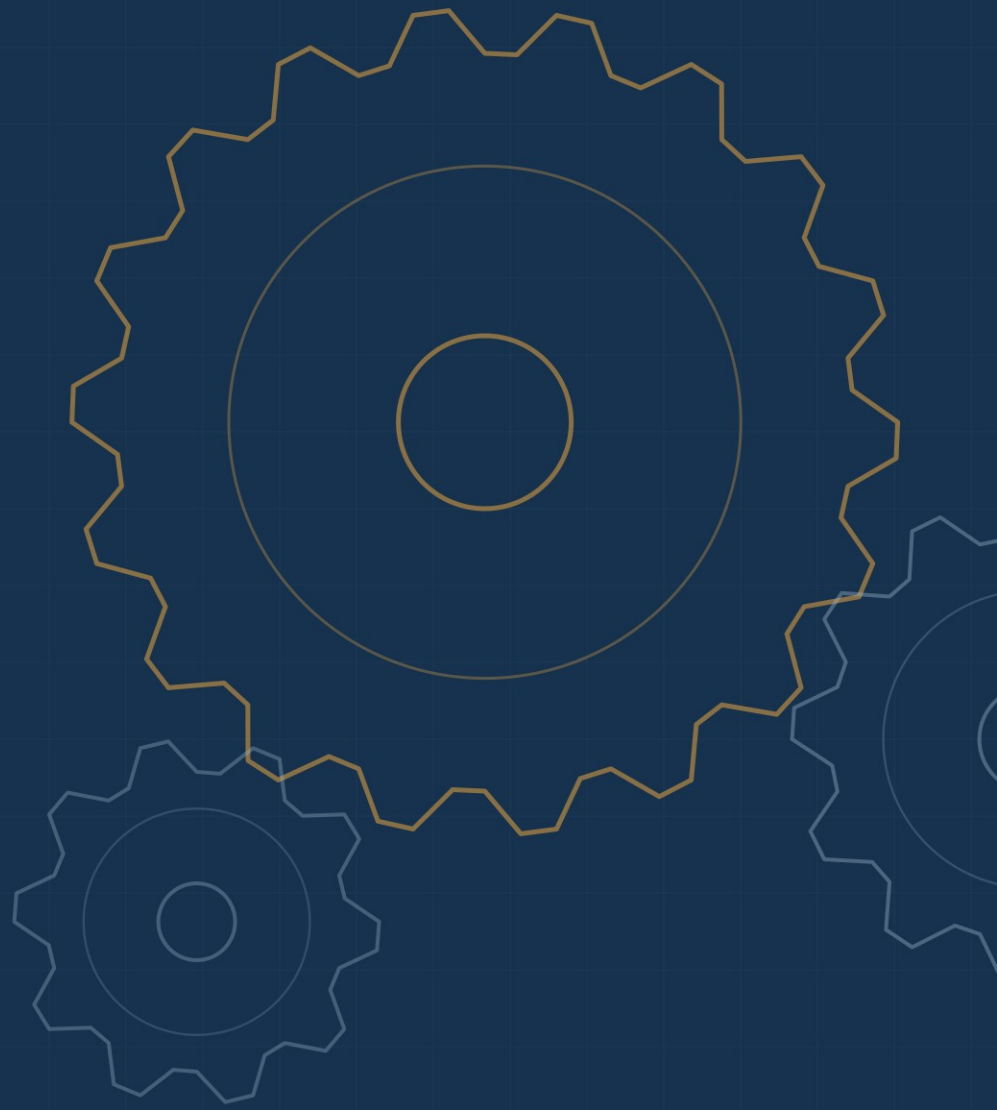
BASICS OF MACHINE OPERATION

Block 1 · Lecture 1 · 2 Dec 2026

Introduction to Machine Operation and Machines as Technical Means

dr inż. Radosław Gościniak

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: L1. Introduction to Machine Operation and Machines as Technical Means

Schedule of the course

#	Block · date	Topics
L1	**Block 1 · 2 Dec 2026**	**Introduction to Machine Operation and Machines as Technical Means**
L2	**Block 1 · 2 Dec 2026**	Systems Approach and Maintenance Organisation and Strategies
L3	**Block 2 · 9 Dec 2026**	Modern Maintenance Concepts; Availability, Durability and Wear
L4	**Block 2 · 9 Dec 2026**	Tribology and Lubrication; Fundamentals of Technical Diagnostics
L5	**Block 3 · 20 Jan 2027**	Condition Monitoring Techniques; Reliability Fundamentals
L6	**Block 3 · 20 Jan 2027**	System Reliability; Failure Analysis and Reliability Improvement
L7	**Block 4 · 27 Jan 2027**	Life Data, Maintenance Logistics and Industry 4.0; Course Review

Wednesdays · lectures 08:00–13:20 (R33) · laboratory 13:30–16:30 (R11) · two lectures per block, block 4: lecture 7 and review

Learning outcomes

After completing the course, the student is able to:

Explain
the role of machine operation in the product life cycle and the basic terminology (EN 13306, ISO 55000, IEC 60050-192).

Describe
wear processes, durability and the technical condition of machines, and how they change in time.

Select
an appropriate maintenance strategy (reactive, preventive, condition-based, RCM, TPM) for a given machine.

Calculate
basic indicators: availability, MTBF, MTTR, OEE, reliability of simple systems.

Apply
diagnostic and condition-monitoring methods, and interpret their results.

Analyse
failures using FMEA and root cause analysis, and propose improvement actions.

Recommended literature

Słowiński B.
Inżynieria eksploatacji maszyn. Wyd. Politechniki Koszalińskiej (core source of lectures 1–6, in Polish).

Moubray J.
Reliability-Centred Maintenance (RCM II). Industrial Press.

Ebeling C. E.
An Introduction to Reliability and Maintainability Engineering. Waveland Press.

Mobley R. K.
An Introduction to Predictive Maintenance. Butterworth-Heinemann.

Nakajima S.
Introduction to TPM: Total Productive Maintenance. Productivity Press.

Standards
EN 13306, ISO 55000, IEC 60050-192, EN ISO 12100, ISO 17359, ISO 20816; Regulation (EU) 2023/1230.

ACTIVITY

What happens when a machine stops?

Work in pairs for **3 minutes**. Think about one machine you know – in a factory, a workshop, a hospital, or at home. Discuss:



Who is affected?

Operators, customers, the company, other machines in the line?



What does it cost?

Repair, spare parts, lost production, penalties, reputation?



Could it be prevented?

Were there any early warning signs? Who should have noticed them?



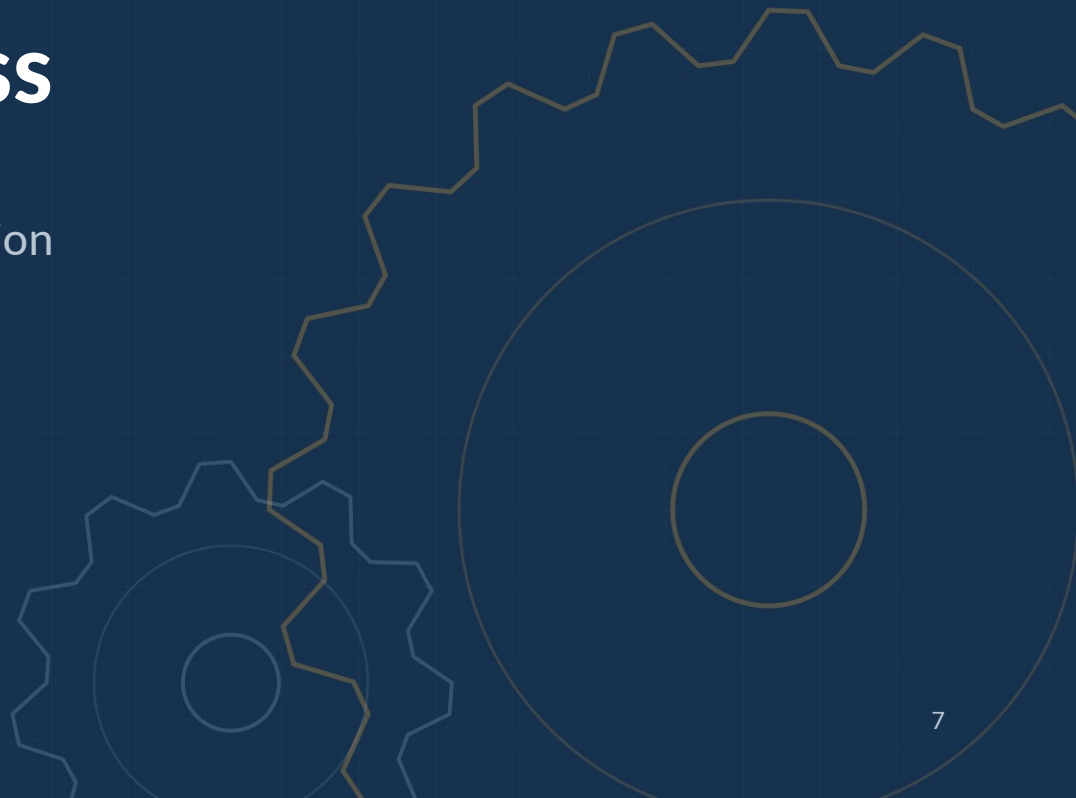
Who is responsible?

The designer, the manufacturer, the user, the maintenance team?

01

The industrial realisation process

From customer needs, through design and manufacturing, to operation



Economic activity as a realisation process

Humans are social beings – they live and act among other people. Cooperation has led to organisations, including those running **economic activity: manufacturing products or providing services for profit**.

A **realisation process** is a set of actions aimed at satisfying someone's needs. **Every repeatable process in which a product for sale is created using machines or other devices, with work divided between participants, is called an industrial realisation process.**

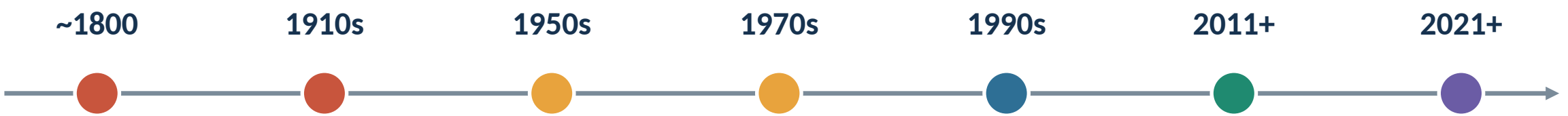
The most common industrial realisation processes are **production processes** – transforming resources into useful products. Production is social in nature, because people cooperate with each other.



KEY TAKEAWAY

Industrial realisation = **repeatable** process, **machines**, **division of work**, **product for sale**.

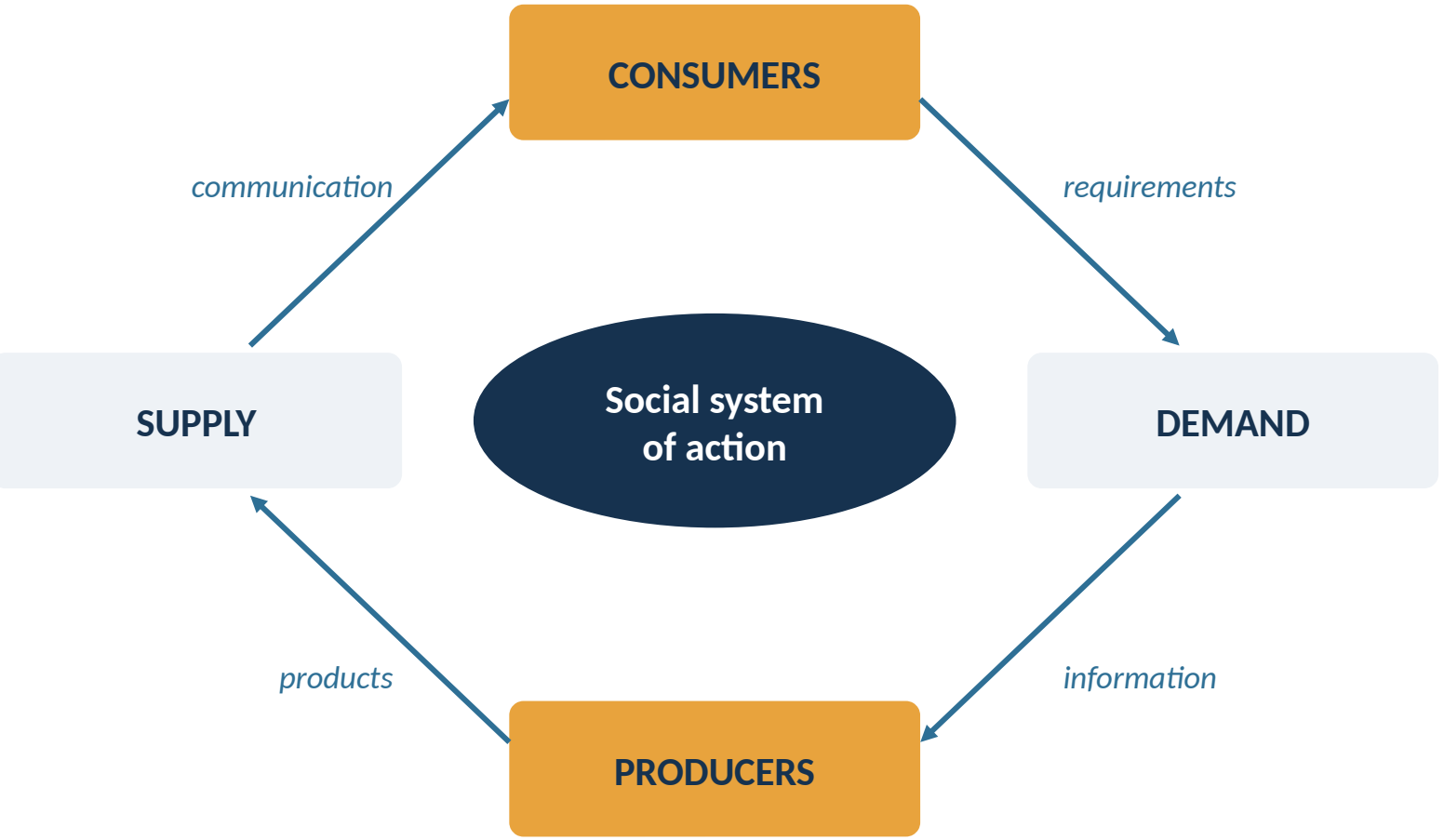
A short history of machine operation and maintenance



~1800	1910s	1950s	1970s	1990s	2011+	2021+
Steam power	**Mass production**	**Preventive maintenance**	**RCM and TPM**	**CMMS & condition monitoring**	**Industry 4.0**	**Industry 5.0**
Repair after failure – “fix it when it breaks”	Assembly lines – downtime stops the whole line	Planned inspections and overhauls at fixed intervals	Reliability-Centred Maintenance (aviation) and Total Productive Maintenance (Japan)	Computers, vibration analysis, thermography	Sensors, IIoT, data, predictive maintenance	Human-centric, sustainable and resilient industry; AI

From reacting to failures → to preventing them → to predicting them

The social system of action



The main driving force of industrial processes is, and will remain, the **manufacturing sector**. Its domain is production processes.

A production process takes place in the environment of a **production system – the enterprise**.

Three organic features of an industrial process

Regardless of the type of activity or the size of the enterprise, every industrial process is described by three features:



Division of work

A series of tasks or activities divided into separate operations and workstations.



Equipped workstations

Workstations are equipped with machines or other devices that increase productivity.



Organised cooperation

Cooperation between people and machines is organised within the technological process.

Integration of marketing, design and manufacturing

The customer market determines the whole production philosophy. The industrial process is not a goal in itself – it is a means of delivering a good or service of **expected value at an acceptable price**. This requires the integrated action of three groups:



Marketing

identifying and understanding customer needs



Design

conceiving a product with the desired features



Manufacturing

a series of operations that materialise the designers' concepts

Two complementary spheres: abstraction and concrete

Conceptually, production materialises energy; giving matter a required form is **processing**. It covers the **sphere of abstraction** (conceiving) and the **sphere of concrete** (making).

SPHERE OF ABSTRACTION – result: an idea (mental work)

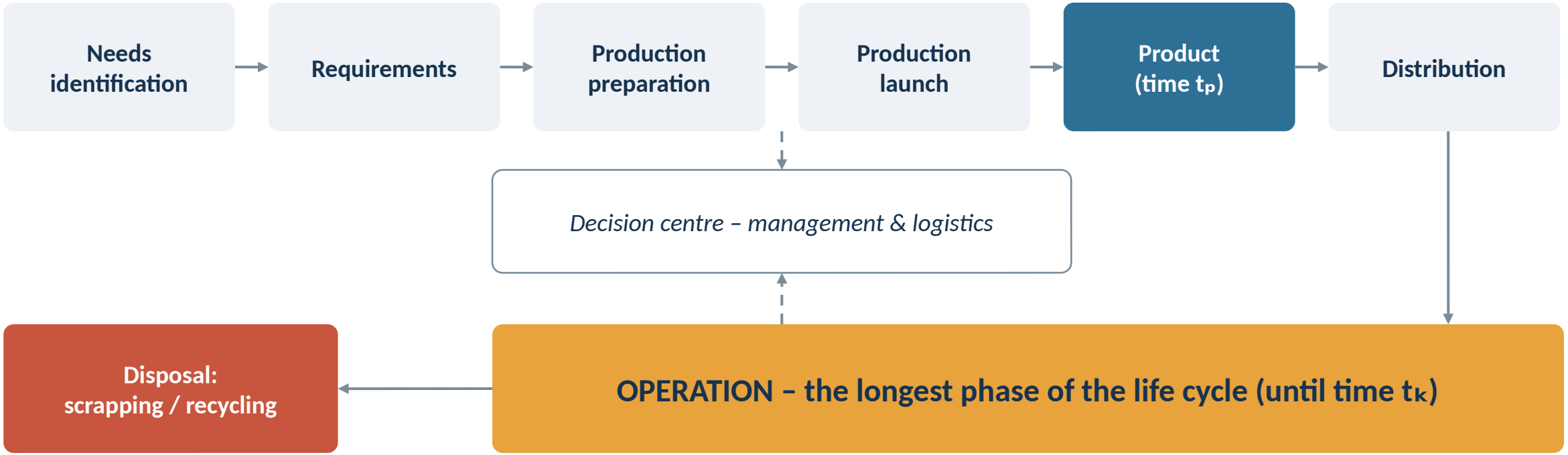


SPHERE OF CONCRETE – result: a physical product



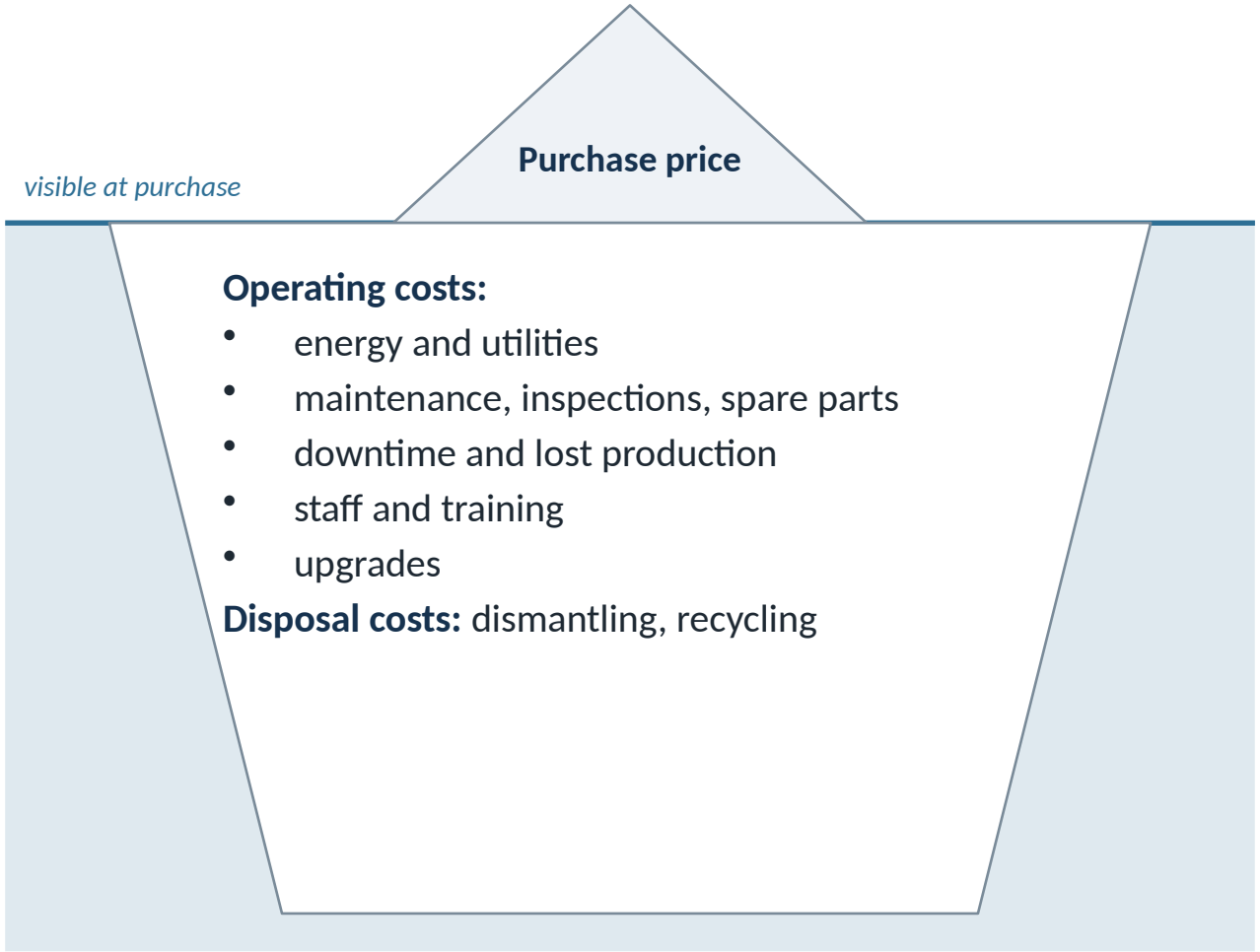
Abstraction: analysing needs, predicting operating conditions, setting reliability measures, conceiving. Concrete: drawing, manufacturing and operation.

The product life cycle



Every technical object is manufactured **in order to be operated**. A product put into operation and performing its tasks becomes a **technical means**. Keeping technical means in working order is the task of **machine operation engineering**.

Life cycle cost (LCC) – the iceberg



LCC (Life Cycle Cost) – the total of all costs incurred over the life of an asset: concept, acquisition, operation and disposal.

The purchase price is usually only the **tip of the iceberg** – most costs arise during **operation**.

LCC methodology: **IEC 60300-3-3**.

CASE STUDY

Which pump is cheaper? – the task

Data	Pump A	Pump B
Purchase price	8 000 €	10 000 €
Power consumption	15 kW	12.5 kW
Maintenance cost per year	1 000 €	1 200 €

Common assumptions:

- operating time: **6 000 h per year**
- electricity price: **0.15 € per kWh**
- analysis period: **10 years**
- no discounting (simplified)

Your task (5 minutes, in pairs):

1. Which pump would you buy if you look only at the price?
2. Calculate the 10-year cost of energy for each pump.
3. Calculate the total LCC. Which pump is cheaper?

CASE STUDY

Which pump is cheaper? – the solution

Cost over 10 years	Pump A	Pump B
Purchase	8 000 €	10 000 €
Energy: kW × 6 000 h × 0.15 € × 10	135 000 €	112 500 €
Maintenance: per year × 10	10 000 €	12 000 €
TOTAL LCC	**153 000 €**	**134 500 €**

Pump B saves

18 500 €

about 12% of the total cost – although it is 2 000 € more expensive to buy

Conclusions: energy is about **88%** of the LCC of Pump A, the purchase price only about **5%**. The decision should be based on the life cycle cost, not on the price. In a full analysis we would also **discount** future costs and include downtime and disposal.

WORKED EXAMPLE

EXAMPLE

What does one hour of downtime cost?

DATA – a packaging line stops for 1 hour

- line output: **120 units per hour**
- contribution margin: **25 € per unit**
- repair team: **3 technicians × 50 € per hour**
- spare part (bearing + seal): **800 €**
- scrapped products after restart: **40 units × 10 € material**

Lost margin	*120 × 25 €*	**3 000 €**
Repair labour	*3 × 50 €*	**150 €**
Spare parts		**800 €**
Scrap	*40 × 10 €*	**400 €**

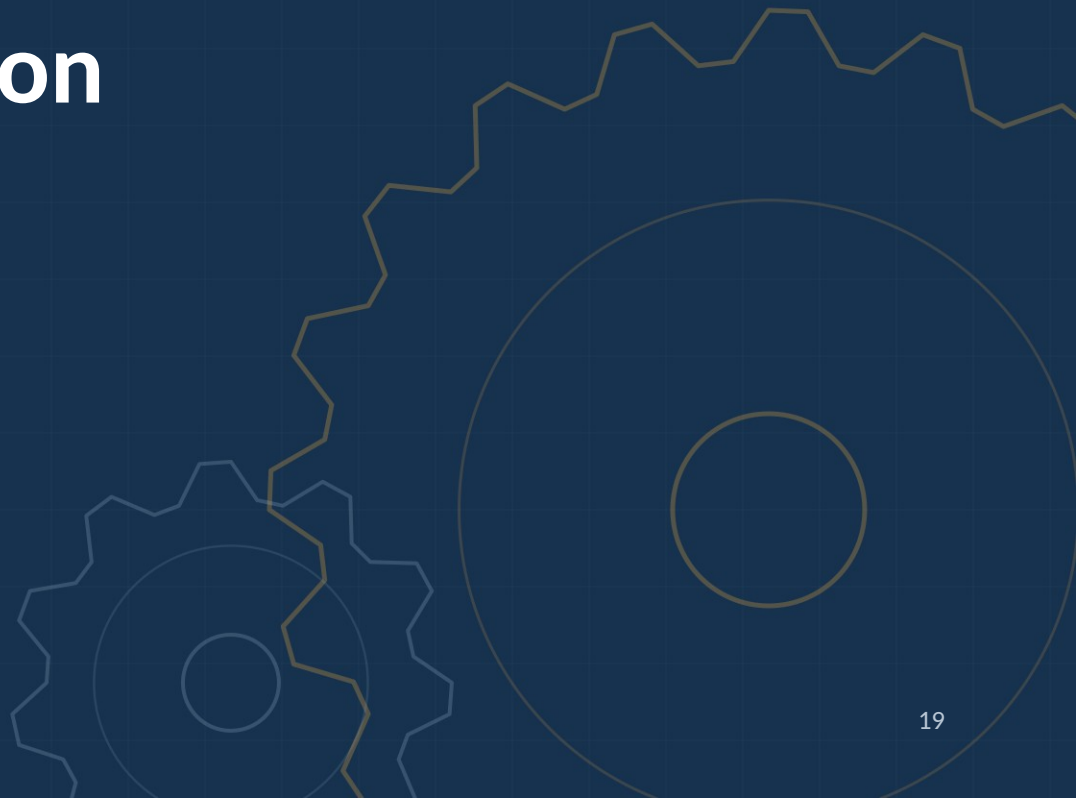
Total: 4 350 € per hour

Repair itself is only ~22% – the biggest cost is lost production

02

The essence of machine operation

What operation is, what it covers, and how it is defined today



One word – different meanings

In Polish, the term „eksploatacja” is interdisciplinary and is understood differently depending on the profession:

Engineer

operation = using machines, devices or other technical systems, including repairs, maintenance etc.

Economist

exploitation of mineral deposits, e.g. coal, or management of the company’s fixed assets

Politician

exploitation of the workforce, class exploitation

The common core of all meanings

Every human activity aims to change reality in the most favourable direction with as little effort as possible. All meanings of operation share a common core:

Long-term activity

operation is a long-lasting activity, not a one-off undertaking

Long-term benefits

the activity should provide benefits over a long time

A means, not a goal

operation is not the goal itself – it enables the goal to be achieved

Definitions of operation and its management

Polish scientific tradition (terminology standard PN-82/N-04001) treats operation holistically:

Operation

a set of purposeful organisational, technical and economic activities of people with a technical object, and the relations between them, from taking the object over for its intended use until its disposal.

Operation management

planning and decision-making, organising, leading and controlling the resources of the operation system (human, financial, material, information) to use technical objects rationally and keep them in a functional state.

International terminology today

In international practice, the terminology is defined by European and ISO/IEC standards:

EN 13306:2017

Maintenance – combination of all technical, administrative and managerial actions during the life cycle of an item, intended to retain it in, or restore it to, a state in which it can perform the required function.

ISO 55000:2024

Asset management – coordinated activity of an organisation to realise value from assets, including the machinery park, over their whole life cycle.

IEC 60050-192:2015

Vocabulary of **dependability**: availability, reliability, maintainability and maintenance support – used throughout this course.

Machine and technical object

Machine operation engineering is the totality of activities related to the **rational use of machines or technical objects**, where:



Machine

An artificial device intended to partially or fully replace human **energetic, physiological or intellectual** functions.



Technical object

Any device which:

- has a defined purpose (a set of applications),
- fails and requires maintenance,
- can be improved,
- may harm people and the environment,
- passes through various phases (life stages).

Two aspects of machine operation



Activity

The machine plays two roles: as the **subject** of action it is **used**, and as the **object** of action it is **maintained**.



Set of states

States grouped into the phases of its existence – quality states: **market** quality Qr, **design** quality Qp, **manufacturing** quality Qw and **operational** quality Qe.

Machine durability as a random variable

Moving to the next life stage transforms the machine's quality features. At each stage **random factors** cause dispersion of these features (Qp1, Qp2, … Qpn).

A **state** is everything that happens to an object at a given moment t – so the trajectory of states is random, and the **durability period Tk is also a random variable**.

It can only be estimated approximately, e.g. with a **linear wear model**, where wear results from variable loads QF.

LINEAR WEAR MODEL

$$Q_e = b - at$$

where:

b – constant dependent on technical quality (Qp + Qw),

a – constant describing the intensity of wear processes in the machine.

EXAMPLE

First look at basic measures: MTBF, MTTR, availability

MTBF

Mean Time Between Failures

average operating time between two failures

MTTR

Mean Time To Repair

average time needed to restore the machine

A

Availability

share of time when the machine is ready to work

$$A = \frac{MTBF}{MTBF + MTTR}$$

EXAMPLE – one month of a CNC lathe

- total operating time: **680 h**
- number of failures: **4**
- total repair time: **20 h**

$$MTBF = 680 / 4 = 170\ h$$

$$MTTR = 20 / 4 = 5\ h$$

$$\mathbf{A = 170 / (170 + 5) \approx 0.971}$$

→ the lathe is ready to work about 97% of the time

QUIZ

Quiz 1 – the essence of machine operation

1 **Which phase of the product life cycle is usually the longest?**

A) design | B) manufacturing | C) operation | D) disposal

2 **According to EN 13306, maintenance means...**

A) only repairs after failure | B) all technical and managerial actions | C) buying new machines | D) cleaning the machine

3 **Life Cycle Cost (LCC) of a pump is usually dominated by...**

A) purchase price | B) transport | C) energy and operation | D) disposal

4 **A machine fails 4 times in 680 h of operation. MTBF equals...**

A) 4 h | B) 85 h | C) 170 h | D) 680 h

5 **Operation in the engineering sense is...**

A) a goal in itself | B) a one-off project | C) a means to achieve a goal | D) only the use of a machine

ANSWERS

Quiz 1 – answers

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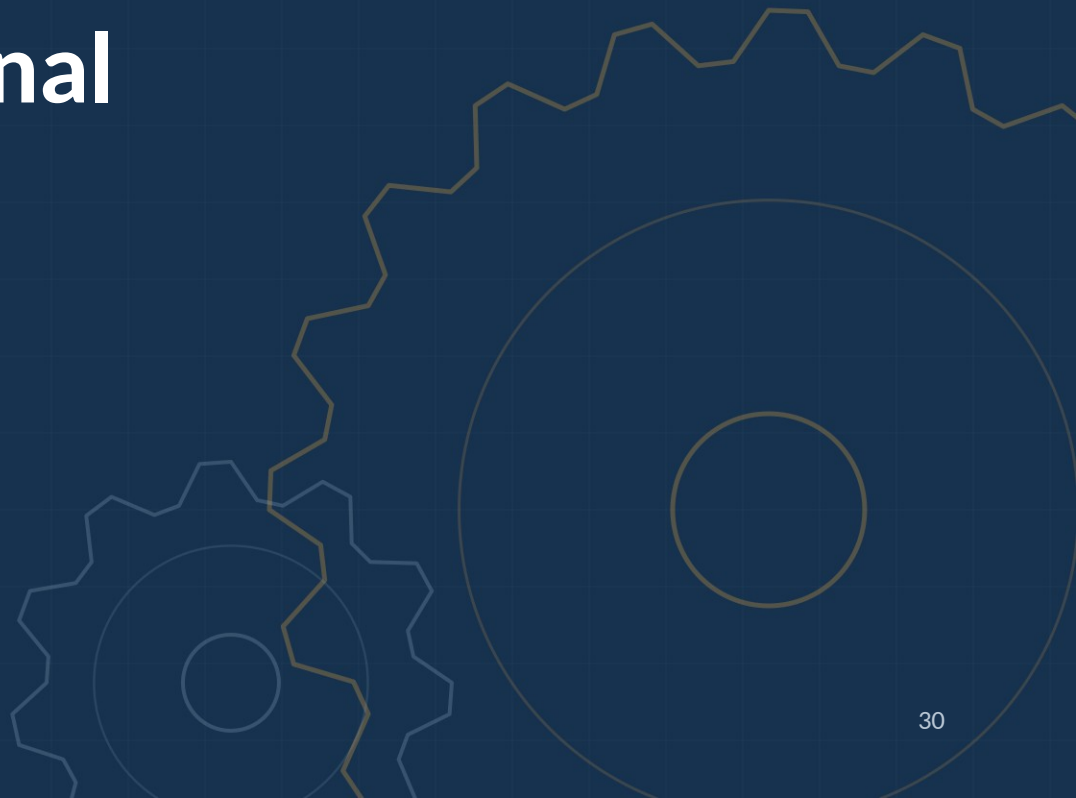
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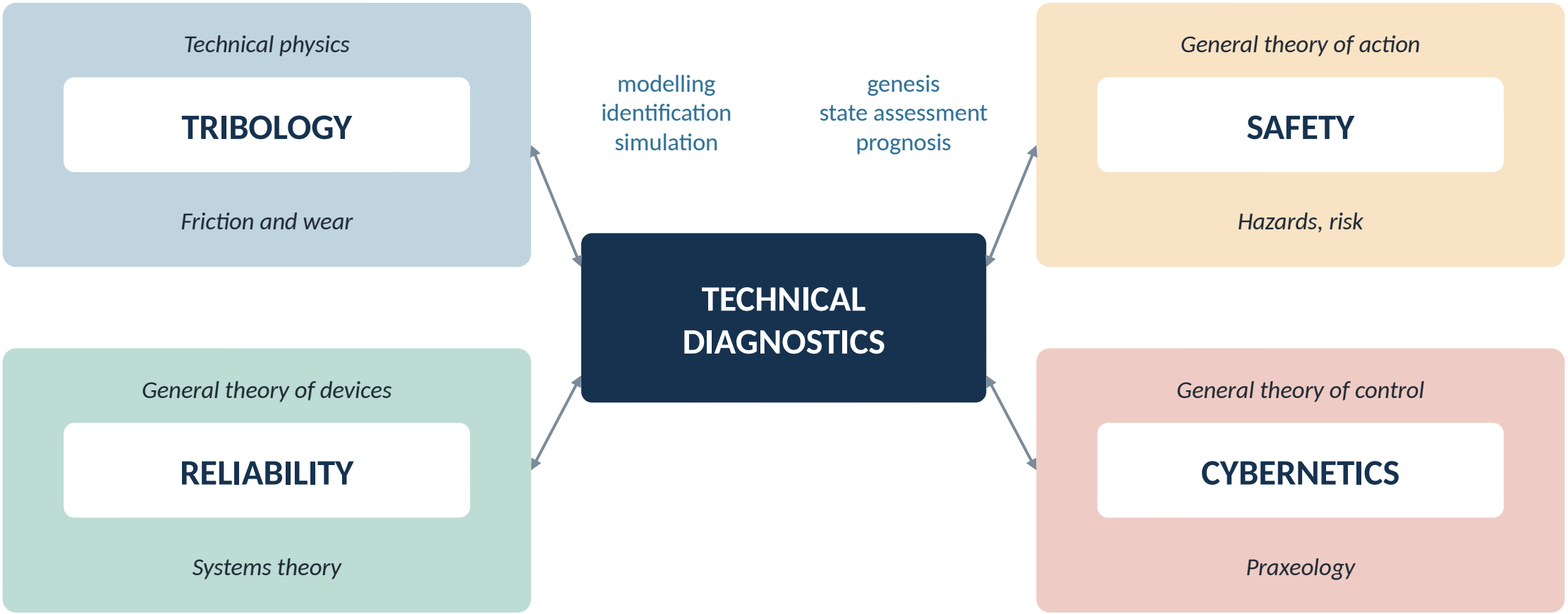
03

Operation science and operational problems

Fields of knowledge, types of problems and modelling



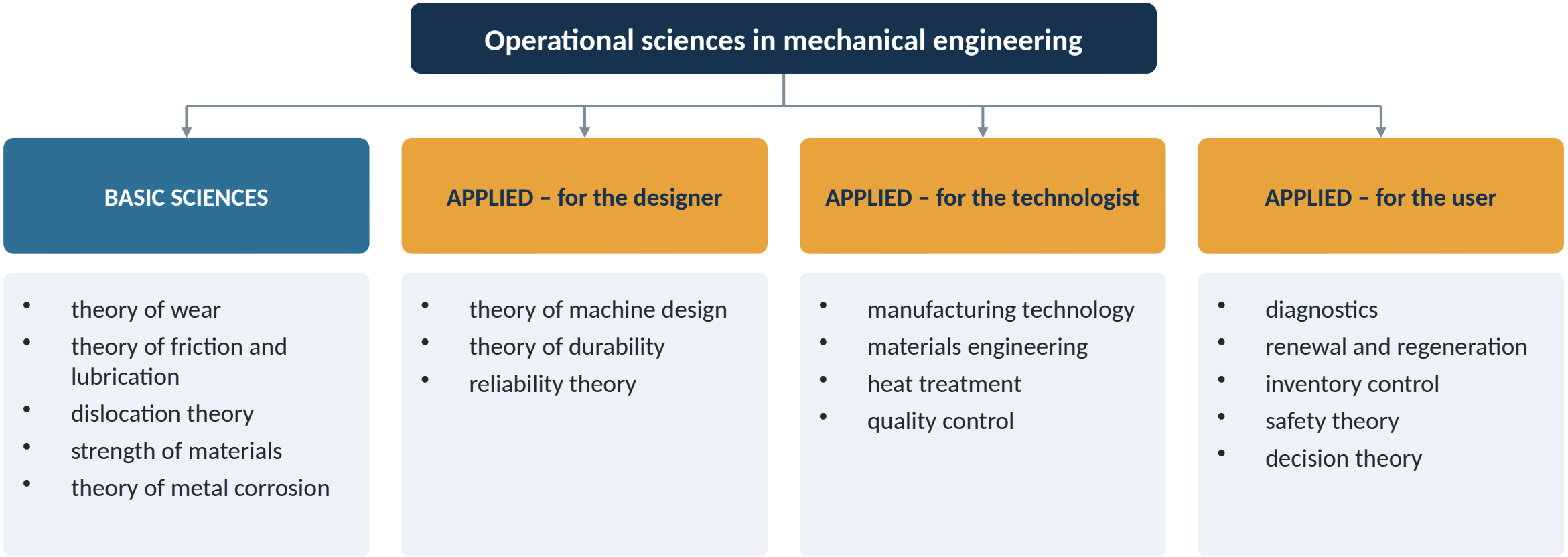
Main fields of operational knowledge



Diagnostics links the basic sciences with the operational sciences.

Operational sciences in mechanical engineering

Two complementary groups are distinguished: **basic** (first in solving problems) and **applied** (the final result of research – "recipes" for action).



What is an operational problem?

During the use of machines, various unforeseen events occur, which we generally call **problems**. A problem is a task that cannot be solved with known patterns (existing knowledge).

Only some events create problems. A machine failure is certainly a problem; starting the machine should not be – unless there is no power supply, the user does not know how to start it, or the battery of an engine is discharged.

The starting point for finding a solution is usually a good **classification of the problem**.



KEY TAKEAWAY

A problem = a task **without a known solution pattern**.
First step: **classify** it.

Classification of operational problems

CRITERION	OPERATIONAL PROBLEMS
Function of the device	primary devices · auxiliary devices
Complexity	simple devices (e.g. tools) · complex devices (machine tools, vehicles)
Number of devices	single devices · groups of devices
Human role in the action	direct actions · indirect actions (managerial problems)
Role of the device	devices in use · devices being maintained
Interested institution	research (designers) · training (staff education) · implementing (manufacturers, operation services)
Subsystem of operation	supply · repair · current maintenance · information processing · use

The engineering view: three types of problems

Deviation problems

a defect appears in the system, but its cause is unknown

Optimisation problems

the extremum of a function must be found (cost, time, availability…)

Innovation problems

the system needs to be rebuilt

Optimisation is the most important: durability can easily be increased with stronger components – but the price rises. Operation science should indicate the **optimal maintenance strategy**.

CASE STUDY

A deviation problem in practice – the “5 Whys”

Problem: a belt conveyor stopped – the drive bearing seized. The bearing was replaced, but **it failed again after 6 weeks**.

1	**Why did the bearing seize?**	It overheated.
2	**Why did it overheat?**	There was no grease in the bearing.
3	**Why was there no grease?**	Nobody lubricated it.
4	**Why did nobody lubricate it?**	The lubrication point is not on the inspection checklist.
5	**Why is it not on the checklist?**	**The conveyor was modernised and the maintenance plan was not updated.**

Root cause: missing management of change → corrective action: update the maintenance plan after every modification.

Typical optimisation questions

Properties of the device

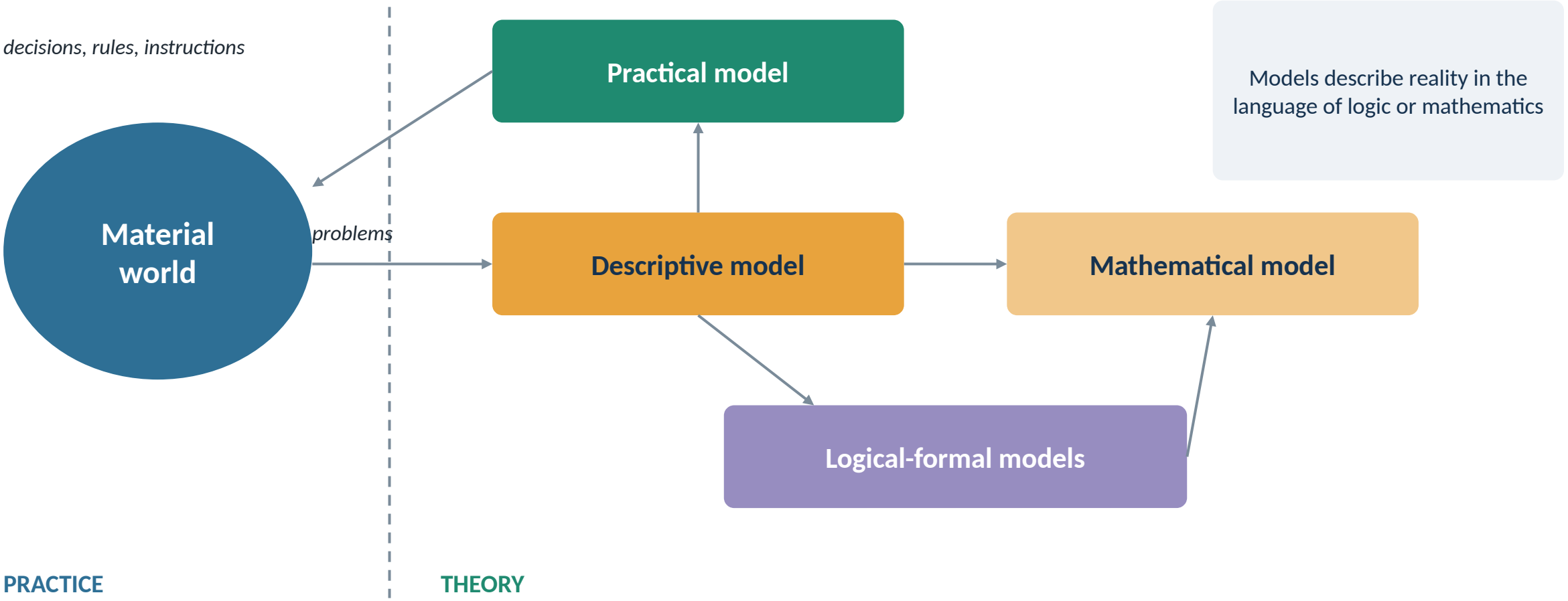
- How to set the scope of maintenance and intervals?
- How to introduce a new device into operation?
- When to withdraw a device from operation?
- What is needed to extend the service life?
- What is the optimal intensity of use?

Organisation of the operation system

- How large should maintenance units be?
- What territorial structure should the system have?
- How to organise storage and transport?
- How should maintenance units be equipped?

Optimisation criteria (or constraints): cost, time, mobility, continuity of task performance.

Modelling as a way to solve operational problems

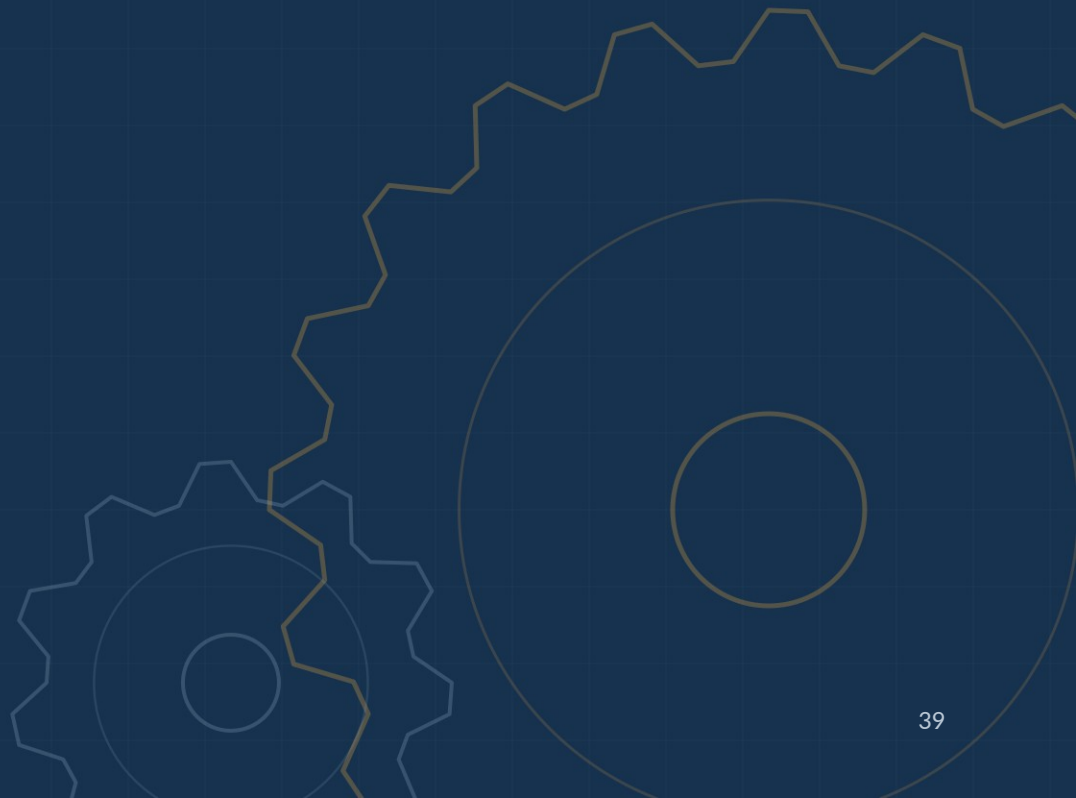


Models describe reality in the language of logic or mathematics

04

Technical means and machines

How machines transform mass, energy and information



Human action and technical means

Action is conscious human behaviour aimed at satisfying a need. Because of limited physical capacity, people use aids – **technical means**: artificially made objects performing assigned functions. Their essence is the **transformation of mass, energy or information**:

Energy machines

transform energy, e.g. engines and motors

Technological machines

transform mass, e.g. machine tools

Electronic machines

transform information, e.g. computers

A machine replaces humans in the task space; the basic requirement is **task capability**. Today's quality requirements are so high that often only automated machines can meet them.

Mechanisation and automation

Mechanisation

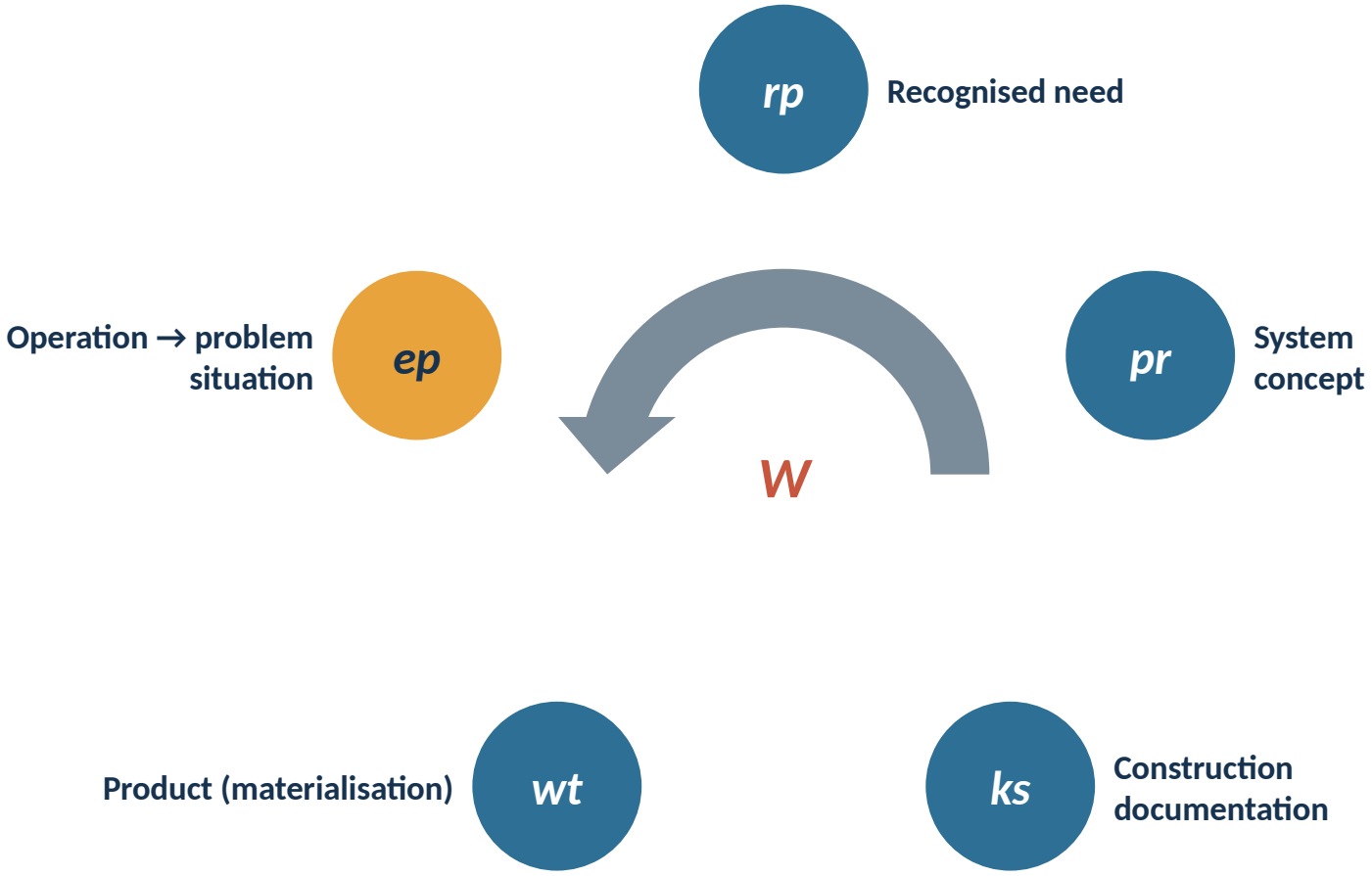
replacing manual work with machine work; humans no longer supply energy, but direct the machine and control its internal processes.

Automation

complete elimination (full automation) or significant reduction (partial automation) of direct human participation in machine operation.

Automation is one of the best ways to achieve operational efficiency, especially combined with modern IT. It can be technical, economic and organisational in nature.

Dietrych's automaton – life cycle of technical means



The cycle shows the **cause-and-effect chain** of realising technical means: need → system → construction → product → operation.

Operation creates new **problem situations** – and the cycle starts again.

W – reverse verification: each stage checks the results of the following one (e.g. marketing verifies the system, the designer verifies the construction).

Tool, machine and device

Technical means are divided into **rooms** (slowing down changes, e.g. due to climate) and **devices** (accelerating changes, e.g. during machining). Devices include tools and machines:



Tool

a material system used to purposefully transform other material systems and/or transmit messages. It **requires manipulation** and is characterised by **flexibility**.



Machine

a combination of rigid bodies arranged so that natural forces can be made to do work. It **requires operation (attendance)** and is characterised by **specialisation**. A machine must be supplied with energy other than human muscle power.

Property and characteristic

Every technical means is characterised by two kinds of features:

Property (inherent)

given during design; when it is lost, the product becomes something else – e.g. a chair without its backrest becomes a stool.

Characteristic (relational)

acquired during operation in relation to other technical means – e.g. one car consumes more fuel than another.

A machine as a system – example of a CNC lathe

Every machine consists of functional subsystems. Each of them wears differently and needs a different type of maintenance:

Drive
electric motors, inverters, servo drives

Transmission
belts, gears, ball screws, couplings

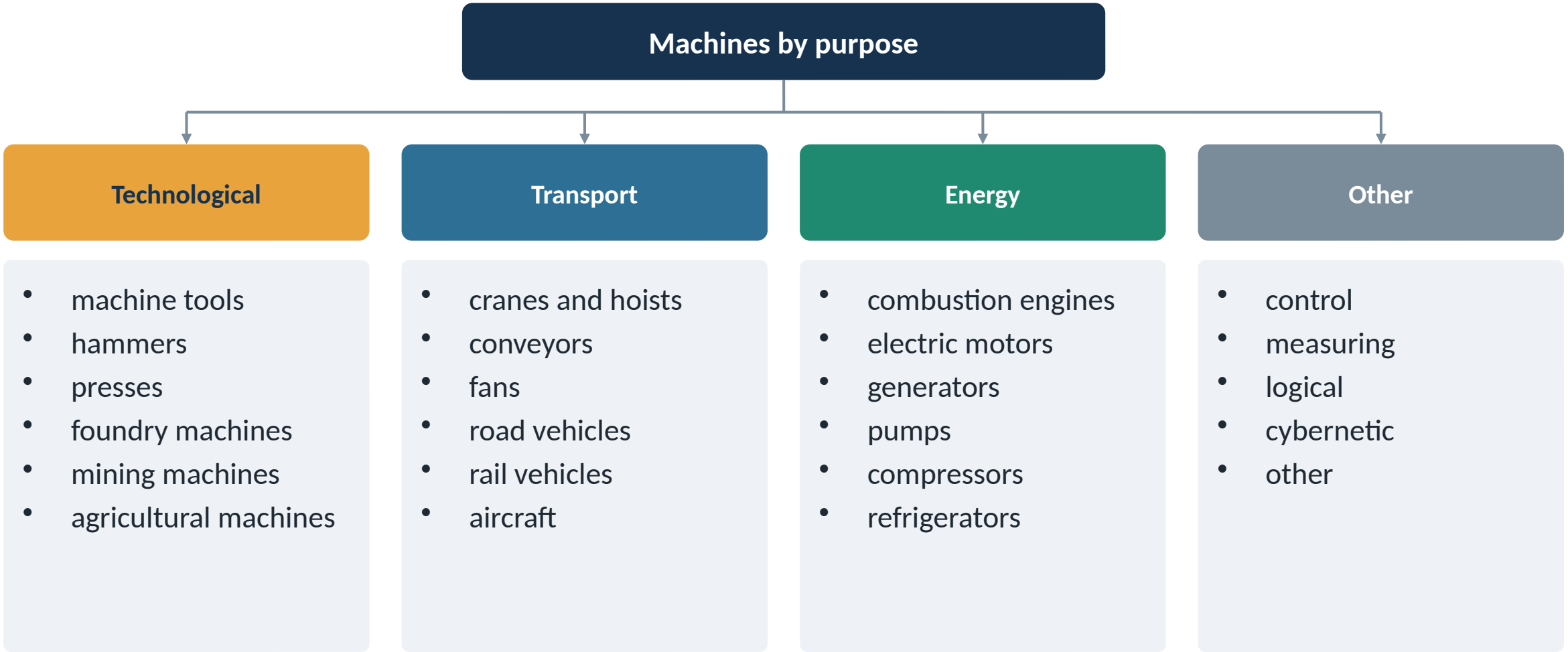
Working unit
spindle, turret, cutting tools

Control
CNC controller, sensors, PLC, software

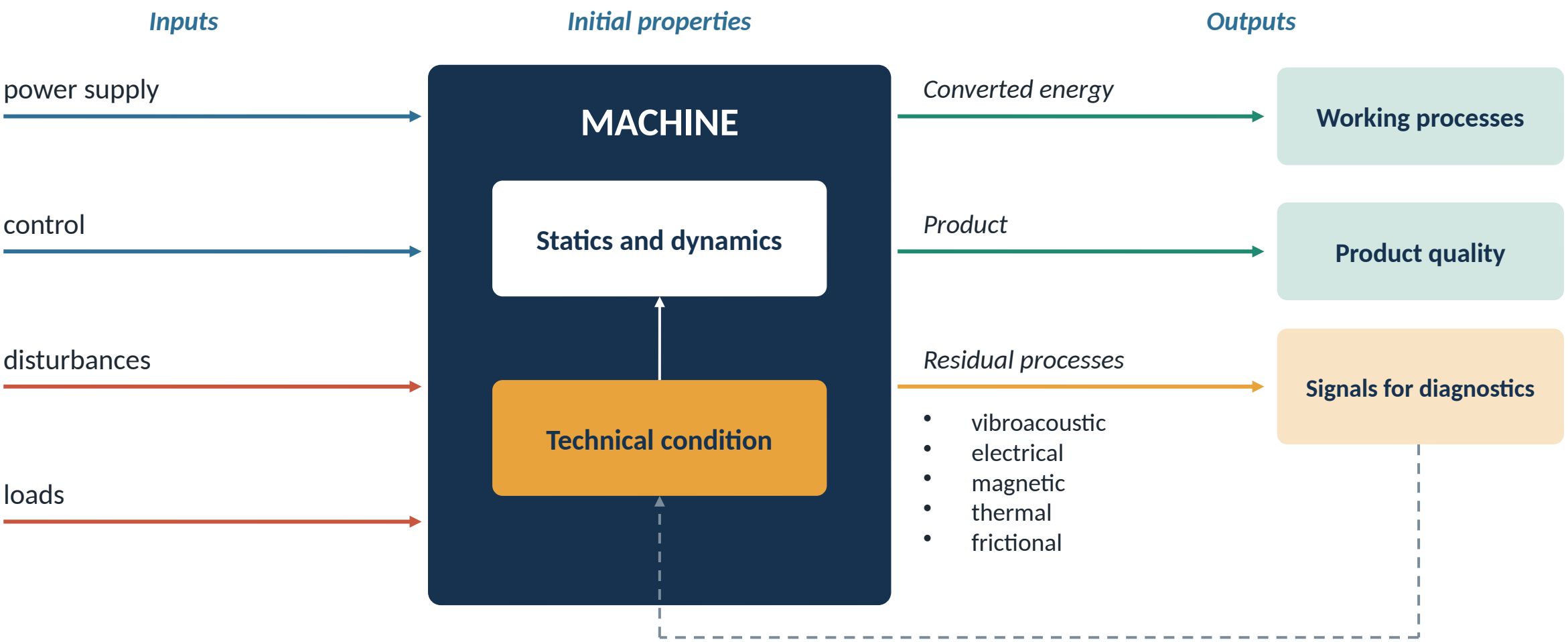
Frame and guides
bed, slideways, covers – accuracy and stiffness

Auxiliary systems
lubrication, cooling, chip removal, hydraulics, pneumatics

Classification of machines by purpose



Factors describing a machine – the “3 I” model



Efficiency of a technical means

When an action is performed with a machine, we distinguish:

- **theoretical intensity of action** ωmax – a **property**, foreseen by the designer,
- **practical intensity of action** ωp – a **characteristic**, obtained during operation.

The ratio of the two is the **efficiency** of the technical means.

EFFICIENCY

$$\eta = \frac{\omega_p}{\omega_{max}}$$

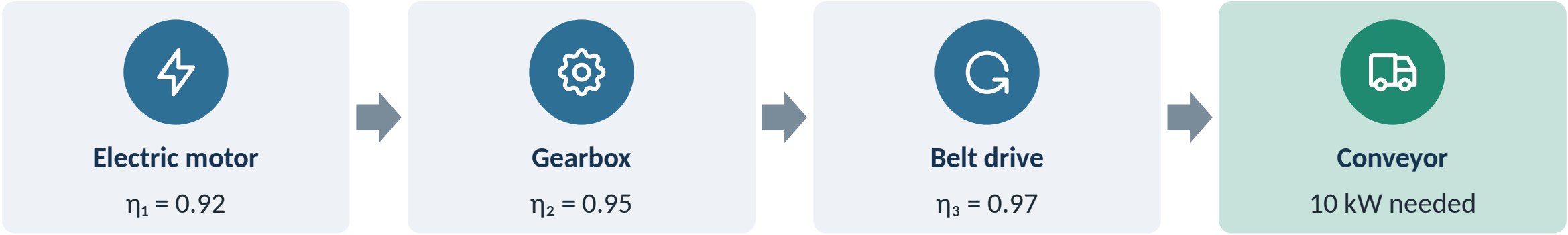
A machine can move only if **η > 0**

By the 2nd law of thermodynamics always **η < 1**

WORKED EXAMPLE

EXAMPLE

Efficiency of a drive chain



$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 = 0.92 \cdot 0.95 \cdot 0.97 \approx 0.848$$

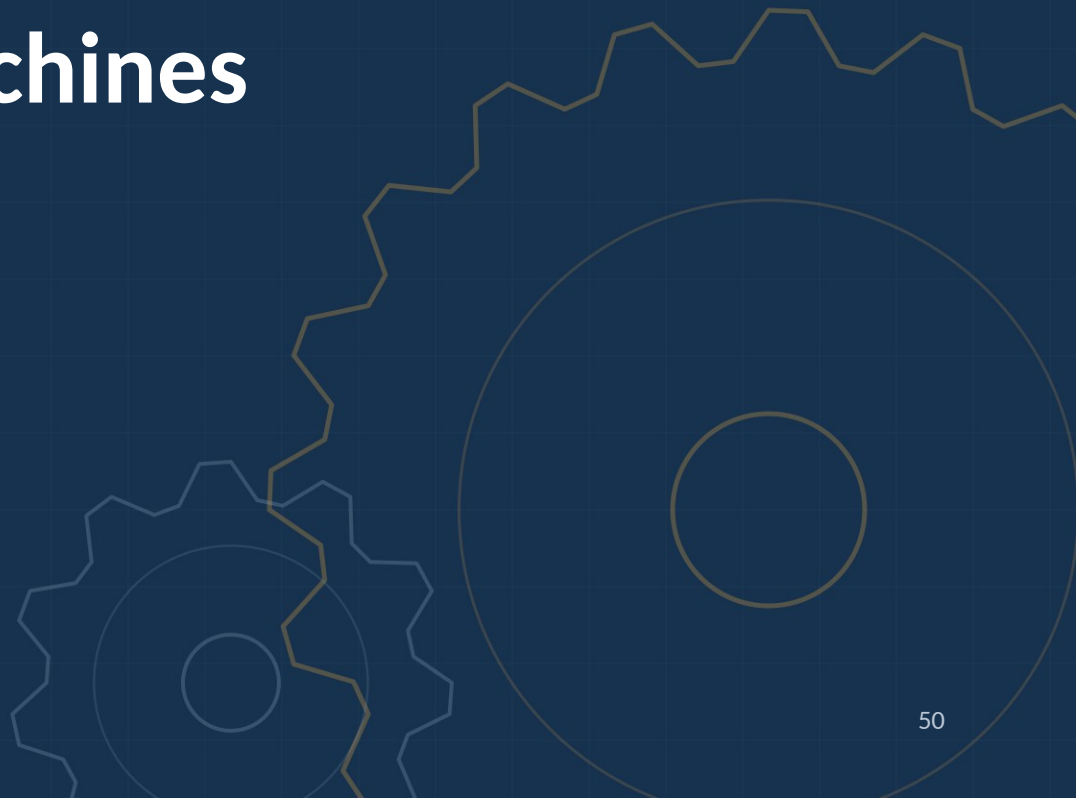
$$P_{in} = P_{out} / \eta = 10 / 0.848 \approx 11.8\ kW$$

Losses ≈ 1.8 kW are converted mainly into **heat**, noise and vibration. Over 6 000 h per year this is about **10 800 kWh** – and these residual processes are exactly what diagnostics can measure.

05

Requirements and safety of machines

From a set of requirements to EU law and risk assessment



Three levels of requirements

A requirement is a condition (or set of conditions) that something must satisfy. The most general set of requirements for technical means:



Mandatory

requirements that must be met unconditionally (safety)



Desirable

requirements that are wanted but not essential

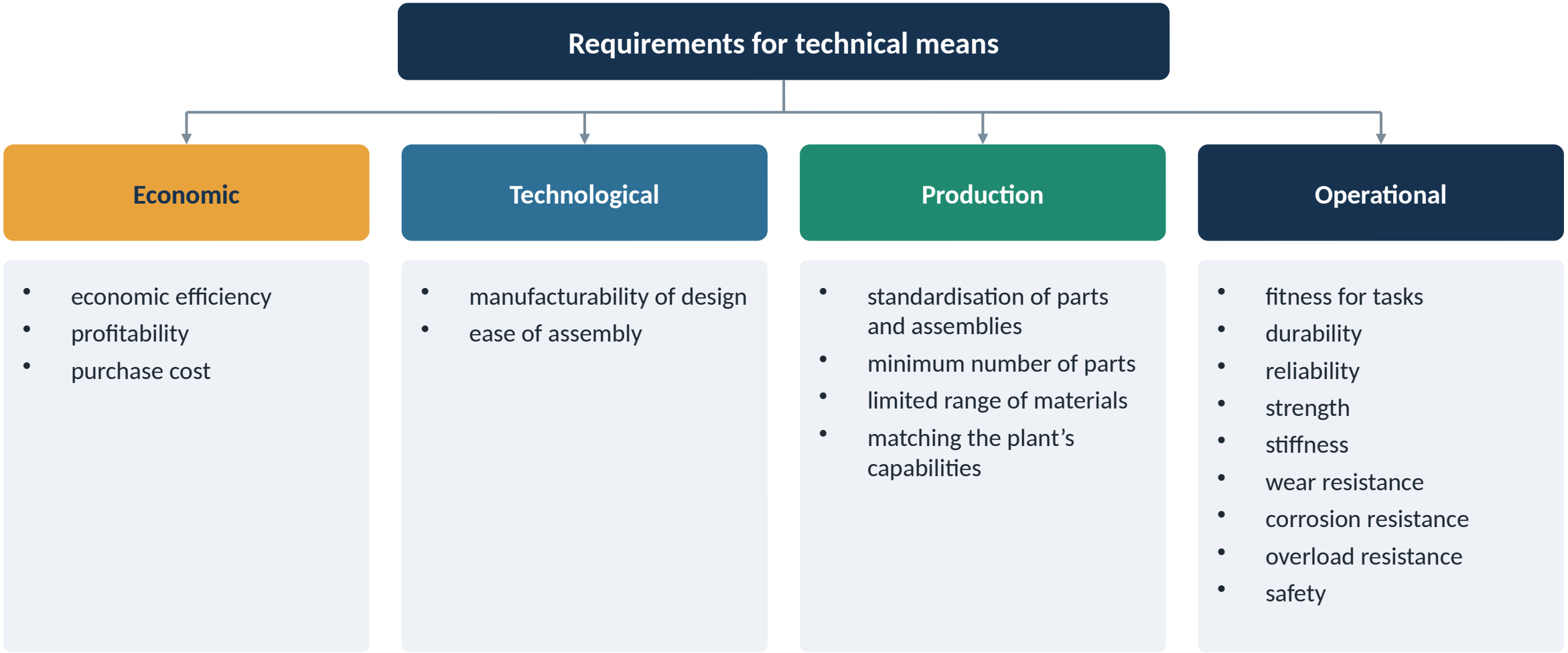


Secondary

requirements of minor importance that could be omitted

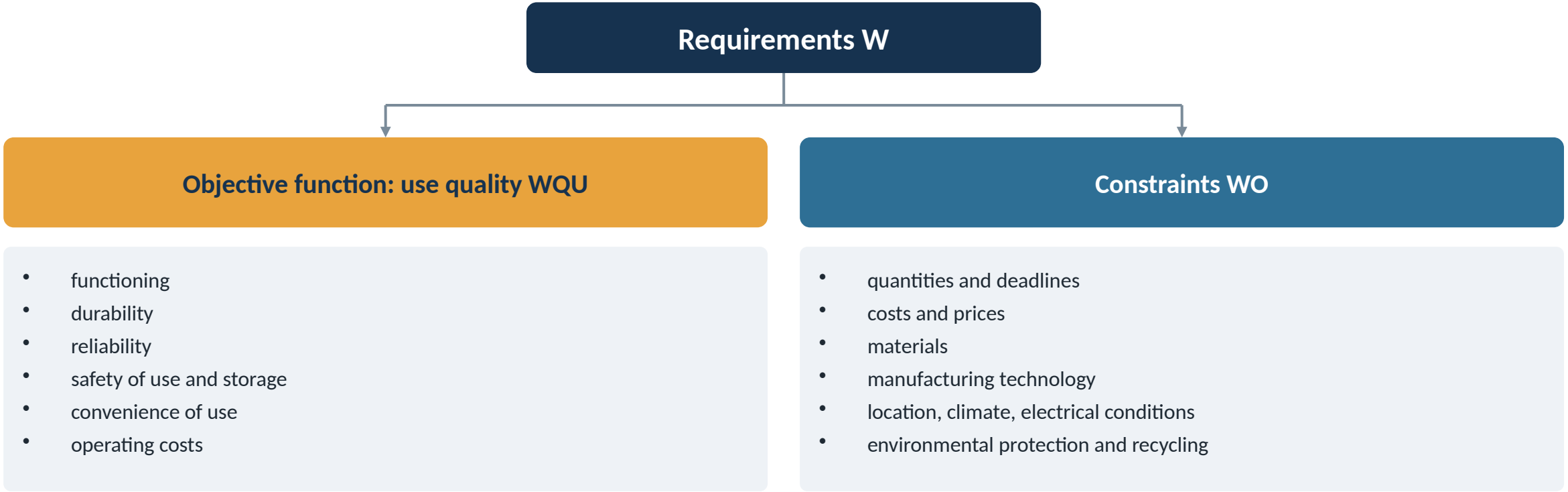
A requirement describes **what** the technical means should achieve; **how** it achieves it is the subject of design.

Requirements for machines as technical means



Objective function and constraints

From the set of requirements W, those concerning **use (operational) quality WQU**, technological quality WQT or distribution quality WQD are usually treated as the **objective function** – a criterion for choosing the best of the acceptable solutions. The remaining requirements are **constraints WO** that must not be exceeded.



From the Machinery Directive to the Machinery Regulation

2006
Machinery Directive 2006/42/EC adopted

29.12.2009
Directive 2006/42/EC applies

29.06.2023
Regulation (EU) 2023/1230 published

20.01.2027
Regulation replaces the Directive

Artificial intelligence
requirements for machines with self-evolving behaviour or logic

Cybersecurity
protection of control systems against corruption and remote interference

Digital instructions
documentation may be electronic (paper on request)

Regulation
applies directly in all EU Member States – no transposition

Two perspectives: producer and employer

Producer – Machinery Directive / Regulation

Placing safe machines on the EU market: identify all hazards, design them out, prepare technical documentation, **EU declaration of conformity** and **CE marking**.

Employer – Directive 2009/104/EC

Minimum safety requirements for the **use of work equipment** (new and used): proper installation, maintenance, inspections and use only by **trained workers**. Replaced Directive 89/655/EEC.

Requirement → adaptive measure (examples)

REQUIREMENT

Start-up only by deliberate action on a control device intended for that purpose

→

ADAPTIVE MEASURE

Solutions preventing unexpected start-up, e.g. after closing an interlocked guard, activating a limit switch or restoration of power

REQUIREMENT

Limited direct contact with moving parts that may cause accidents

→

ADAPTIVE MEASURE

Robust guards blocking access to the danger zone, which cannot easily be removed or defeated

REQUIREMENT

The machine must be equipped with an emergency stop

→

ADAPTIVE MEASURE

A mushroom-shaped emergency stop actuator: red on a yellow background

Risk assessment according to EN ISO 12100

1. Determine the limits of the machine
2. Identify hazards
3. Estimate the risk
4. Evaluate the risk (acceptable?)

NO

RISK REDUCTION – THREE-STEP METHOD

1. Inherently safe design

eliminate hazards at the design stage

2. Safeguarding

guards, interlocks, light curtains, emergency stop

3. Information for use

signs, warnings, instructions, training, PPE

RISK ANALYSIS

iterative process – re-assess after applying measures

The road to CE marking – step by step

1 **Identify applicable EU law**

Machinery Regulation, EMC, Low Voltage, RoHS…

2 **Risk assessment**

EN ISO 12100 – hazards and risk reduction

3 **Apply harmonised standards**

presumption of conformity

4 **Conformity assessment**

self-assessment or notified body (high-risk machines)

5 **Technical documentation**

drawings, calculations, risk assessment, tests

6 **EU declaration of conformity**

signed by the producer

7 **CE marking + instructions**

on the machine; instructions in the user’s language

The CE marking is a declaration by the producer – not a quality mark and not a certificate issued by the EU.

Safety standards: types A, B and C

Type A – Basic safety standards

general principles for all machinery

EN ISO 12100 – risk assessment

Type B – Generic safety standards

B1: safety aspects · B2: safeguards

EN ISO 13849-1 (control systems), EN ISO 13850 (emergency stop), EN ISO 14119 (interlocks), EN ISO 13857 (safety distances)

Type C – Machine safety standards

detailed requirements for a specific machine type

e.g. ISO 23125 (turning machines), EN 1570 (lifting tables), EN 693 (hydraulic presses)

If a type-C standard exists for the machine, it has priority over types A and B.

GROUP EXERCISE

ACTIVITY

Risk assessment of a pedestal drill

Work in groups of 3–4 for **10 minutes**. A small workshop uses a pedestal drill (bench drilling machine). Students and new workers often use it.



Step 1: Identify at least four hazards



Step 2: Estimate each risk with the risk matrix (consequence × probability)



Step 3: Propose measures using the three-step method: design → safeguarding → information



Step 4: Choose one person to present your results (2 minutes)

Hint: think about rotating parts, the workpiece, chips, electricity, noise and the operator's clothing and hair.

GROUP EXERCISE

ANSWERS

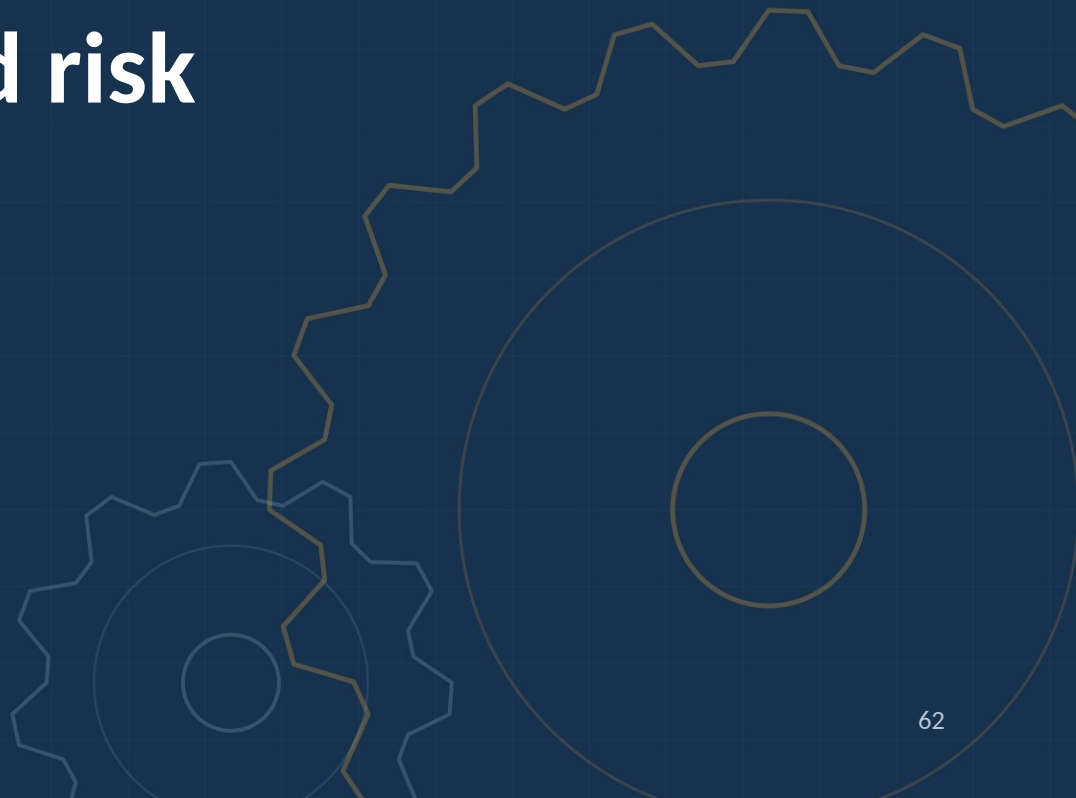
Pedestal drill – example solution

Hazard	Risk (example)	Measures
Entanglement of hair, sleeves or gloves in the rotating spindle	major × likely = 9	Chuck guard with interlock; no gloves, tight clothing, hair tied (instructions + training)
Workpiece rotating with the drill	moderate × likely = 6	Machine vice or clamps – never hold the workpiece by hand
Flying chips into the eyes	moderate × likely = 6	Transparent guard; safety glasses (PPE)
Electric shock	catastrophic × unlikely = 8	Protective earthing, RCD, regular electrical inspection
Unexpected start after power failure	major × unlikely = 6	No-volt release switch; emergency stop within reach
Noise	minor × likely = 3	Maintenance of bearings and belts; hearing protection if needed

06

Features of technical means and risk

Critical, major and minor features; acceptable risk



Critical, major and minor features

A **feature** is a distinct characteristic of a product – a design property or operational characteristic that can be determined (ideally measured). Features are usually classified into three groups:



Critical

decide on hazards to human life or health, or on loss of the product's utility



Major (important)

significant for usability; may take different values depending on the purpose



Minor

generally related to the overall quality of the product

Major features of machines

Strength

mechanical strength, insulation breakdown resistance, correct operation of protective systems and emergency switches

Functionality

measured e.g. by productivity and efficiency

Reliability

probability of performing the required tasks under given conditions for a given time or number of cycles; average failure rate

Durability / service life

time until functionality drops below the required level; total life including repairs; mean time between failures

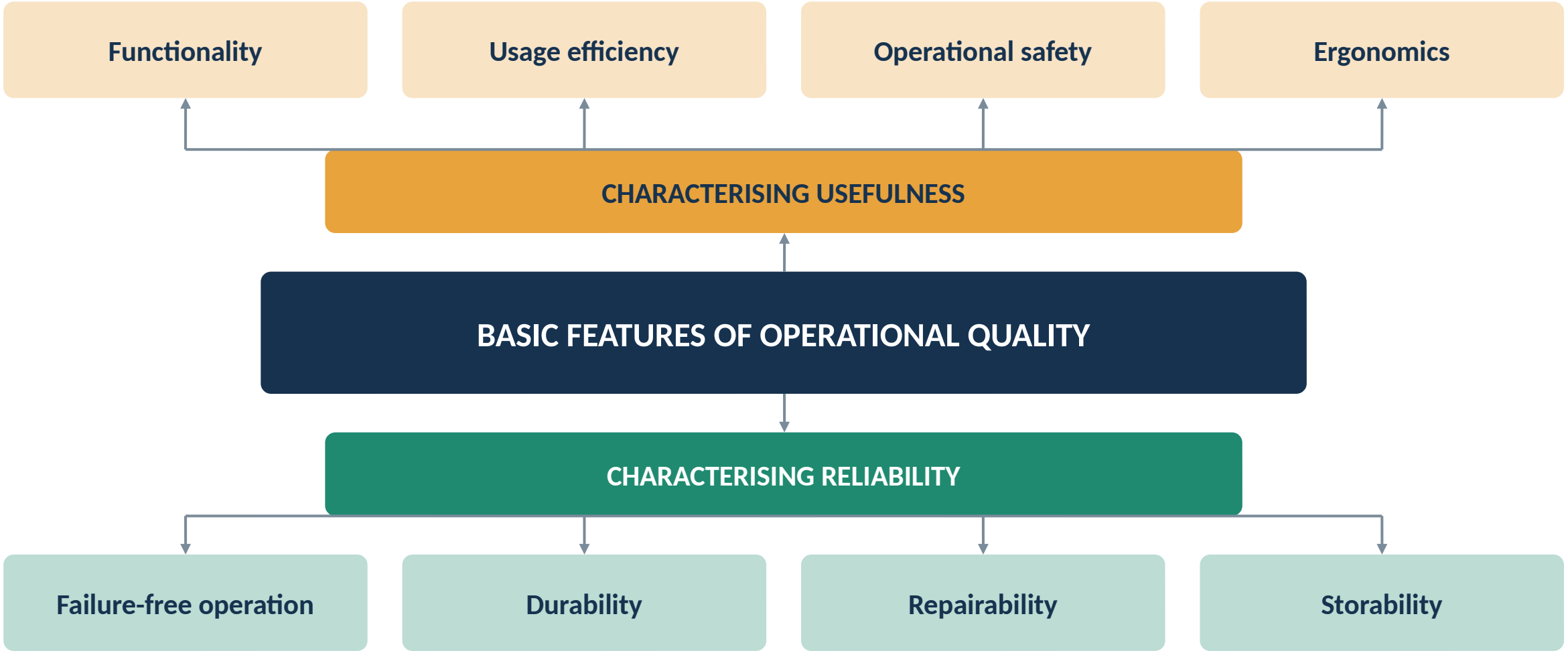
Repairability

repair time, labour and material consumption of repairs and maintenance

Industrial design

secondary (aesthetic) features – not measurable by technical methods, the domain of design

Basic features of operational quality



Acceptable level of technical risk

Safety in engineering refers to **people**; the “safety” of a machine is expressed through its **reliability** – a reliable machine has no sudden failures and is therefore safe.

Risk = consequence × probability – the expected value of negative outcomes.

In design, the technical risk of loss of life is usually assumed between **10^{-4} and 10^{-6}** – one accident in 10 000 to 1 000 000 cases.

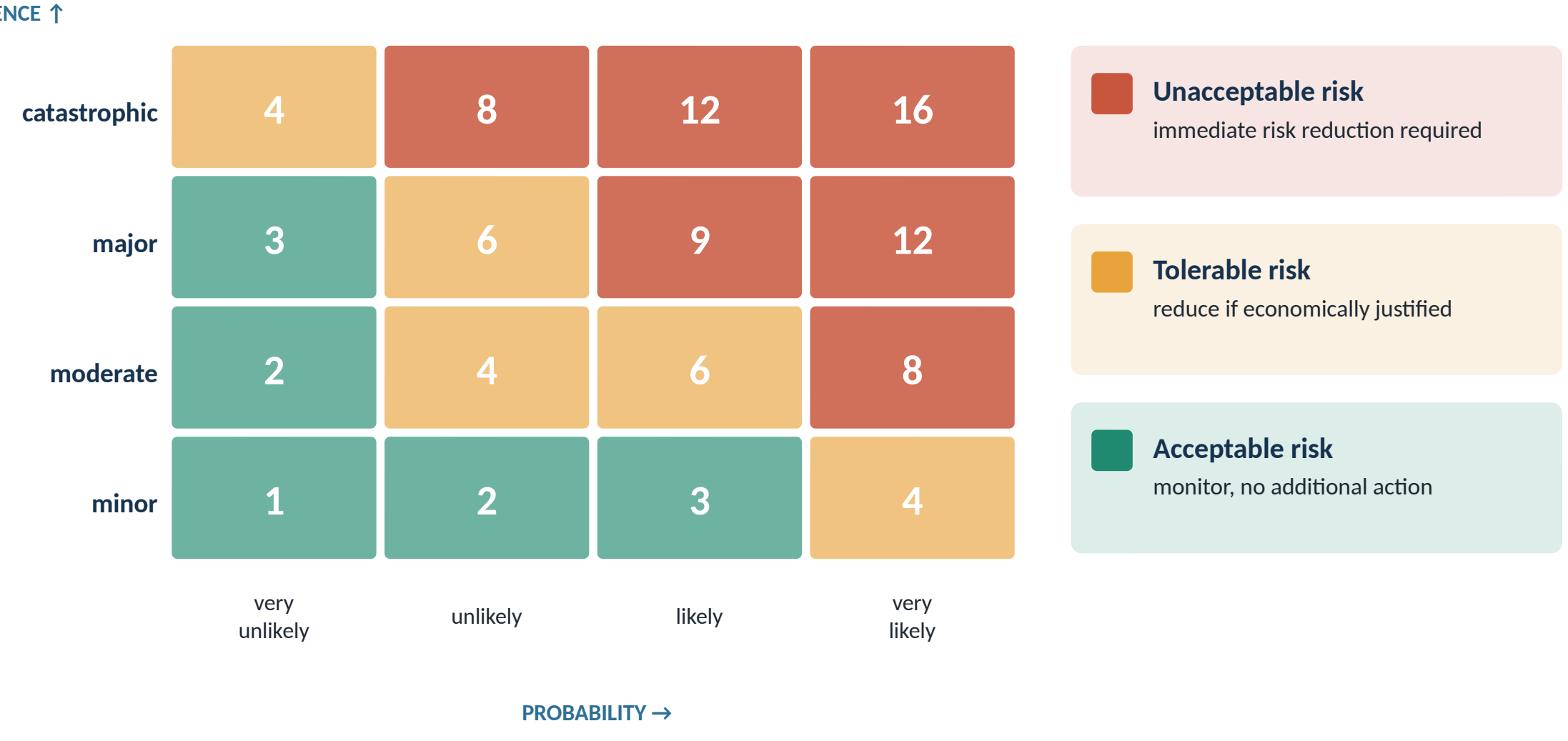
As the machine ages, risk **increases** due to wear.

RISK OF LOSS OF LIFE (per case)

10^{-3}	not socially acceptable
10^{-4}	accepted – strong pressure to reduce
10^{-5}	pressure decreases
10^{-6}	accepted

EXERCISE

Risk matrix – consequence × probability



Unacceptable risk
immediate risk reduction required

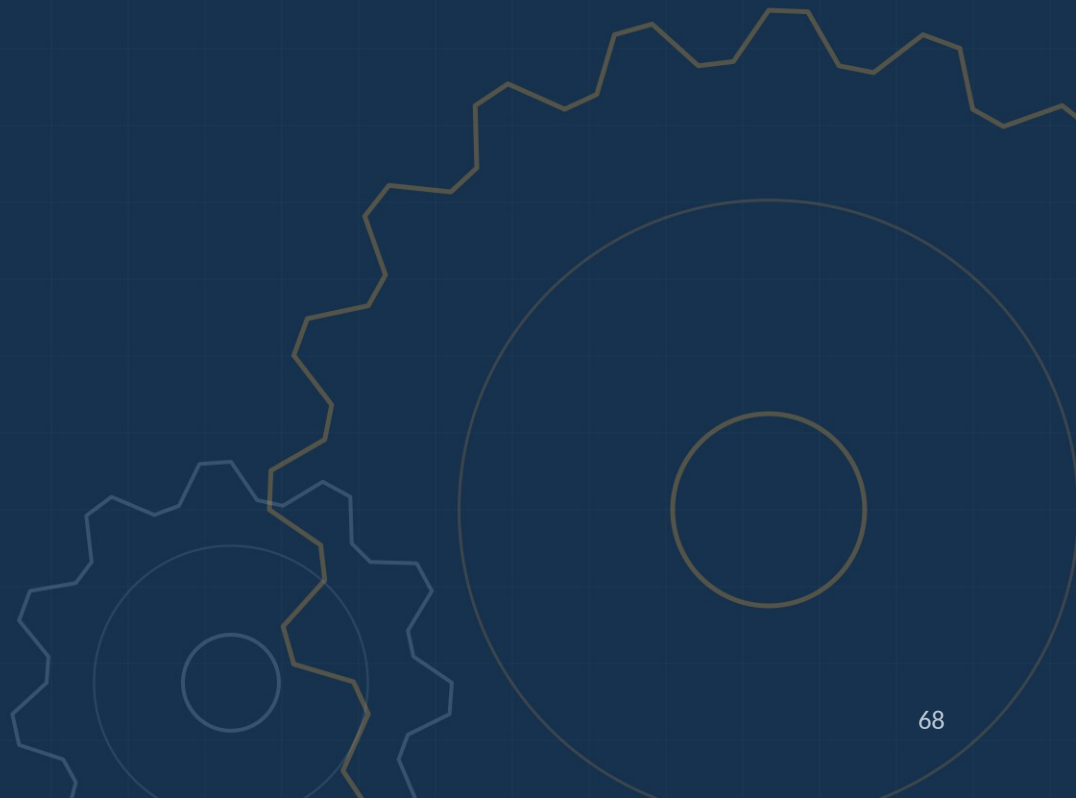
Tolerable risk
reduce if economically justified

Acceptable risk
monitor, no additional action

07

Wear of technical means

Physical and economic wear; the three phases of wear



Wear – definition and classification

Wear is the process of changes in the surface layer of a part, kinematic pair, assembly or the whole machine, resulting in the loss of its functional properties. Its effect can be measured **by volume, length or mass**. Wear processes can be classified by:

Causes

tribological and non-tribological

Course

stabilised and unstabilised

Effects

normal and catastrophic (pathological)

Physical wear and economic (moral) wear

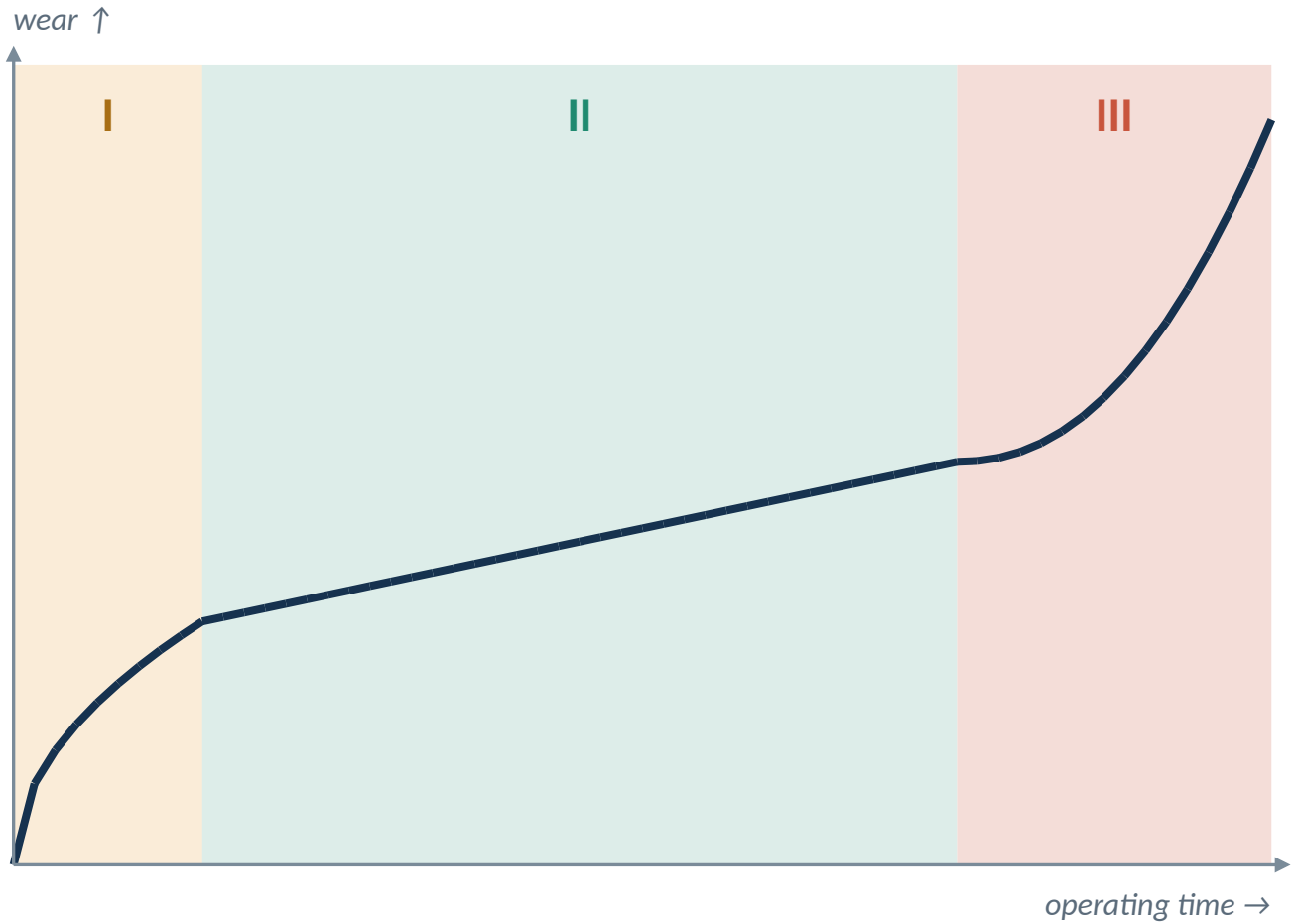
Physical wear

caused by friction, corrosion and other physical or chemical factors: **mechanical, corrosive and corrosive-mechanical**. Leads to increased clearances, leaks, noise and vibration, loss of accuracy. Also occurs **during standstill** (e.g. corrosion).

Economic (moral) wear

decrease in the utility value of a machine compared with new, more productive machines – a consequence of **technical progress**.

Three phases of wear of mating surfaces



I — Running-in

short but crucial: surfaces smooth and adapt to each other

II — Normal (steady) wear

nearly constant intensity – its length determines the durability of the part

III — Accelerated (catastrophic) wear

admissible clearance exceeded → dynamic loads, lubrication disturbed, pitting – avalanche wear

Wear in practice – typical symptoms

Machine element	Wear symptoms	How we can detect it
Rolling bearings	noise, vibration, higher temperature	vibration analysis, thermography, listening
Gears	pitting, noise, metal particles in oil	oil analysis, vibration analysis, visual inspection
Seals	leaks, contamination of lubricant	visual inspection, oil level
Belts and chains	slip, elongation, cracks	tension measurement, visual inspection
Slideways and guides	loss of accuracy, play	measurement of workpieces, dial indicator
Cutting tools	worse surface finish, higher cutting force	surface roughness, motor current, tool monitoring

Diagnostic methods are covered in Lectures 4 and 5.

What determines the phases and intensity of wear?

Design features

shape of surfaces, loads, type of lubrication, materials of the mating parts

Technological features

final machining, heat or thermo-chemical treatment, surface roughness, assembly quality

Operational features

correct use, maintenance and servicing between repairs

Wear should always be counteracted – e.g. proper surface preparation and correct lubrication slow it down. Machine operation must **not enter phase III**.

SUMMARY

Careers in machine operation and maintenance



Maintenance technician

repairs and services machines – mechanical, electrical, automation



Maintenance planner / engineer

plans work, spare parts and the maintenance team



Reliability engineer

analyses failures, applies FMEA and RCM, improves machines



Condition monitoring specialist

vibration, thermography, oil analysis – certified e.g. to ISO 18436



Asset manager

manages the machine park economically – ISO 55000



Data analyst for maintenance

sensors, IIoT and AI for predictive maintenance

SUMMARY

Key takeaways from today

Every technical object is made **to be operated** – operation is the longest phase of the life cycle.

Purchase price is the tip of the iceberg – decide using **Life Cycle Cost**.

Maintenance = technical, administrative and managerial actions (**EN 13306**).

Machines transform **mass, energy or information**; residual processes carry diagnostic information.

Safety first: **EN ISO 12100** – design, safeguarding, information. Regulation **2023/1230** from 20 Jan 2027.

Wear has three phases – good maintenance keeps the machine **out of phase III**.

QUIZ

Quiz 2 – machines, safety and wear

1 In the three-step method of EN ISO 12100, the first step is...

A) warning signs | B) inherently safe design | C) safety training | D) personal protective equipment

2 Regulation (EU) 2023/1230 applies from...

A) 29 Dec 2009 | B) 29 Jun 2023 | C) 20 Jan 2027 | D) 1 Jan 2030

3 Efficiency of a chain: 0.9 · 0.9 equals...

A) 0.81 | B) 0.90 | C) 1.80 | D) 0.99

4 Risk is calculated as...

A) cost × time | B) consequence × probability | C) MTBF / MTTR | D) load × speed

5 Pitting and avalanche-like wear belong to...

A) running-in | B) normal wear | C) accelerated wear | D) economic wear

ANSWERS

Quiz 2 – answers

1 In the three-step method of EN ISO 12100, the first step is...

- A) warning signs
- **B) inherently safe design**
- C) safety training
- D) personal protective equipment

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5 Pitting and avalanche-like wear belong to...

- A) running-in
- B) normal wear
- **C) accelerated wear**
- D) economic wear

REVIEW

Review questions



1. Define the industrial realisation process and list its three organic features.
2. Describe the stages of the product life cycle. Why is the operation phase decisive for life cycle cost?
3. Define maintenance according to EN 13306 and asset management according to ISO 55000.
4. Explain the “3 I” model of a machine. Why are residual processes important for diagnostics?
5. What changes does Regulation (EU) 2023/1230 introduce? Describe the three-step risk reduction method of EN ISO 12100.
6. Sketch the wear curve and characterise its three phases.

Thank you for your attention

Next: after the break – Lecture 2 · Systems Approach and Maintenance Organisation and Strategies

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