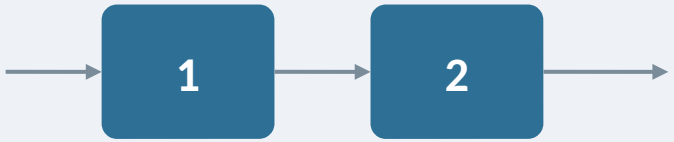
b) with disturbances and control



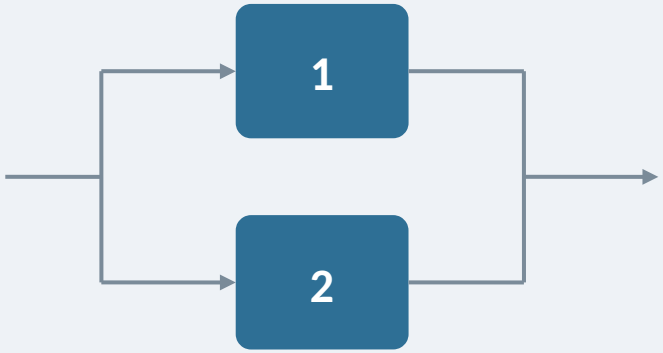
Types of coupling between elements

A **coupling** exists when the output of one subsystem becomes the input of another. Couplings are the basic part of the structure of a system model.

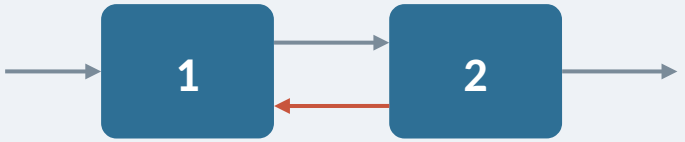
a) series coupling



b) parallel coupling



c) feedback coupling



Preview of reliability (Lecture 6): in **series**, one failed element stops the whole system; in **parallel**, the system works as long as one element works.

Structure: ordering and organising

Structure is the spatial configuration of elements – but we consider only the relations that are important for our goal. The structure of a material system (such as a machine) consists mainly of **material, energy and information couplings**. Two groups of structures:



Ordering structures

e.g. membership, spatial, connection structures



Organising structures

e.g. functional, information, hierarchical structures

Three concepts of a system model

Functional – “black box”

the system is described by relations between its properties observed from outside. It abstracts from the internal structure and describes the behaviour of the whole in its environment. **Relation: transformation y = f(x).**

Structural – “glass box”

the system is analysed as a set of connected elements with known properties – how well they integrate into one working organism. **Relation: movement between elements.**

Hierarchical – “pyramid”

every system has a leading (managing) part – the supersystem – and executive parts that can be treated as subsystems. **Relation: subordination.**

Three features of every model

Operation systems can be studied not only by practical experience, but also by **simulation on models**. A model describes only the aspect of reality that is important for its author or user:

Representation

it reflects a real object

Simplification

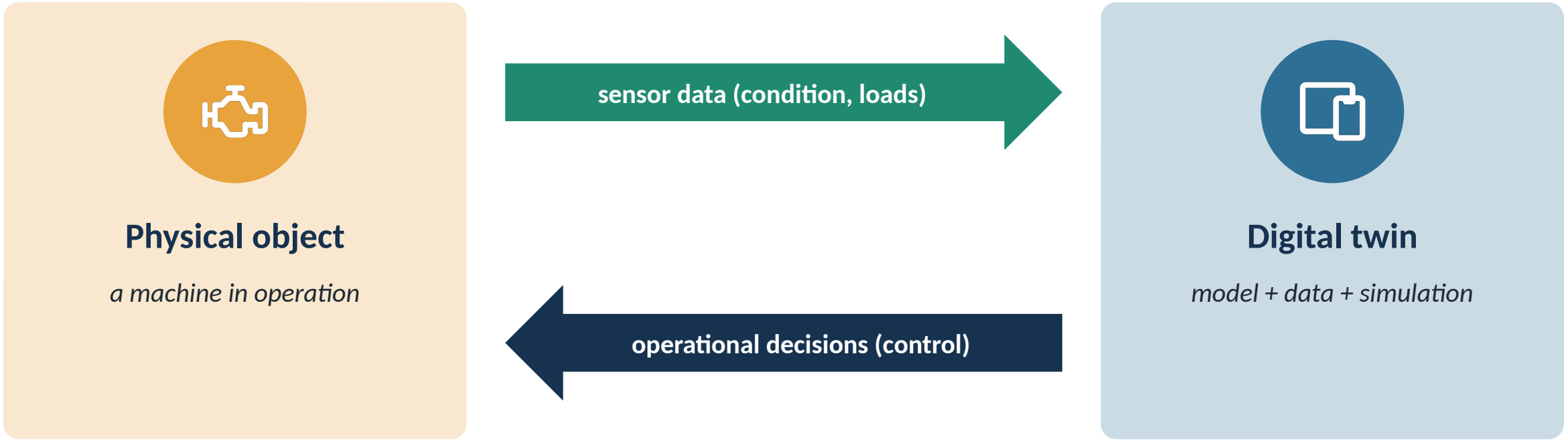
it leaves out what is not important

Pragmatism

it serves a specific purpose

A model always has an **observer** with specific intentions. General systems theory only gives the formal “building blocks” – the grammar of description.

The digital twin – a modern system model



Functional model (inputs–outputs) + structural model + **feedback** = an operation system represented digitally. We can simulate the effects of a decision – for example, the date of maintenance – before we make it. Reference framework: **ISO 23247** (digital twins in manufacturing).

QUIZ

Quiz 1 – systems approach

1 Who defined a system as “a set of elements in mutual interaction with each other and with the environment”?

A) F. W. Taylor | B) L. von Bertalanffy | C) N. Wiener | D) T. Kotarbiński

2 The two elementary subsystems of an operation system are...

A) design and production | B) use and maintenance | C) supply and sales | D) input and output

3 In the iceberg model, the deepest level is...

A) events | B) patterns | C) system structures | D) mental models

4 A model that describes a system only by inputs and outputs is...

A) a black box | B) a glass box | C) a pyramid | D) a digital twin

5 In a series coupling, the failure of one element...

A) has no effect | B) stops the whole system | C) improves reliability | D) is impossible

ANSWERS

Quiz 1 – answers

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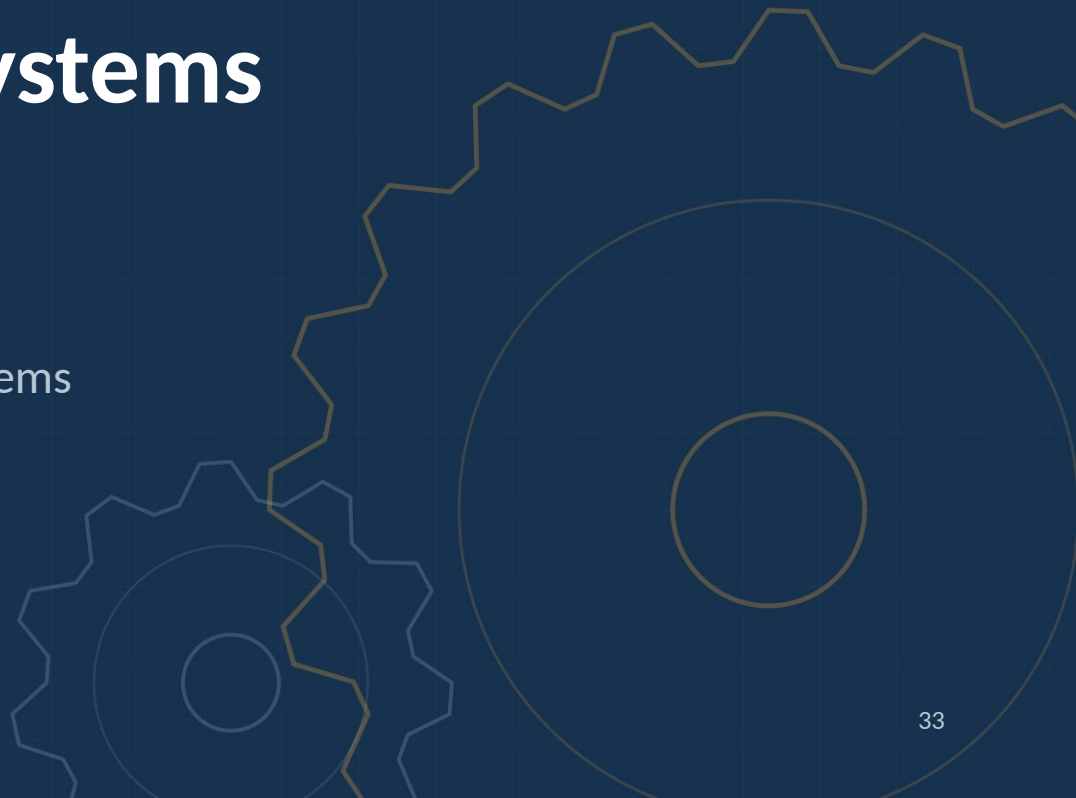
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04

The human in the system and systems engineering

Anthropotechnical systems, human factors and the questions of systems engineering



Information systems and transport systems

Technical arrangements are artificial objects built by people. We call a simple technical object an **element**, and an object made of ordered elements an **arrangement (system)**. Technical arrangements are divided into two groups:

Information systems

related to the transmission and processing of information – images, sounds, data.

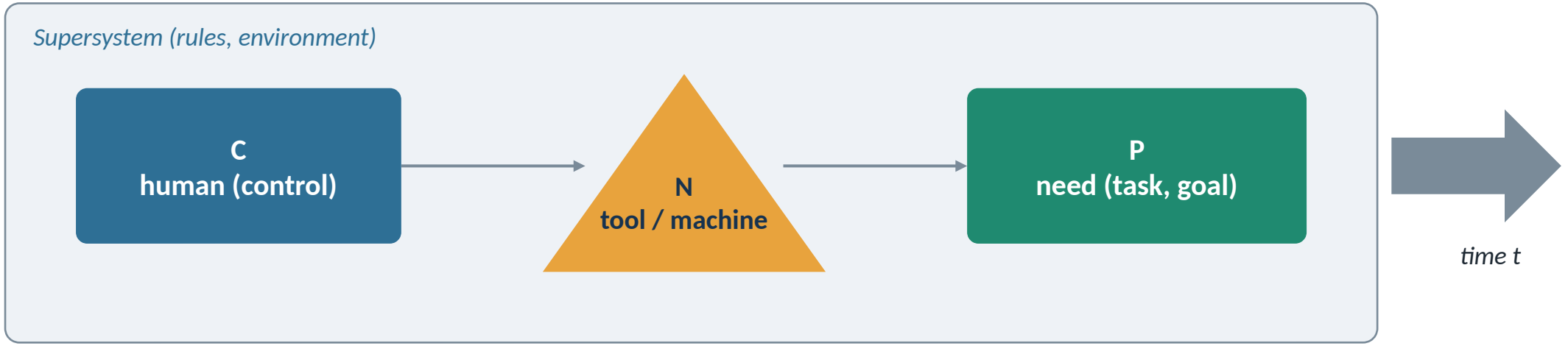
Transport (energy) systems

related to the processing and transmission of mass and energy.

Technical object (TO) and anthropotechnical system (ATS)

In operation, an “arrangement” has two meanings:

- a set of cooperating elements forming a machine – a **technical object (TO)**,
- a set of elements that depend on each other functionally but do not form one whole – an **anthropotechnical system (ATS)**: a human + a machine.



Every technical object controlled by a human forms, together with the human, a system of action.

Roles of the human in the system

a) Decision maker (operator)

human → operator influence → technical means → task

b) Researcher (diagnostician)

task → technical means → diagnostic influence → human

c) Relay

task → human → control influence → technical means

70–90%

of accidents and failures of technical means are caused by human errors in a broad sense

The human forms the **control subsystem**, the machine – the **executive subsystem**. The human is the decisive element of the system – and at the same time **the weakest one**. Psychophysical factors, information processing and decision-making need special attention, especially in high-risk objects.

Human factors in maintenance – the “Dirty Dozen”

A list of twelve common causes of human error in maintenance, developed in aviation (G. Dupont, Transport Canada). It is now used in many industries:

- **Lack of communication**
- **Complacency**
- **Lack of knowledge**
- **Distraction**
- **Lack of teamwork**
- **Fatigue**
- **Lack of resources**
- **Pressure**
- **Lack of assertiveness**
- **Stress**
- **Lack of awareness**
- **Norms (“we always do it this way”)**

Engineering is in people's heads

There is a common view that "engineering" means machines (mechanical engineer) or buildings (civil engineer). This is not quite right: **"engineering is not hidden in machines or devices, but in people's heads"**.

A modern definition: engineering is **the broadly understood theory or practice of knowing, purposefully changing and controlling any process or system**.

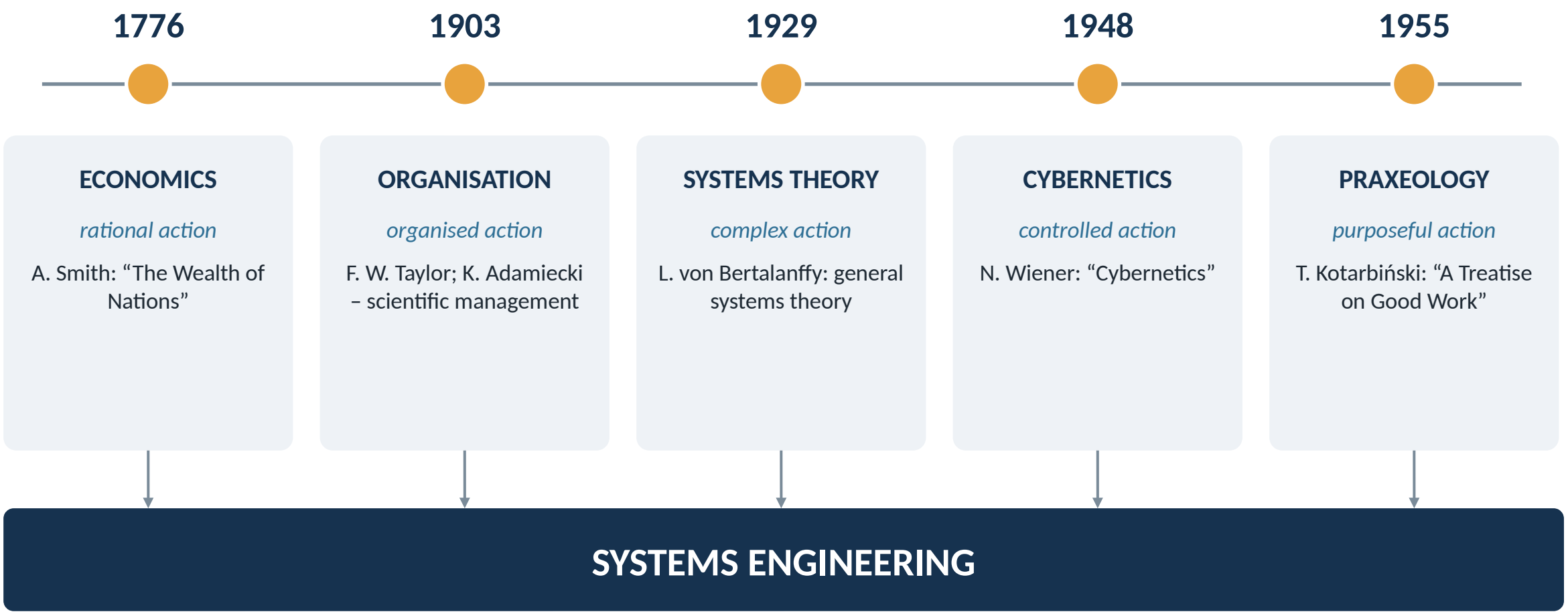
Systems engineering – a technology of working with sets – covers practical programmes of action based on logic and probability, using formal mathematical tools. It is closely connected with the **sciences of action**.



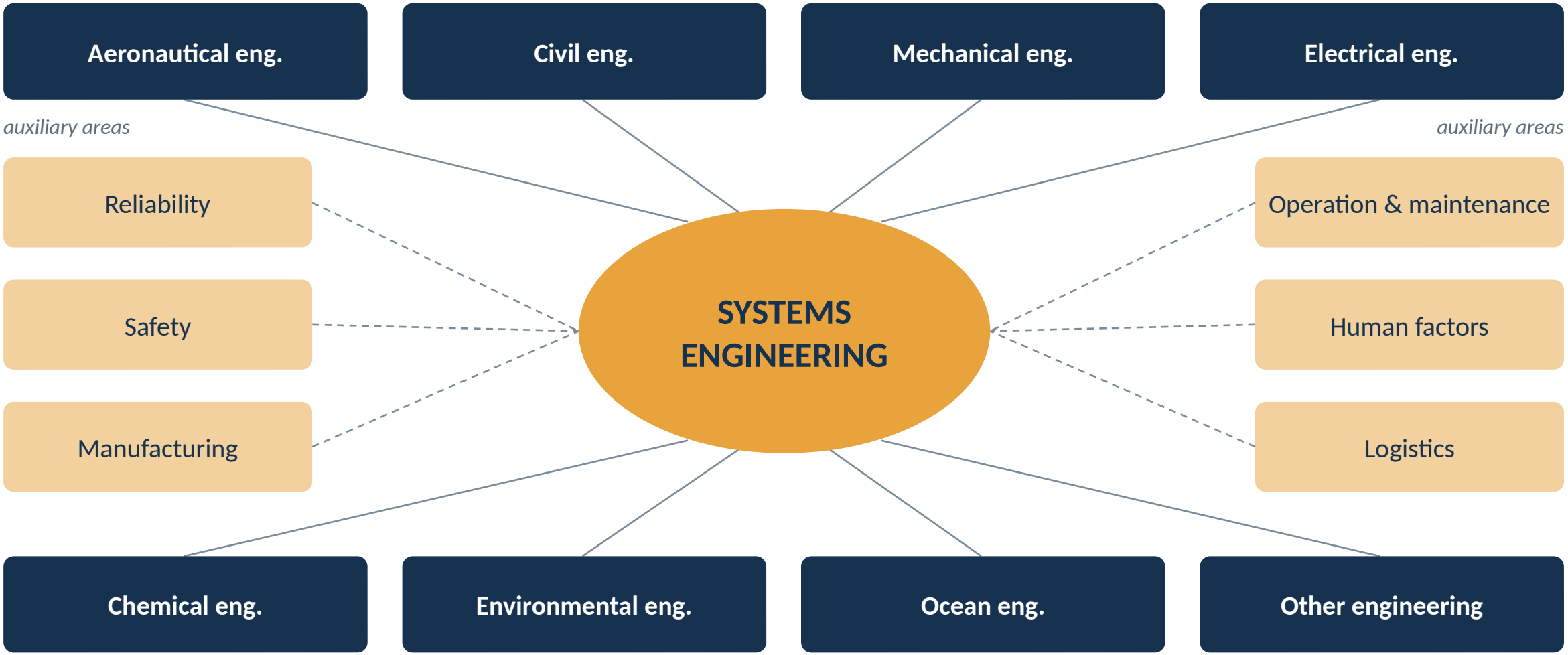
KEY TAKEAWAY

Systems engineering: **optimise the output** of a system according to given criteria – using dynamics and cost analysis.

Systems engineering and the sciences of action



Main and auxiliary areas of systems engineering



Seven key questions of systems engineering

The main task of systems engineering in operation is to study and co-design complex machines using **computer simulation** and **structural models**. The essence is described by seven questions:

1. What functions does the object perform, and what are the performance standards (output, operating cost, safety…)?
2. How can the object fail to perform its functions?
3. What can cause each functional failure?
4. What are the effects of each failure?
5. How important is each failure?
6. What can be done to prevent each failure?
7. What should be done if no suitable preventive action can be found?



KEY TAKEAWAY

These are exactly the **seven questions of RCM** – Reliability-Centred Maintenance.

The same questions in RCM (SAE JA1011)

#	Question (concept)	RCM term	Result
1	Functions and performance standards	Functions	list of functions
2	Functional failures	Functional failures	how it can fail
3	Failure modes (causes)	Failure modes	what causes it
4	Failure effects	Failure effects	what happens
5	Failure consequences	Failure consequences	how much it matters
6	Proactive tasks	Proactive tasks	how to prevent it
7	Default actions	Default actions	what if prevention is impossible

Answers to questions 1–5 form an FMEA/FMECA analysis; questions 6–7 form the maintenance programme. More in Lectures 3 and 6.

Dynamics of the system – operational clocks

A model of an operation system must include **dynamics**. We introduce at least three **clocks** – a clock is a "set of distinguished moments in time". A clock can be **discrete** (countable moments) or **continuous**.

Decision clock

moments when decisions are made – e.g. weekly maintenance planning meeting

Information clock

moments when information is collected – e.g. sensor readings every second, monthly reports

Working clock

moments of real operation – e.g. machine running hours, number of cycles

Operation time is quantised from two points of view: management activities and execution activities.

05

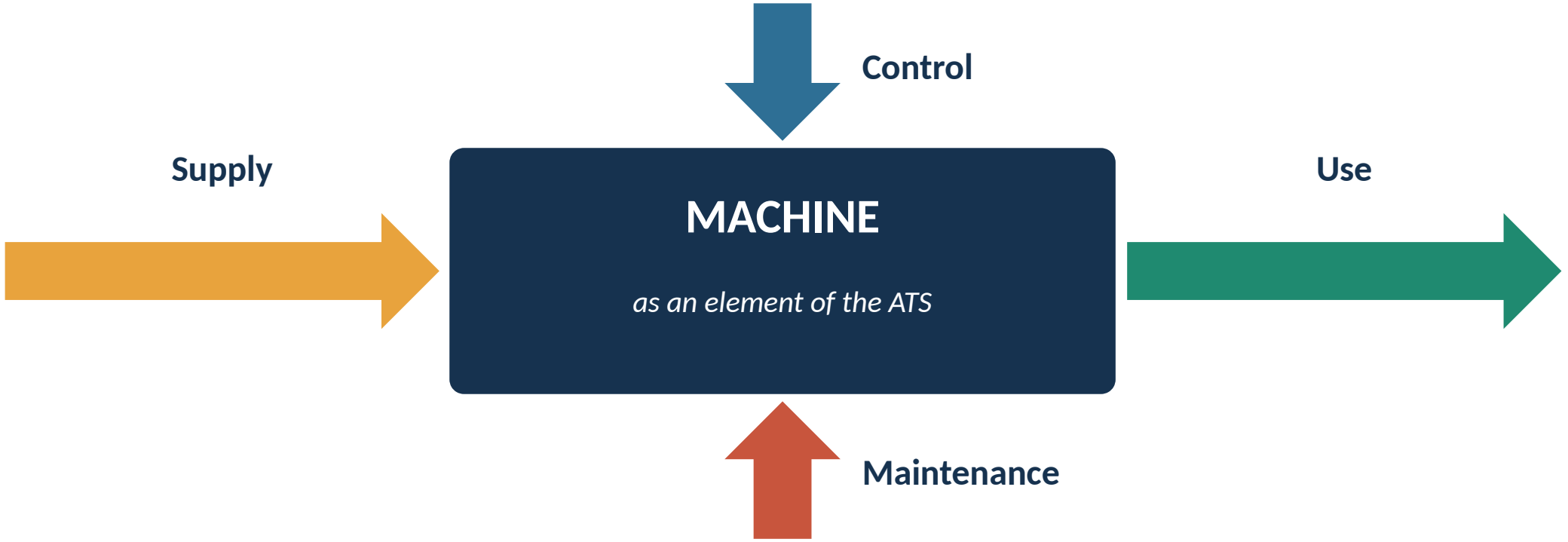
Maintenance problems

Why companies need a maintenance function – and what decisions it makes



Four groups of human actions around a machine

A machine used for specific tasks requires various human actions. Each of them requires an operational decision:



Example – a delivery van: refuelling (supply), starting and driving (control), delivering goods (use), replacing a bulb (maintenance).

Why a maintenance department?

Each action may create a problem – how to do it? One car – a dozen problems. A fleet of cars – hundreds of problems.

That is why companies with many machines create specialised units – the **maintenance department** (in Polish tradition: the Chief Mechanic's department). It solves most of these problems.

Machine operation should be treated not only as the third phase of the industrial process, but also as a **multi-aspect maintenance process**.



KEY TAKEAWAY

Maintenance does not create "added value" directly – but **without it, production is impossible**.

Invisible – but effective at the right moment

A main problem of maintenance is the paradox: it should be as **invisible** as possible (costs, time of inspections and repairs), and at the same time it must act **effectively at the right moment**.

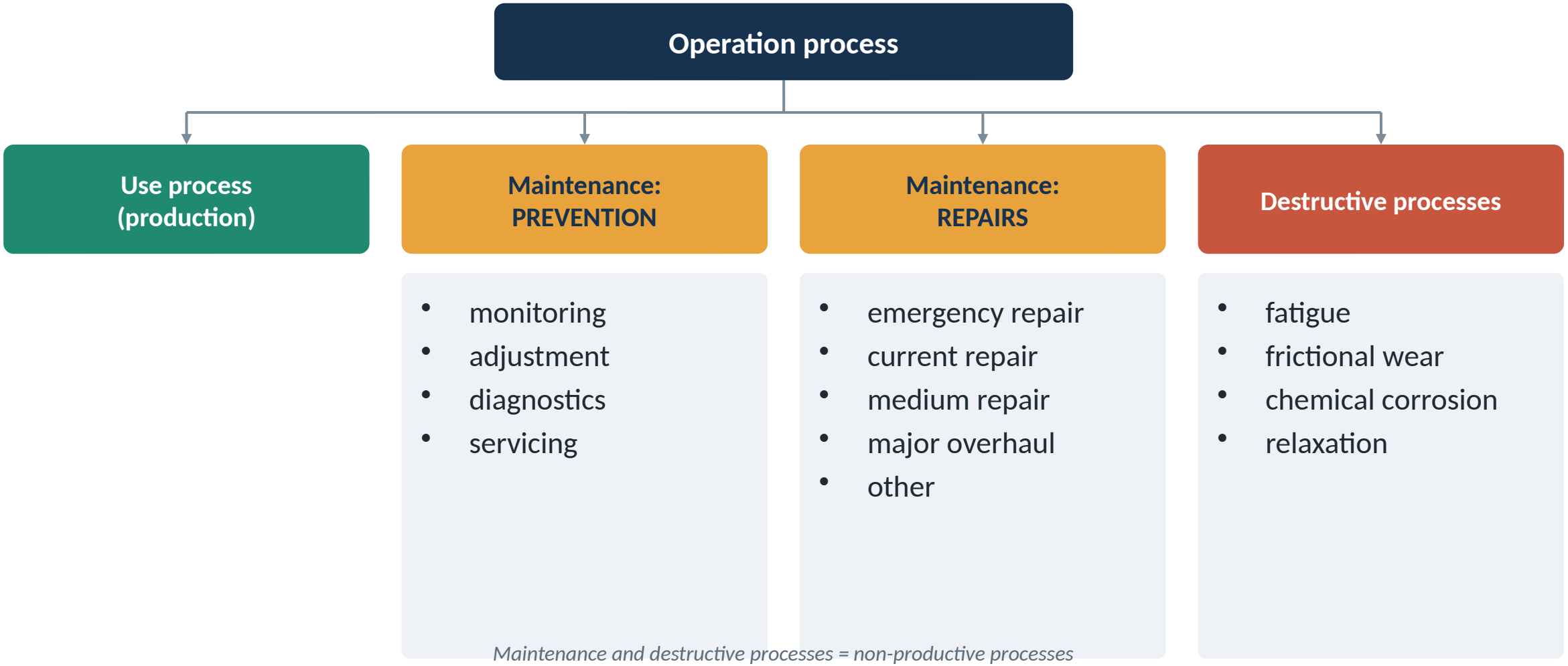
Under strong competition, equipment becomes more complex and needs proper supervision. Maintenance keeps machines in good working order by planned one-off or periodic tasks that **prevent degradation** – and, when failures happen, removes them by **repairs**.



KEY TAKEAWAY

Good maintenance is like a good referee: **you notice it only when it fails**.

Prevention and repair in the operation process



Maintenance and destructive processes = non-productive processes

Repair or replace?

A basic maintenance question: **repair or replace?** We need to know the repair possibilities of the plant, repair time, costs, availability of parts – and the total cost.

If there are no substitutes and original parts are expensive, we can consider **regeneration**. If we repair, we must check the method and the quality of the repair.

Not every part can be regenerated. Many repairs are attempted with poor quality results. Replacing the part is often the better way to guarantee fault-free operation. **In the end, the economic calculation usually decides.**



KEY TAKEAWAY

Wear is not the same as damage. A worn part may be regenerated – a broken one usually not.

EXAMPLE

Repair or replace? – a gearbox decision

	Repair the old gearbox	Buy a new gearbox
Cost	3 500 €	6 000 €
Downtime (machine stopped)	5 days	2 days (part in stock at supplier)
Expected life after the action	2 years	6 years

Downtime cost of the line: 2 000 € per day

Repair

$(3\,500 + 5 \times 2\,000) \;/\; 2 \text{ years}$

= 6 750 € per year

Replace

$(6\,000 + 2 \times 2\,000) \;/\; 6 \text{ years}$

≈ 1 667 € per year

Consumables, repairable parts and remanufacturing

Consumables

lose their properties and must be replaced with new ones – e.g. brake pads, spark plugs, filters.

Repairable assemblies

still have high technical and economic value – e.g. pumps, gearboxes. Best repaired in specialised centres or by the manufacturer. A part must be **worn**, not broken or corroded.

Remanufacturing

the manufacturer disassembles the unit, keeps the housing and undamaged parts, replaces wear parts (e.g. starter brushes) and tests it like new – part of the **circular economy**.

Use versus maintenance – the problem of “two managers”

In most companies, tasks related to **using** the machine (production) and **maintaining** it (repairs) are separated. Usage decisions are separated from diagnostic decisions.

This gives greater **specialisation** – but it is also a potential source of conflicts: the problem of **“two managers”**.

Production wants the machine running; maintenance wants time to service it. Without shared goals (e.g. availability, OEE), each side blames the other.



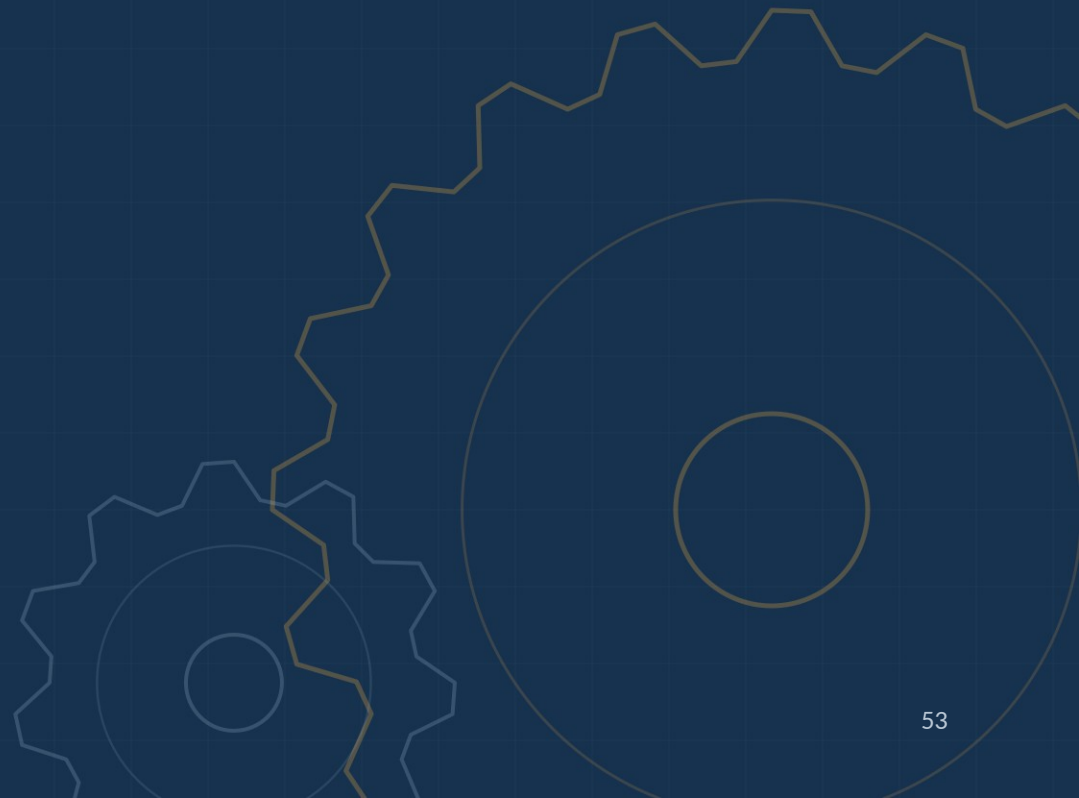
KEY TAKEAWAY

Shared indicators and planned maintenance windows reduce the conflict – this is the idea behind **TPM** (Lecture 3).

06

The maintenance department

Organisation, tasks, overhauls and indicators



Organisation of a maintenance department (large company)

Maintenance Manager (Chief Engineer)

- Planning and reporting
- Supervision and acceptance
- Failure analysis
- Documentation

Mechanical maintenance section	Electrical and energy section
Technologist	Electrical installation crews
Work preparation and dispatch	
Maintenance crews	Repair of motors and electrical devices
Repair and fitting crews	
Construction crews	Automation and PLC technicians
Machining workshop	

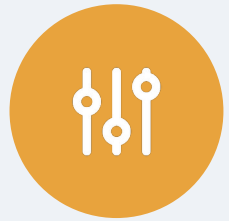
Two groups of tasks: technical (readiness and good condition of machines) and documentation (planning and collecting information).

Maintenance adapted to the machine

A well-organised and well-managed maintenance department is necessary for the full production capacity of a company. It influences **productivity, quality, production cost, work safety and environmental impact**.

The way of maintaining machines depends on their design and their role in the production process. Complex, expensive machines working in automated lines must be maintained very carefully – **their failure stops the whole line**.

The type of maintenance must be adapted to the specific machine and its operating conditions.



KEY TAKEAWAY

Not all machines are equal – **critical machines** need the most attention.

Types of inspections and services

Technical inspections and services

- Daily service
- Running-in service
- Periodic service
- Protective (preservation) service
- Seasonal service
- Warranty service

Diagnostic service

- Preservation and cleaning
- Diagnostics

Qualification tests

- Prevention
- Adjustment

Overhaul or repair?

Principle: “it is easier to keep something in good condition than to bring it back to good condition”. The maintenance manager – usually a mechanical engineer – should run **preventive** activity and know the rules of repairs and overhauls. Terminology:



Overhaul

when we speak about the whole object (machine)

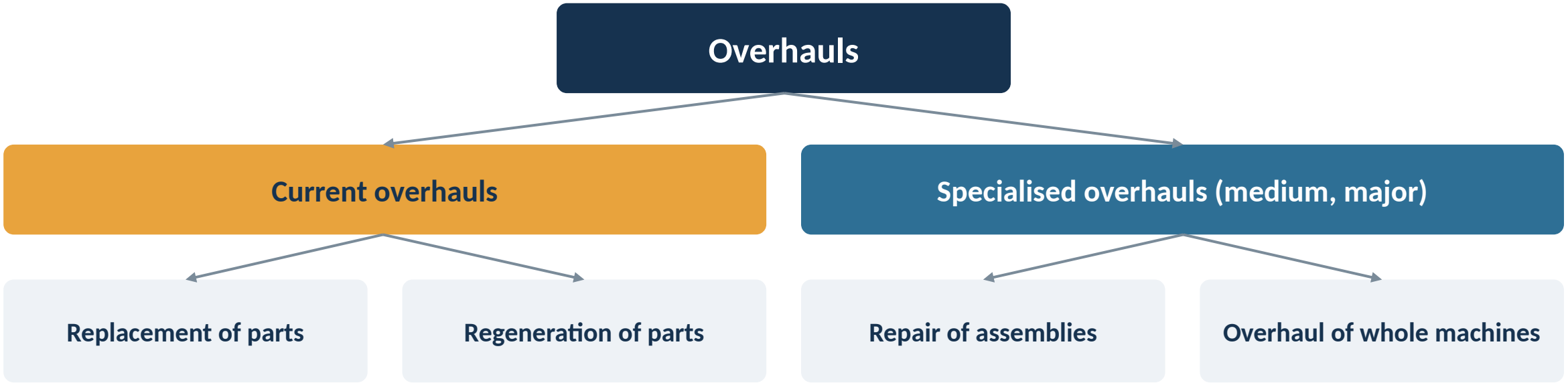


Repair

when we speak about components of the object

Typical phrase: “during the overhaul of machine X, the following assemblies must be repaired…”.

Overhauls, repairs and regeneration methods



REGENERATION METHODS

Repair dimensions (oversize/undersize)	Compensating elements (sleeves, shims)	Selection of used parts	Coating (welding, spraying, plating)

Regeneration should restore the **original properties** of the part.

Goals of planned maintenance

Overhauls and repairs serve the general goals of planned maintenance:

Keeping assets at the required level

Effective work of the maintenance team through forecasting and planning

Reducing or eliminating major repairs and expensive replacements through early detection of changes and preventive work

What is needed to reach these goals?

- Understanding the role of maintenance in the company
- A register of all overhaul and preventive work
- An electronic system that generates reports (CMMS)
- Standardised maintenance procedures
- The right maintenance strategy for machines and equipment

The life of a work order



Every closed work order adds data to the **machine history**. Without good data, we cannot calculate MTBF and MTTR or choose the right strategy. **LOTO** = lockout/tagout – isolating energy before work.

How do we measure maintenance? – key performance indicators

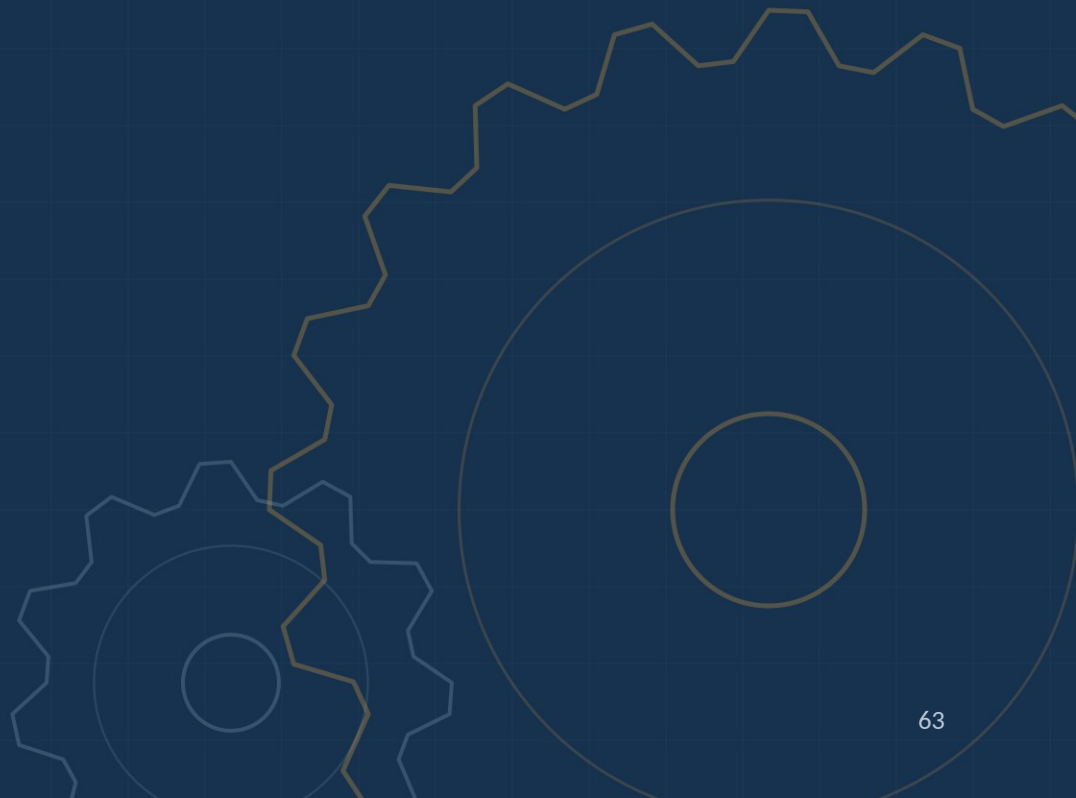
Indicator	Definition	Direction
Availability	share of time the machine is ready to work	higher is better
MTBF	mean operating time between failures	higher is better
MTTR	mean time to restore after a failure	lower is better
PM compliance	preventive tasks done on time / tasks planned	higher is better
Planned work ratio	planned work hours / all maintenance hours	higher is better
Maintenance cost / asset value	annual maintenance cost / replacement value of assets	compare with benchmarks

A standard set of maintenance KPIs is defined in EN 15341. Choose a few indicators and follow their trend.

07

Maintenance strategies

From “I produce – you repair” to condition-based maintenance



The stereotype “I produce – you repair”

In many companies, a traditional division of duties is common: **“I produce – you repair”**. It means that all service and repair activities, even the simplest ones, belong to the maintenance department.

Maintenance departments developed different strategies within this convention. A **strategy** in general means the main orientation – economic, social, military – that expresses the dominant direction of action of a system.



KEY TAKEAWAY

Strategy = **the dominant direction of action**.

Four decision problems behind every strategy

A **maintenance strategy** is a sequence of decisions defining a programme for preventing failures and removing them. It is based on four decision problems:



Prevent failures – or reduce their effects?



How to recognise early symptoms of a possible failure?



How to detect hidden failures?



What to do when prevention is not possible?

Four categories of maintenance tasks

Time-based tasks

directly prevent or delay failures: inspections after a set time or amount of work. Key criterion: **periodic** character.

Condition-based tasks

detect early symptoms of failure: measuring operating parameters and comparing them with alarm values.

Failure-finding tasks

detect existing (hidden) failures and protect the device from further damage – e.g. periodic vehicle inspections, testing safety valves.

Run-to-failure

a conscious decision to operate until failure – when other actions are impossible or not worth the money.

Criteria influencing the choice of strategy

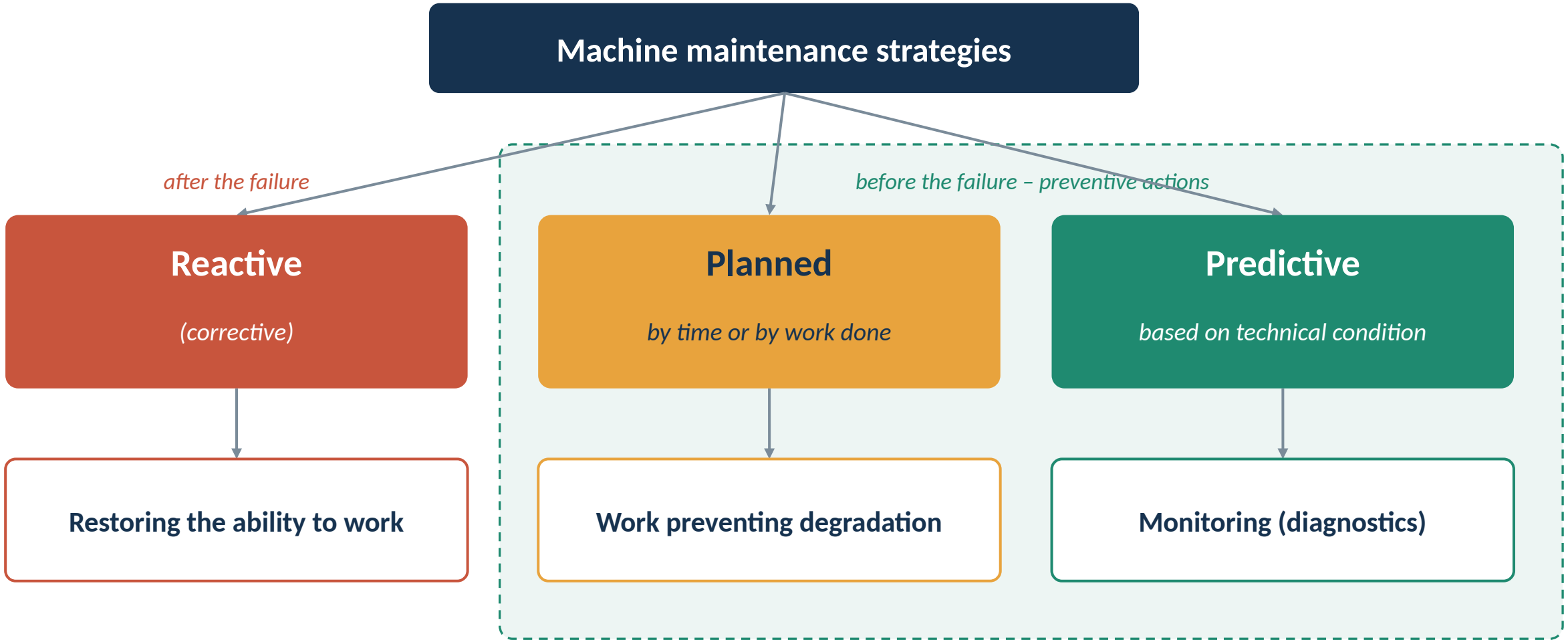
Criterion	Concept of action	Strategy name
Methodological attitude	Improving the existing	**incremental**
	New solution	**model-based**
Scope of changes	One device	**corrective**
	Many devices	**correcting**
Search pattern for solutions	Trial and error	**overload**
	Reliability forecast	**preventive**



"In managing machine availability, **business thinking** matters most – not the analysis of technical possibilities."

— A. Góralczyk

Typical maintenance strategies



Reactive and preventive strategies

Reactive strategies

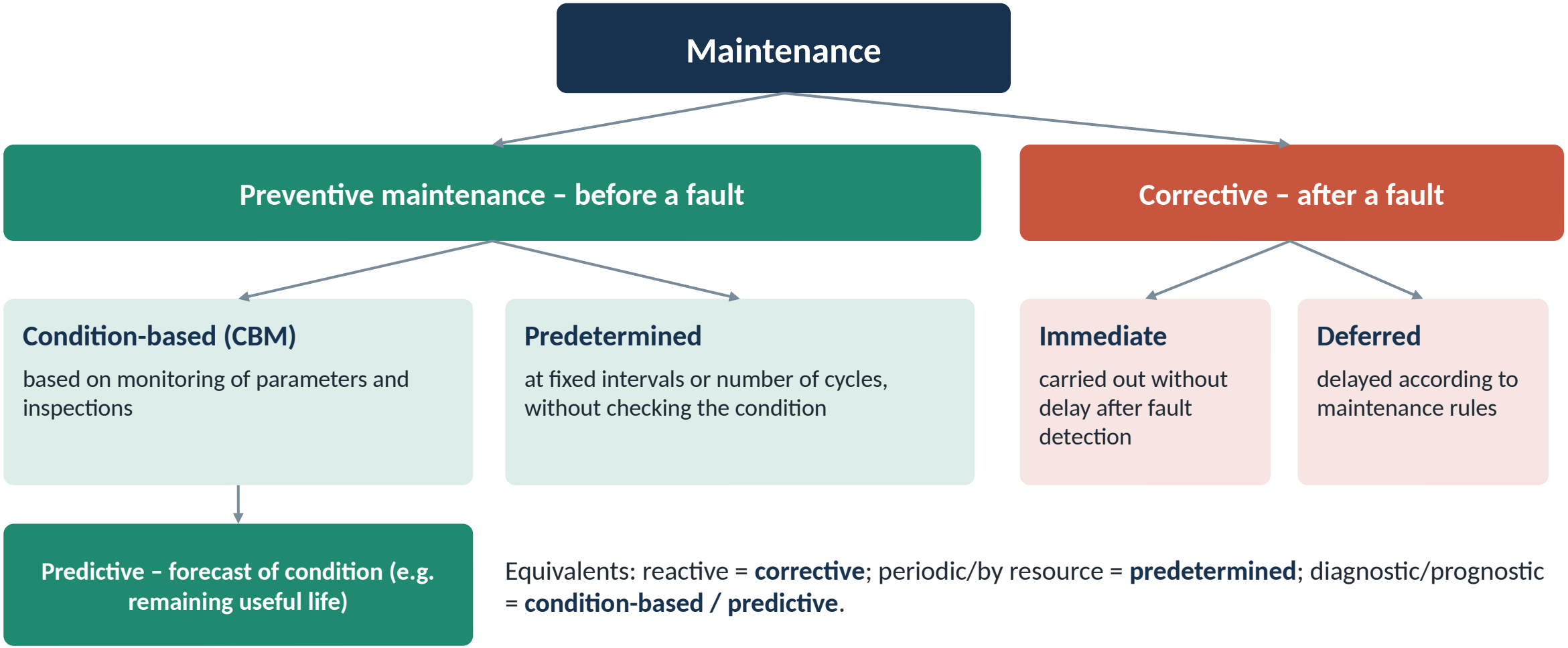
accept that a fault can occur, but take no special action to control or prevent it. Example: a light bulb is used until it fails, then replaced.

Preventive strategies

based on preventing failures, using assumptions about the life cycle and the risk of failure. Three forms: **periodic** (by elapsed time), **by resource** (by work done – hours, km, cycles), **diagnostic** (by the real condition of the machine).

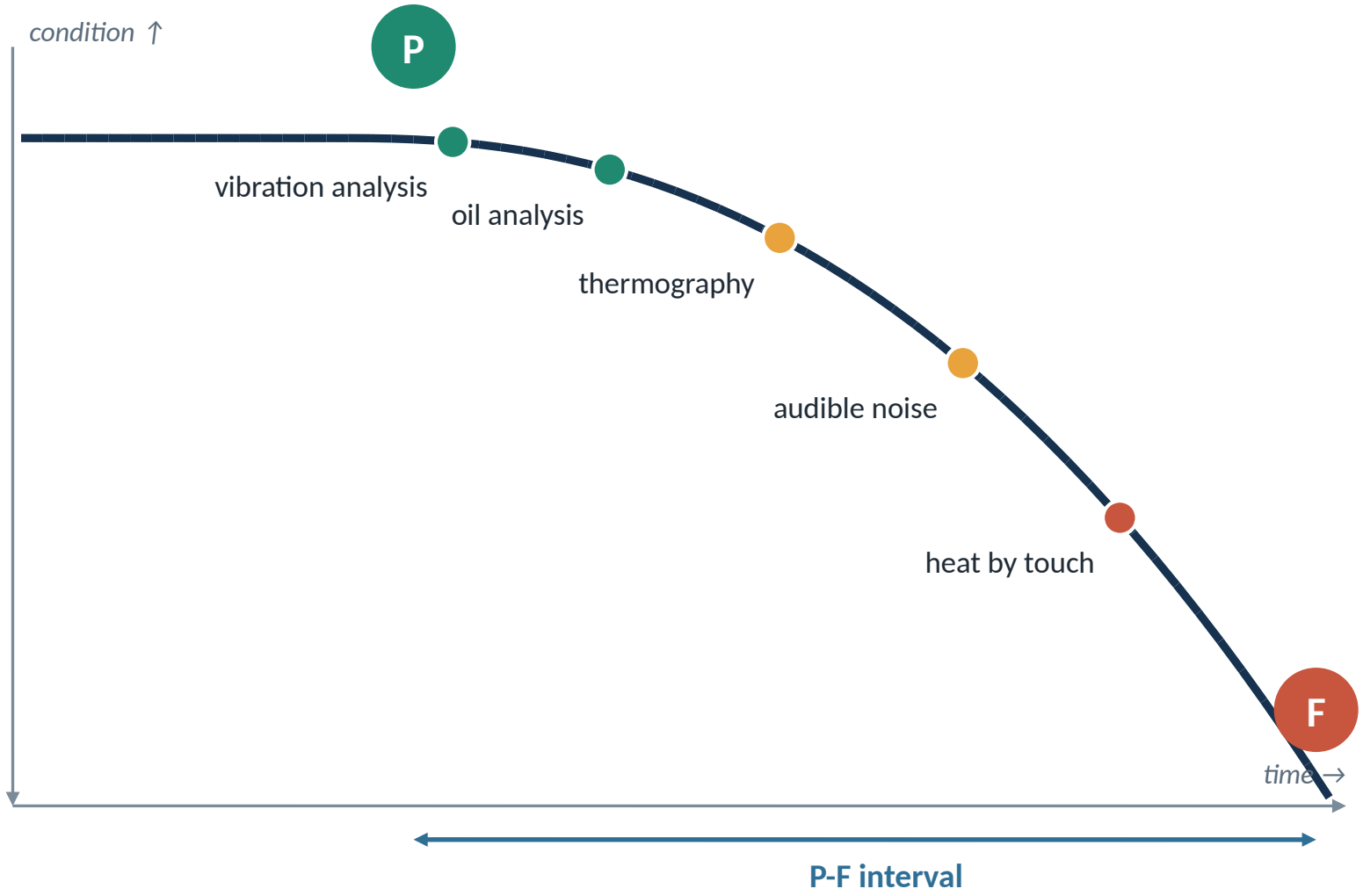
Diagnostic maintenance turns guesswork into facts: we measure the real condition first – e.g. replacing tyres when the tread is worn, not after a fixed number of kilometres.

Types of maintenance according to EN 13306



Equivalents: reactive = **corrective**; periodic/by resource = **predetermined**; diagnostic/prognostic = **condition-based / predictive**.

The P-F curve – why monitor condition?



P – potential failure: the first detectable sign of a developing failure.

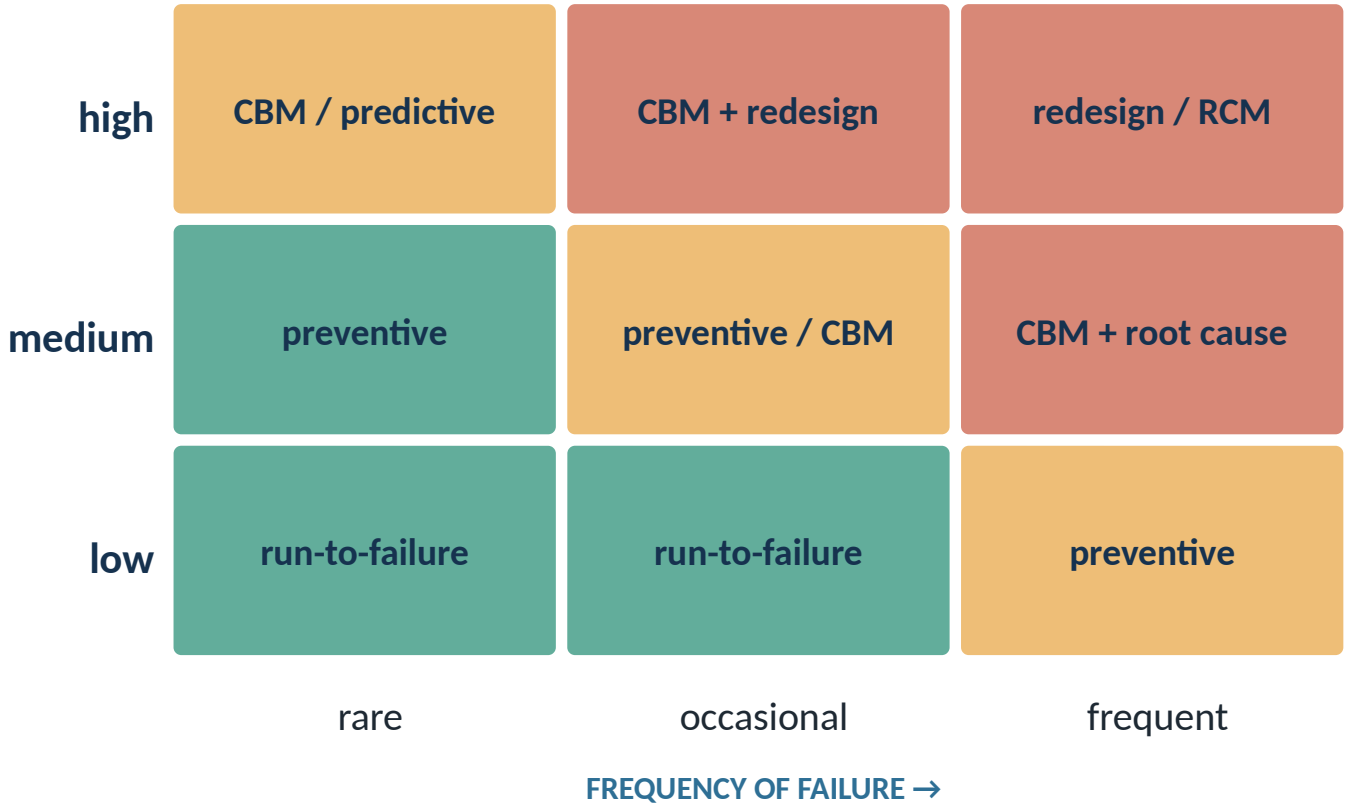
F – functional failure: the machine loses its required function.

Diagnostics moves detection **to the left** – more time for a **planned** intervention.

Rule: inspection interval < P-F interval.

Choosing a strategy with a criticality matrix

CONSEQUENCES OF FAILURE ↑



Consequences – safety, environment, production loss, repair cost.

Hidden failures (safety devices, standby equipment) need **failure-finding tests**.

If no strategy works and the consequences are serious – **redesign** the machine.

GROUP EXERCISE

ACTIVITY

Choose the right strategy

Work in pairs for **8 minutes**. For each machine choose: **run-to-failure, preventive (time-based), condition-based or failure-finding**. Justify your choice.



1. LED lamp in an office corridor



2. Air compressor supplying a whole factory (one unit, no backup)



3. Spindle bearings of a CNC machining centre



4. Hydraulic oil filter on an injection moulding machine



5. Emergency diesel generator in a hospital



6. Pressure relief valve on a steam boiler

ANSWERS

Choose the right strategy – example solution

Machine	Strategy	Why?
1. LED lamp in a corridor	Run-to-failure	cheap, fast to replace, no serious consequences
2. Factory air compressor	Condition-based (+ preventive)	high consequences; vibration, temperature and oil can be monitored
3. CNC spindle bearings	Condition-based	expensive, long delivery; vibration analysis gives early warning
4. Hydraulic oil filter	Condition-based or preventive	differential pressure sensor shows clogging; or change at fixed hours
5. Hospital emergency generator	Failure-finding + preventive	standby equipment – a hidden failure; regular test runs under load
6. Boiler pressure relief valve	Failure-finding (+ legal inspection)	protective device – fails hidden; periodic testing required by law

QUIZ

Quiz 2 – maintenance and strategies

1 **Replacing a light bulb only after it fails is an example of...**

A) predictive maintenance | B) run-to-failure (reactive) | C) TPM | D) failure-finding

2 **Maintenance at fixed intervals without checking the condition is called (EN 13306)...**

A) condition-based | B) predetermined | C) deferred | D) predictive

3 **Point P on the P-F curve is...**

A) the moment of purchase | B) the first detectable sign of failure | C) the functional failure | D) the end of warranty

4 **Repair 3 500 € + 10 000 € downtime, life 2 years. The annual cost is...**

A) 1 750 € | B) 5 000 € | C) 6 750 € | D) 13 500 €

5 **Testing a hospital emergency generator every month is...**

A) run-to-failure | B) failure-finding | C) overhaul | D) regeneration

ANSWERS

Quiz 2 – answers

1 Replacing a light bulb only after it fails is an example of...

A) predictive maintenance	**B) run-to-failure (reactive)**	C) TPM	D) failure-finding

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A) condition-based	**B) predetermined**	C) deferred	D) predictive

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5 Testing a hospital emergency generator every month is...

A) run-to-failure	**B) failure-finding**	C) overhaul	D) regeneration

SUMMARY

Key takeaways from today

A system = elements + relations + environment; **structure determines behaviour**.

The operation system = **use** subsystem + **maintenance** subsystem (+ supply).

Look below the tip of the iceberg: **patterns, structures, mental models**.

The human is the decisive and the weakest element – **human factors** matter.

Strategies: **reactive, preventive (predetermined), condition-based, predictive**; P-F curve.

Choose the strategy by **consequences and frequency** – not by habit.

REVIEW

Review questions



1. Define a system (Bertalanffy, Pabis). What does the principle “the whole is more than the sum of its parts” mean?
2. Describe the operation system: its subsystems and environment. Give an example from transport or industry.
3. Explain the iceberg model of systems thinking with an example of a recurring failure.
4. What are the roles of the human in an anthropotechnical system? Name five of the “Dirty Dozen”.
5. Compare reactive, predetermined, condition-based and predictive maintenance (EN 13306). Explain the P-F curve.
6. How would you choose a maintenance strategy for a critical machine with hidden failures?

Thank you for your attention

Next: laboratory today 13:30 (R11) · next block 9 Dec 2026 – Lectures 3 and 4

dr inż. Radosław Gościniak

