BASICS OF MACHINE OPERATION

Laboratory · Exercise 3

Safe technological equipment – risk assessment

Energy analysis · Risk Score · risk graph



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Academic year 2026/2027

1. Goal and assumptions

Goal. Identify the hazards of an automated workstation with the energy analysis method, estimate the risk with the Risk Score method, and select protective measures that reduce every risk to an acceptable level. The result is the completed risk assessment worksheet – the input to Exercise 4.

Assumptions. Each team gets one workstation (topic t1–t7, section 3.4). The same team designs the safeguards of the same workstation in Exercise 4.

Organisation.

- Teams of 3–4 students; one worksheet and one report per team.
- In class (about 80 min): workstation description, hazard identification and risk before measures.
- At home: protective measures, residual risk, safety functions and the report.
- Files: BMO_Ex3_<team>.xlsx (worksheet) and BMO_Ex3_<team>.pdf (report).

2. Background

2.1 Why risk assessment

Published accident statistics name four main groups of causes: wrong behaviour of the worker (over 50%), poor work organisation (about 13%), poor condition of machines and equipment (about 12%), and lack or wrong use of the material factor (about 9%). The last two point to the design and operation of machines.

Risk can never be zero. The **residual risk** that remains after protective measures must be reduced to a **tolerable** level – accepted in the given context on the basis of the state of the art, costs, organisation, training and awareness. Safety is freedom from unacceptable risk.

Risk assessment follows **EN ISO 12100** (it replaced EN 1050 and EN ISO 14121): determine the limits of the machine → identify hazards → estimate the risk → evaluate the risk → if not acceptable, reduce it (inherently safe design → safeguarding → information for use) and repeat. Directive 2006/42/EC applies until 19 January 2027; from 20 January 2027 Regulation (EU) 2023/1230 applies.

2.2 Step 1 – Limits and functions of the machine

Describe: production data (product, output, materials, media), location and space limits, intended service life, operating modes (automatic and manual cycles, setting, cleaning, maintenance), expected malfunctions, persons who use and service the machine, intended use and **reasonably foreseeable misuse**.

Typical foreseeable misuse: reflex actions during a malfunction; lack of attention due to haste or fatigue; the “path of least resistance”; pressure to keep the machine running; behaviour of bystanders; loss of control; restarting after a fault stop (e.g. clearing a jam by hand while the machine runs); late reaction to disturbances.

2.3 Step 2 – Hazard identification: energy analysis

An accident happens when a person is exposed to an **uncontrolled flow of energy** above the resistance of the body. Every form of energy is reviewed for three volumes:

- **Operator volume** – where the operator works (worksheet tab operator_volume).
- **Internal (service) volume** – inside the guards; setting, adjustment, maintenance, repair (tab service_volume).

- **External volume** – the surroundings with other workers, supervisors, transport and maintenance staff (tab external_volume).

Energy	Sources (checklist)
Potential	person or object at height, collapsing structure, lifting and carrying, tensioned spring, stressed material, pressurised gas or steam lines, vacuum
Kinetic	elements on linear guides, robot and manipulator arms, chips and fragments, conveyors, floor vehicles (AGVs), pressurised fluids, transported materials, rotating parts, belts, shafts and ball screws
Electrical	supply voltage, capacitors, batteries, current (inductive storage, heating), magnetic field
Heat and cold	hot or cold objects, heat sources, liquid or molten substances, chemical reactions
Chemical	explosives and reactions, toxic, corrosive and asphyxiating substances
Radiation	noise, electromagnetic, infrasound and ultrasound, ionising

Protective strategies: remove people from the energy zone, modify the energy, change its direction, block the flow, control the source, use a counter-acting energy.

2.4 Step 3 – Risk estimation: Risk Score

$$R = S \times E \times P$$

S – consequences	Value
Major catastrophe – many fatalities	100
Catastrophe – several fatalities	50
Very serious – one fatality	15
Serious – severe injury	7
Medium – absence from work	3
Minor – first aid	1

E – exposure	Value
Continuous (operator)	10
Frequent – daily (other workers nearby)	6
Occasional – weekly (service staff)	3
Unusual – monthly	2
Rare – a few times a year	1
Very rare – once a year	0.5

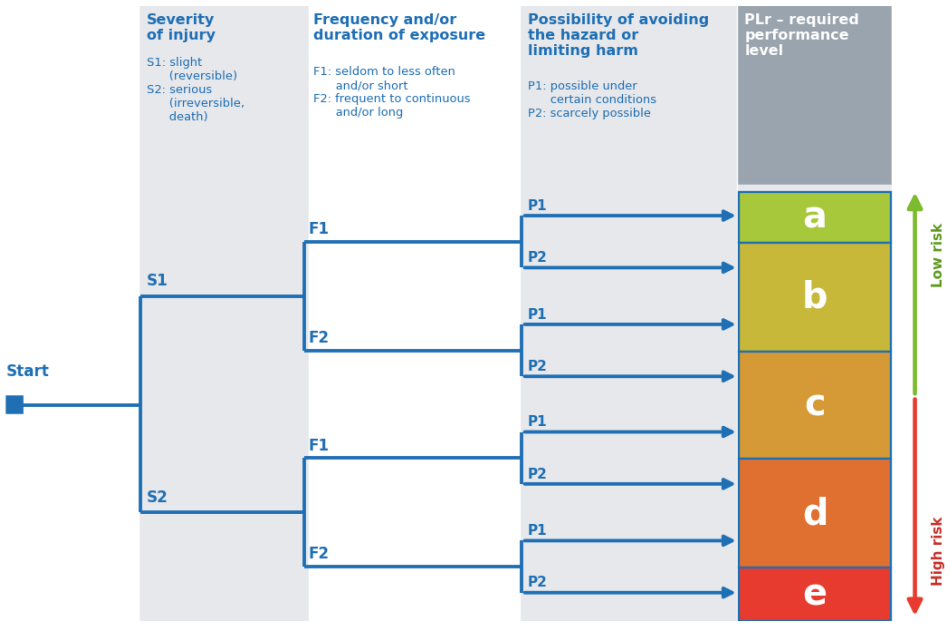
P – probability	Value
Very likely	10
Quite possible	6
Unlikely	3
Only occasionally	1
Conceivable	0.5
Practically possible	0.2
Theoretically possible	0.1

R – risk	Category	Action
R ≤ 20	acceptable	monitoring advised
20 < R ≤ 70	low	control needed
70 < R ≤ 200	significant	improvement needed
200 < R ≤ 400	high	immediate improvement
R > 400	very high	stop work

Take the most serious reasonably possible injury, even when it is unlikely. Probability depends on the event, the frequency and duration of exposure and the possibility to avoid harm.

2.5 Risk graph – required performance level PLr

For each safety function (e.g. “stop the robot when the guard door opens”) the required performance level PLr is found with the risk graph of EN ISO 13849-1 (tabs safety_functions and risk_graph).



3. Materials

3.1 Worksheet

File **BMO_Ex3_Risk_Assessment_Worksheet_EN.xlsx**: tabs operator_volume, external_volume, service_volume, RISK_SCORE (scales and categories), safeguards, safety_functions and risk_graph. R is calculated automatically; risks above 70 are marked "!!!".

3.2 Standards

EN ISO 12100, EN ISO 13849-1, EN ISO 13850 (emergency stop), EN ISO 13857 (safety distances), EN ISO 13855 (positioning of protective equipment), EN ISO 10218-1/-2 (industrial robots).

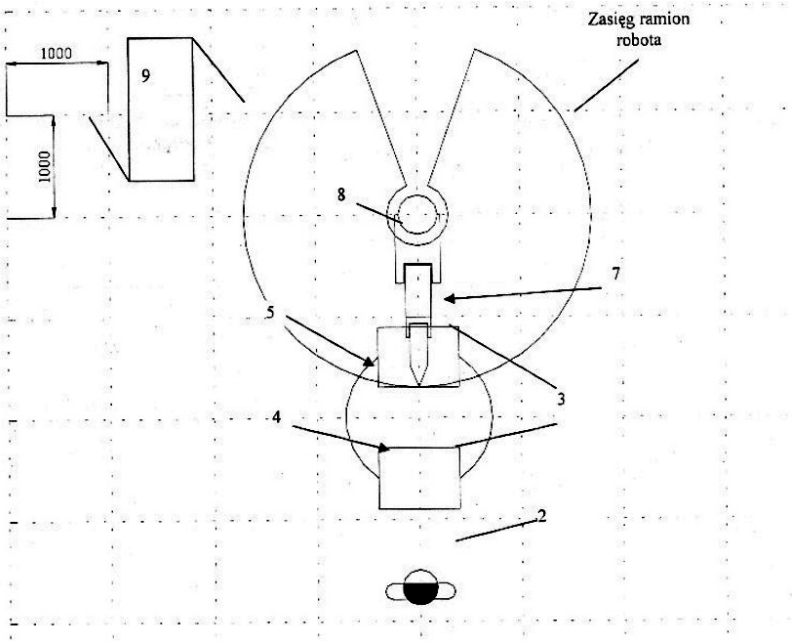
3.3 Team card

First page of the report: topic (t1–t7), team members and file name. Exercises 3 and 4 are graded together (max. 5 points: Exercise 3 – max. 3, Exercise 4 – max. 2).

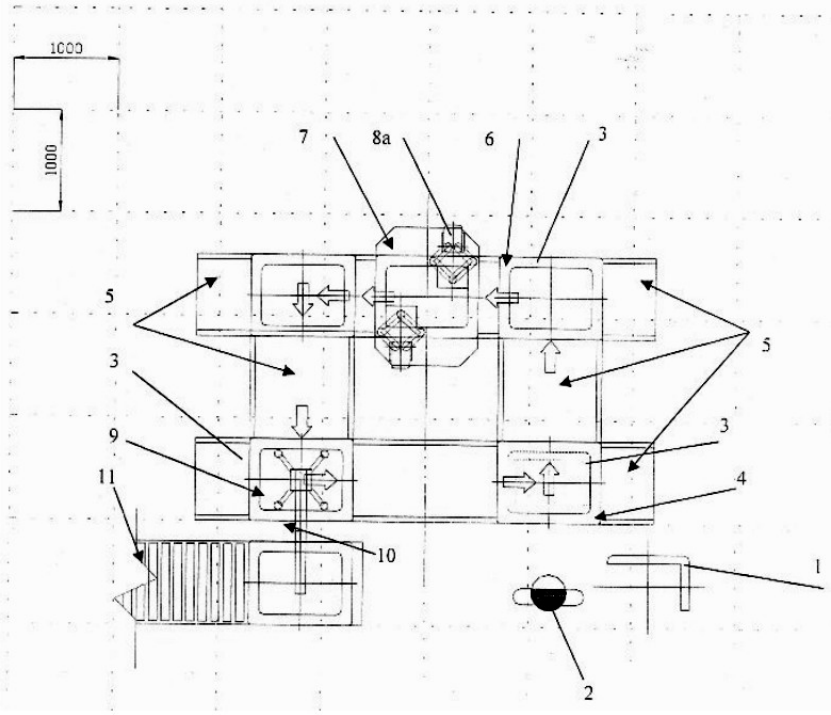
3.4 Workstations t1–t7

Drawings on a 1 000 × 1 000 mm grid.

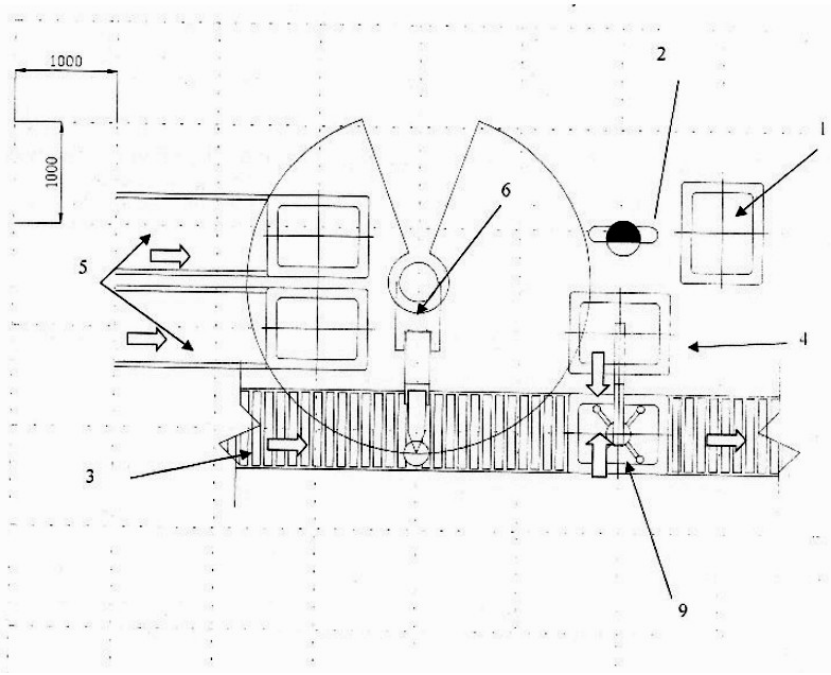
t1 – Welding of bicycle frames. The operator (2) loads frame parts into the welding fixture on one of two pallets (3) at the loading station (4) and clamps them with levers. A rotary pallet changer (5) moves the pallet from the loading station (6) to the welding station (7), where a 5-axis Mitsubishi robot (8) welds. The pallet returns to the unloading station (4); frames are removed by hand while the next frame is welded. Control cabinet (9).



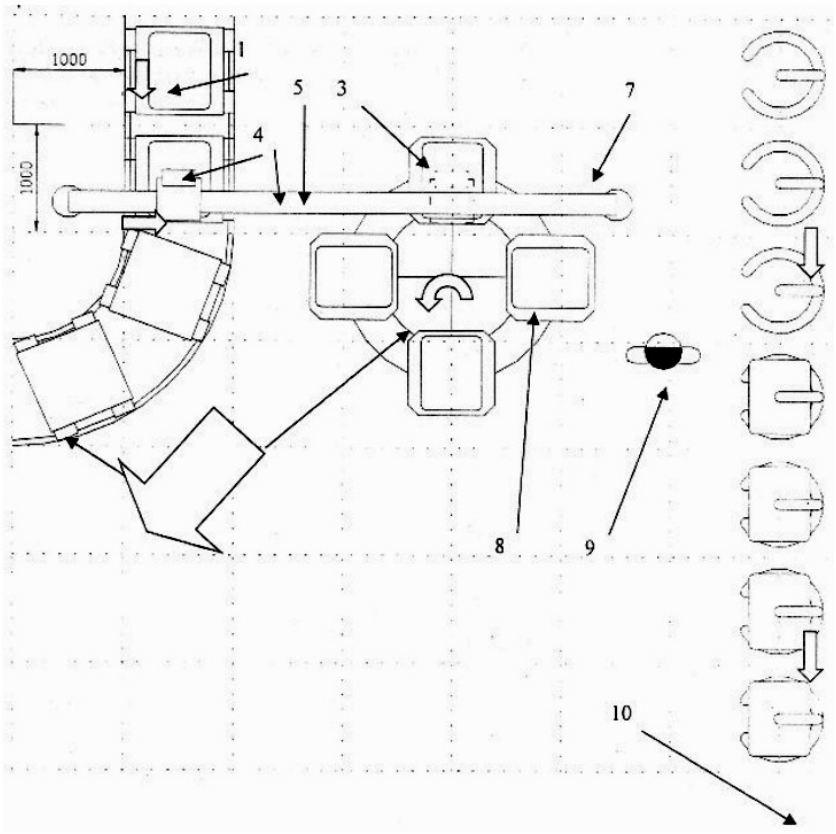
t2 – Welding of sheet-metal blanks. The operator (2) loads two blanks (1) on one of four pallets (3) at the loading station (4) and presses them in so that the snap clamps work. A linear conveyor (5) moves pallets to the waiting station (6) and the welding station (7) with two Mitsubishi robots (8a, 8b) welding at the same time. At the unloading station (9) a 2-axis pneumatic manipulator (10) with suction cups places the frame on a roller conveyor (11); the operator pushes stacks of about 30 pieces by hand. The welding area is air-cooled and the operator cleans the fixtures with compressed air. Five pallets circulate.



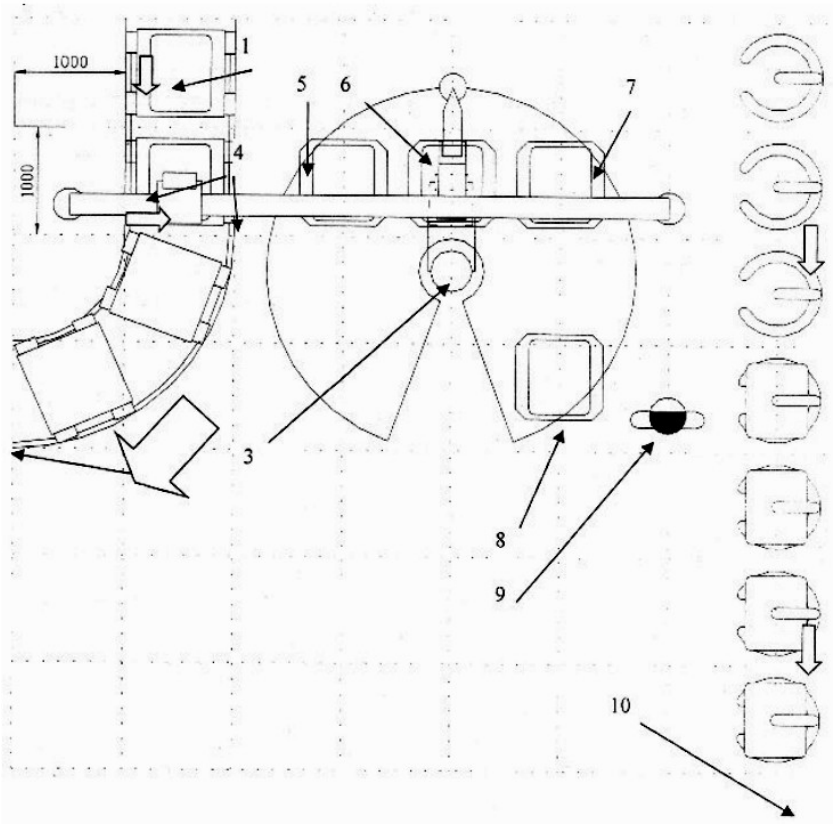
t3 – Transparency inspection of CRT screens. A Mitsubishi robot (6) with a suction cup moves screens (1) from the linear conveyors (5) of the annealing ovens to the main roller conveyor (3). On a control signal the screen stops at the unloading station (9) and a 2-axis pneumatic manipulator moves it to station (4). The operator (2) loads random screens into the inspection fixture; good screens return to the conveyor.



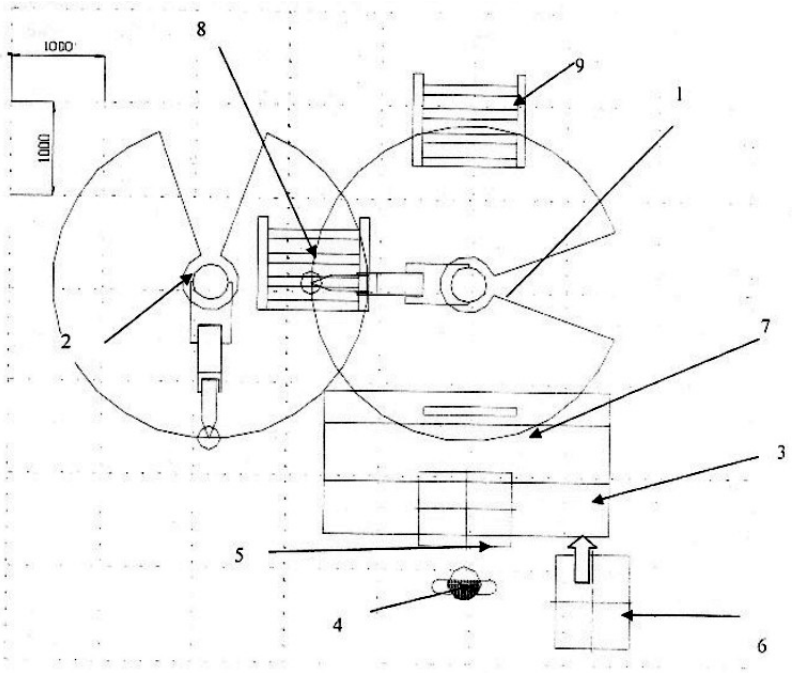
t4 – Unloading CRT tubes from a tunnel oven (rotary table). Tubes (1) travel on carts (2) along an oval track. A 2-axis electric manipulator (4) with a suction cup places them in nests (3) of a rotary indexing table (6) with induction heating; the table turns in 90° steps. From position (8) the operator (9) moves finished tubes to continuously moving hangers (10).



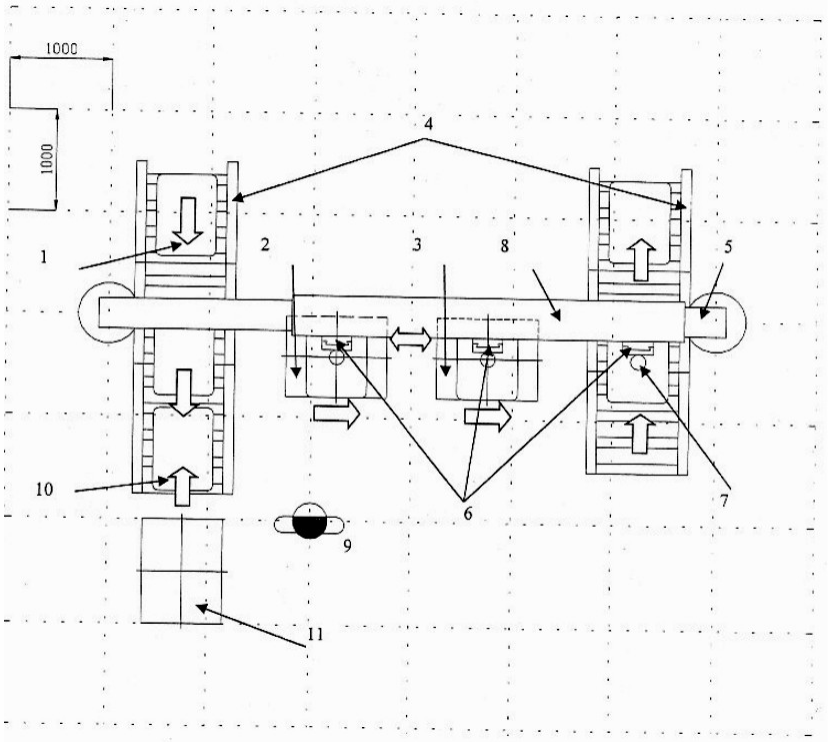
t5 – Unloading CRT tubes from a tunnel oven (robot). As t4, but the manipulator (4) places tubes on three tables (5), (6), (7) with induction heating, and a Mitsubishi robot (3) moves them to position (8), where the operator (9) loads them onto the hangers (10).



t6 – Cutting, bending and welding of frames. The operator (4) feeds 5 kg sheets (5) by hand from the separating device (6) to an automatic press brake (3), which makes two bends and cuts a channel profile. Profiles go by conveyor to area (7), robot (1) places six profiles in the welding fixture (8), robot (2) welds, and robot (1) moves the frame to the finished-goods pallet (9).



t7 – Geometry inspection of screens. Screens (1) arrive on roller conveyors (4) at 0.9 m. A gantry manipulator (5) with three pneumatic vertical slides (6) and suction cups (7) on a common beam (8) lifts screens to 2.0 m and moves them between the measuring stations (2) and (3). Every 2 minutes the operator (9) takes a screen from station (10), checks it on the lit table (11) and puts it back. Screen mass 5 kg; slides pneumatic, other drives electric.



4. Tasks

Task 1: Limits and functions

Describe the workstation according to Step 1, with at least five cases of foreseeable misuse.

Result: description, operating modes, persons, misuse.

Task 2: Hazards and risk before measures

In the three volume tabs mark the energies, describe the hazards and give S, E, P and R **before** protective measures.

Result: three completed tabs.

Task 3: Protective measures and residual risk

For every risk R > 20 propose measures in the order of EN ISO 12100 (design → safeguards → information/PPE) and give S, E, P and R **after** the measures.

Result: measures and residual risk in the worksheet.

Task 4: Safety functions, PPE and procedures

Specify the safety functions with PLr from the risk graph; list PPE, safe-work procedures and procedures for checking the technical condition.

Result: tabs safeguards and safety_functions.

Task 5: Report

Max. 4 pages: team card, workstation description, highest risks before and after, protective measures, safety functions with PLr, conclusions.

5. Assessment

Criterion	Weight
Hazard identification	30%
Correct risk estimation	30%
Adequacy of measures	30%
Presentation	10%