



TIRAX

Worksheet W.001

Robot-Assisted Inspection of Wasted Automotive Batteries



MASTER



Co-funded by
the European Union

The TI-RAX Project has received funding from the European Union's Horizon Europe research and innovation action programme, via the Open Call #2 – MASTER issued and executed under project MASTER (grant agreement Nr. 101093079).



TI-RAX

Teach Industrial Robotics with AI and XR

Title: Worksheet W.001 Robot-Assisted Inspection of Wasted Automotive Batteries

Version: 0.1 (21 febbraio 2026)

Beneficiaries: University of Cagliari, R2M Solution Srl

Authors: Mirko Marras (University of Cagliari), Andrea Giovanni Martis (University of Cagliari), Diego Reforgiato Recupero (University of Cagliari), Daniele Riboni (University of Cagliari), Giuseppe Scarpi (R2M Solution Srl)

Mentor: Panagiotis Karagiannis (University of Patras)

Dissemination level	
Public	X
Restricted to members of the organizations that signed the agreement	
Restricted to a specific group of members of the organizations that signed the agreement	
Confidential, only for the appointed contacts	

XR Learning Activity Specification

Logo



Title

Robot-Assisted Inspection of Wasted Automotive Batteries

Language

English (EN)

Short Description

Robot-assisted XR training for safe inspection and treatment of end-of-life automotive batteries

Long Description

This learning record aims to certify that the participant has successfully completed the XR learning activity “*Robot-Assisted Inspection of Wasted Automotive Batteries*”. The learning activity is set in a virtual industrial recycling facility that reproduces realistic inspection workflows for end-of-life automotive batteries prior to recovery or disposal. Learners operate in a shared human–robot workspace where a collaborative robot performs automated diagnostic procedures, while the human participant supervises and controls the process through structured interactions. The experience is designed as a guided, scenario-based simulation that supports experiential learning and progressive decision-making. Learners are exposed to realistic inspection situations in which they must recognize hazards, respect dynamic safety zones, and coordinate their actions with the robot. They are responsible for selecting inspection modes, supervising execution, interpreting diagnostic feedback, validating system outputs, and determining the appropriate treatment path—recovery, re-routing, or isolation—based on detected battery conditions. Through progressively complex scenarios, time constraints, and performance indicators, the activity develops practical skills for the safe and efficient handling of hazardous battery waste. At the same time, it trains learners to balance productivity, safety, and regulatory compliance, supporting vocational re-/up-skilling in smart manufacturing, recycling, and industrial safety contexts.

Keywords

battery recycling; collaborative robotics; industrial safety; circular economy; smart manufacturing

Expected Workload

5 hours

Type of Participation

Online participation in asynchronous, XR-based, scenario-driven learning activities

Target Audience

This scene targets learners with entry-level technical knowledge and basic familiarity with immersive technologies. It is designed to support initial vocational training and reskilling pathways related to industrial recycling, maintenance, and smart manufacturing contexts.

Learning Objectives

- Understand the main safety, environmental, and operational risks associated with robot-assisted inspection of wasted automotive batteries.
- Recognize and respect safe interaction zones within shared human–robot workspaces, and apply appropriate safety behaviors when entering, operating in, and exiting these areas.
- Cooperate with a robot by assigning, supervising, and understanding inspection activities, as well as validating their outcomes as part of a coordinated human–robot workflow.
- Communicate appropriate post-inspection handling decisions (e.g., recovery, re-routing, or isolation) to the robot based on inspection outcomes.

EQF Level

6 (Advanced knowledge and skills; first-cycle higher education level)

ISCED-F Subject Areas

- 0714 – Electronics and automation (robotics, sensors, control systems)
- 0715 – Mechanics and metal trades (industrial machinery, handling, safety)

ESCO Competences

- **Supervise industrial robotic systems**

ESCO: Robotics

<http://data.europa.eu/esco/skill/e87ec79a-c9ff-46f5-84fa-7a0f394cdf40>

- **Sort waste by separating it into its different elements**

ESCO: Sort waste

<http://data.europa.eu/esco/skill/110d7aa3-e44e-4cce-a927-8d4de615f3d9>

- **Manage or dispose of significant amounts of waste materials**

ESCO: Manage waste

<http://data.europa.eu/esco/skill/110d7aa3-e44e-4cce-a927-8d4de615f3d9>

Completion Criteria

Supervision and Identity Verification

No supervision, no identity verification

Assessment Requirement

Completed upon finishing all training modules and achieving an overall performance score ≥ 75%

Detailed Learning Design

Role of the Robot

Traditional Manual Inspection (Without Robots). In conventional battery recycling facilities, inspection was performed manually by human operators. Workers approached damaged or unknown batteries directly, visually examined the casing, touched the surface, and used handheld tools such as thermal probes or basic multimeters. This required standing in close proximity to potentially unstable batteries and often manipulating them by hand. As a result, operators were exposed to multiple hazards, including electrical shock, toxic electrolyte leakage, and thermal runaway. Inspection quality depended heavily on individual experience, fatigue, and time pressure. Procedures were slow, inconsistent, and difficult to document or trace, increasing the risk of undetected failures and unsafe handling decisions.

Robot-Assisted Inspection (With Robots). In modern recycling plants, robotic inspection systems replace direct human contact with hazardous batteries by physically separating people from the inspection process. Batteries are first positioned on an automated loading platform at the boundary between the human work area and the robot cell. Once the inspection is started, the platform transfers the battery into the restricted robot zone, where a collaborative robot performs all diagnostic actions using integrated visual, thermal, and electrical sensors. The human operator never enters the robot cell and never touches the battery during inspection. Instead, the operator remains in a safe corridor and supervises the process through a control console. Based on the robot's measurements and system feedback, the operator validates the inspection outcome and selects the appropriate treatment path.

Operational Parameters

To ensure that the training experience is concrete, repeatable, and implementable, the following operational assumptions define how inspection cycles, timing, and handling flows are realized.

Inspection Modes. The robot can perform three predefined inspection modes:

- *Standard Scan* (visual and thermal surface scan, 2 minutes),
- *Deep Diagnostic* (visual, thermal, and impedance analysis, 4 minutes),
- *Emergency Inspection* (rapid thermal and leak detection, 90 seconds).

Inspection Cycle Duration. Each full inspection cycle includes:

- Task assignment (10–15 seconds),
- Robot inspection (according to the selected mode),
- Result visualization (20 seconds),
- Human validation and handling decision (20–30 seconds).

Thus, one complete inspection lasts approximately:

- 3 minutes (Standard),
- 5 minutes (Deep),
- 2.5 minutes (Emergency).

Handling Bins. After validation, the robot makes a decision on where the battery must be routed:

- *Recovery Bin* (green): battery cleared for recovery,
- *Re-routing Bin* (yellow): battery sent for further manual checks,

- *Isolation Bin* (red): battery placed in a sealed safety container.

Control Console. The control console is the primary human–machine interface of the inspection system. It is structured as a touch-based panel with three persistent menu sections:

- *Process Menu* (left): controls the inspection workflow;
- *Status Panel* (right): displays system state and inspection data;

Process Menu (Workflow Controls).

- Load Battery: confirms that a battery is positioned on the loading platform.
- Start Inspection: opens a submenu to start one of the three inspection modes.
 - Standard Scan: visual and thermal surface inspection (2 minutes).
 - Deep Diagnostic: visual, thermal, and impedance analysis (4 minutes).
 - Emergency Inspection: rapid thermal and leak detection (90 seconds).
- Pause Inspection: temporarily halts robot motion while keeping the safety zones active.
- Cancel Inspection: halts robot motion and deactivates the safety zones.
- Confirm Inspection Decision: finalizes the selected handling path.
 - Recovery: sends the battery to the green recovery bin.
 - Re-route: sends the battery to the yellow secondary inspection bin.
 - Isolate: sends the battery to the red sealed safety container.
- Emergency Stop: immediately stops all robot motion and triggers safety alarms.

Status Panel (System Feedback). The right-hand panel of the control console provides both *real-time operational feedback* and *aggregated performance indicators*. It always displays:

- RobotState Values: {IDLE, SCANNING, PAUSED, ERROR}. *Rationale*: informs the operator of the robot's current execution state and whether interaction is allowed.
- PhaseProgress Range: 0–100% (progress bar). *Rationale*: shows how much of the active inspection phase has been completed, supporting time awareness and planning.
- SystemAlerts Values: INFO, WARNING, CRITICAL. *Rationale*: communicates safety-relevant or system-level events that may require operator intervention.
- BatteryTemperature Range: 0–120 °C. *Rationale*: indicates thermal risk and early signs of runaway or leakage.
- AnomalyFlag Values: NONE, MINOR, MAJOR. *Rationale*: summarizes detected visual, thermal, or electrical anomalies.

During performance-driven modules, the same panel also shows a *KPI dashboard* with:

- TargetCycleTime Range: 2.5–5.0 minutes (mode dependent). *Rationale*: defines the maximum allowed time per inspection to meet throughput goals.
- AvgCycleTime Range: 0–10 minutes. *Rationale*: shows the learner's real operating speed compared to the target cycle time mentioned above.

- TargetThroughput *Range*: 8–15 batteries/hour. *Rationale*: reflects industrial productivity constraints to train the learner against.
- ActualThroughput *Range*: 0–20 batteries/hour. *Rationale*: measures achieved production rate to make the learner compare against the target throughput mentioned above.
- SafetyComplianceScore *Range*: 0–100%. *Rationale*: penalizes unsafe actions and violations, reinforcing that productivity must never override safety.

Training Script

The training activity is designed as a progressive, scenario-based learning experience lasting approximately *five hours*. It is organized into *sequential modules*, combining guided exploration, hands-on interaction, reflective checkpoints, increasing realism, and formative assessment. The structure supports a gradual transition from basic XR interaction skills to autonomous, safety-critical human–robot collaboration in industrial inspection scenarios. Compared to a purely technical tutorial, the training intentionally introduces cognitive load, time pressure, and consequence visualization.

Module 1 – Introduction and Basic Environment Understanding (25 minutes)

Pedagogical Rationale. This module serves as a low-pressure onboarding phase that allows learners to become familiar with the XR environment, basic controls, and spatial layout before engaging in safety-critical or time-sensitive activities. The focus is on exploration and understanding rather than performance or decision-making. No alarms, emergency situations, or handling consequences are introduced at this stage.

Learning Outcomes. At the end of this module, the learner will be able to:

- navigate the virtual workspace using the available controls;
- recognize the main functional areas of the scene;
- interact with objects and interfaces;
- understand where manual interaction is allowed and where robot motion occurs;
- recognize visual indicators of robot activity;
- apply basic personal protective equipment before handling materials.

Learning Flow. Each step must be completed successfully before the next one becomes available. If the learner makes a mistake, the system provides hints and demonstrates the correct behavior.

1. *Orientation.* A wall-mounted *factory layout panel* appears next to the learner, showing a top-down view of the workspace. The robot cell, inspection station, human safe corridor, control console, and emergency exit blink one at a time. The learner selects each area in the order shown to build a mental map of the environment.
2. *Movement.* Three floor circles labeled *A* (entry zone), *B* (inspection table), and *C* (control console) light up in sequence. Direction arrows appear between them. The learner walks to *A*, then *B*, then *C* by stepping into each glowing circle.
3. *Equipment Check.* A personal protective equipment cabinet next to the inspection table opens and a pair of protective gloves is highlighted. A message appears: “*Wear protective gloves before handling the battery.*” The learner must pick up the gloves and put them on their virtual hands before continuing.

4. *Interaction.* A battery is placed on the *inspection table*, located outside the robot motion area, on the left side of the robot cell. The battery glows yellow and a *Rotate* icon appears above it. The *Start Inspection* button on the nearby console flashes blue. The learner grabs the battery, rotates it until a green icon appears, then presses the flashing button.
5. *Robot Awareness.* The robot arm performs a slow demonstration movement inside the robot cell. A transparent visual boundary appears around the robot base and arm, and the floor inside this area is highlighted. The learner observes the motion while standing in the safe corridor. This step introduces the concept of robot motion zones without risk or time pressure.

Learner Monitoring. The system records into a log file: (1) time spent in each step, (2) number of mistakes, (3) navigation errors, (4) PPE compliance, (5) interaction accuracy.

Module 2 – Safety Boundaries Understanding (50 minutes)

Pedagogical Rationale. This module trains learners to behave safely when a robot is operating in a shared workspace. Unlike Module 1, which introduced static areas and basic robot motion, this module focuses on *dynamic safety conditions*, warning signals, and timing rules that must be respected.

Learning Outcomes. At the end of this module, the learner will be able to:

- distinguish safe, collaborative, and restricted robot zones;
- recognize dynamic safety boundaries during robot activity;
- interpret warning lights, sounds, and color codes;
- enter, remain in, and exit shared workspaces safely.

Learning Flow. Each step must be completed successfully before the next one becomes available. If the learner violates a safety rule, the system blocks progression and explains the correct behavior.

1. *Zone Recognition.* The robot cell floor is colored green (safe), yellow (collaborative), and red (restricted). A vertical legend panel appears beside the robot, explaining the meaning of each color. The learner must approach the edge of each zone and select its meaning on the panel.
2. *Timed Safe Entry.* A traffic-light indicator above the robot alternates between red (do not enter) and green (entry allowed). When the light turns green, the learner must step into the yellow collaborative zone. When it turns red again, the learner must return to the green zone. This step trains timing awareness during shared work.
3. *Restricted Area Violation.* The learner is prompted to attempt entry into the red restricted zone. An alarm sounds, the screen flashes, and the learner is automatically moved back to the green zone. A message explains that the red zone is always forbidden. This step makes safety rules explicit.
4. *Emergency Exit Procedure.* A flashing arrow appears on the floor and points toward the emergency exit corridor. The learner must follow the path and reach the exit marker within a time limit. This step practices evacuation behavior under simulated urgency.

Learner Monitoring. The system records into a log file: (1) time spent in each zone, (2) number of boundary violations, (3) reaction time to safety signals, (4) quiz accuracy.

Module 3 – Human Decisions and Robotic Actions Coordination (60 minutes)

Pedagogical Rationale. This module introduces the complete human–robot inspection cycle and trains learners to coordinate their decisions with robotic execution. Unlike previous modules, this phase

explicitly connects inspection results to *post-inspection treatment paths*. Learners understand that inspection is not an end in itself, but a decision step that determines how a battery is handled.

Learning Outcomes. At the end of this module, the learner will be able to:

- assign inspection tasks to the robot using the control console;
- supervise automated robot procedures in real time from safe zones;
- interpret system feedback and inspection results;
- validate robot results and select the corresponding treatment path;
- explain why incorrect validation can lead to unsafe handling.

Learning Flow. Each step must be completed successfully before the next one becomes available. If the learner makes a mistake, the system pauses the process and provides corrective feedback. Each inspection cycle ends with a *guided physical routing action* to a treatment container.

1. *Guided Observation.* The robot performs a complete inspection cycle on a battery placed inside the robot cell while the learner stands in the green safe zone. The control console displays a live status bar showing each inspection phase. A short caption explains what the robot is doing at each stage. This step builds an overview of the full workflow.
2. *Task Assignment.* The control console displays three inspection modes with short descriptions. One option is highlighted. The learner selects it to assign the task to the robot. This step teaches how human input initiates robot activity.
3. *Supervised Execution.* The robot starts the inspection. The console shows progress indicators and system messages. The learner must remain in the green safe zone while observing the process. This step reinforces safe supervision behavior.
4. *Result Visualization.* When the inspection ends, diagnostic values and a color-coded outcome (pass, warning, critical) appear on the console. A short explanation clarifies what the result means. This step teaches how to interpret robot-generated data.
5. *Human Validation.* The console asks the learner to confirm the robot's result. The learner must select the correct option to proceed. This step emphasizes that the robot supports decisions but does not replace human responsibility.
6. *Guided Treatment Routing.* Based on the result, the system highlights the corresponding container: *green approval bin*, *yellow re-routing crate*, or *red isolation container*. The learner must route the battery to the highlighted container. A short caption explains why this treatment path is required.

Learner Monitoring. The system records into a log file: task assignment accuracy, supervision time, validation correctness, routing correctness, safety zone compliance, and reflection response.

Module 4 – Supervised Risk-Based Inspection Scenarios (100 minutes)

Pedagogical Rationale. This module transitions learners from procedural execution to *risk-aware decision-making* aligned with real industrial battery treatment practices. Learners must not only validate inspection outcomes, but also *physically route* batteries into the correct treatment path. Although system guidance is still available, learners must increasingly interpret inspection evidence, manage uncertainty, and understand the safety and operational consequences of their choices. Small stressors, time constraints, and consequence visualizations are introduced to reflect realistic conditions.

Learning Outcomes. At the end of this module, the learner will be able to:

- select inspection sequences based on observed battery risk conditions;
- validate robot-generated inspection results under partial guidance;
- route batteries to the correct physical handling containers;
- choose and communicate appropriate post-inspection handling actions;
- explain the safety and operational consequences of incorrect decisions.

Learning Flow. Each case must be completed before the next one is unlocked. Guidance is reduced and mild time pressure is introduced in later steps. All cases end with a mandatory *physical routing action* to a designated container: *green approval bin*, *yellow re-routing crate*, or *red isolation container*.

1. *Case 1 – Intact Battery (Guided).* A visually intact battery is placed inside the robot cell. The console highlights the recommended inspection sequence and the *approval* handling option. The learner selects the highlighted inspection mode, supervises the robot, reviews the results, and confirms approval. The system then highlights the *green approval bin*. The learner must physically route the battery to this container. A feedback panel explains why this handling path is safe and compliant.
2. *Case 2 – Deformed Battery (Partially Guided).* A battery with visible deformation is placed inside the robot cell. Two inspection sequences are shown without highlighting. The learner chooses one, supervises execution, and validates the robot's result. A timer appears on the console. The system highlights the *yellow re-routing crate*. The learner must physically move the battery to this container. A comparison panel explains the optimal choice and the potential risks of incorrect routing.
3. *Case 3 – Leaking Battery (Critical Condition).* A battery with visible leakage is placed inside the robot cell. A warning symbol and low-volume alarm are activated. The learner must select the *emergency inspection mode*, supervise the robot, and choose *isolation* as the handling decision. The system highlights the *red isolation container*. The learner must route the battery to the isolation container. If the wrong decision is made, a consequence panel explains the real-world impact.
4. *Progressive Challenge.* A random case (intact, deformed, or leaking) is presented without hints. The learner completes the full workflow independently while background factory noise and a countdown timer are active. The learner must select the inspection sequence, validate the result, and route the battery to the correct container. This step prepares the learner for autonomous operation.

Learner Monitoring. The system records into a log file: case selection accuracy, routing correctness, response time, number of hints used, and critical risk errors.

Module 5 – Autonomous Risk-Based Decision-Making (65 minutes)

Pedagogical Rationale. This module simulates realistic industrial operating conditions in which learners must act independently while respecting *production throughput constraints*. In addition to safety and correctness, learners must now manage time pressure and performance targets, as commonly required in real battery sorting facilities. All guidance is removed and the learner must balance speed, safety, and quality. The module reinforces professional autonomy, situational awareness, and accountability.

Learning Outcomes. At the end of this module, the learner will be able to:

- manage the full inspection workflow without system prompts;
- maintain inspection performance within target time limits;
- respond correctly to safety alerts and unexpected events under time pressure;
- choose and justify handling decisions while balancing risk and throughput;

Learning Flow. No visual hints are provided in this module. A live KPI dashboard is always visible on the control console and shows the target inspection time of five minutes per battery, the target throughput of twelve batteries per hour, the average cycle time, and the real-time safety compliance score. The system intervenes only if a critical safety rule is violated or if the learner exceeds the maximum time.

1. *Timed Autonomous Inspection Cycles.* A sequence of *three batteries* is processed consecutively. For each battery, the learner must select the inspection mode, start the robot, supervise the process from the safe zone, and review the results on the console. A countdown timer and production progress bar are visible. This step tests the learner's ability to maintain pace while respecting safety.
2. *Unexpected Critical Alert under KPI Pressure.* During one inspection, a high-priority warning appears indicating an anomaly. The timer continues running. The learner must immediately react with the correct safety response. If the learner delays or chooses incorrectly, the KPI dashboard shows a safety penalty and a production stop.

Learner Monitoring. The system records into a log file the (1) average inspection cycle time, the (2) achieved throughput compared to the target, the (3) safety response latency, the (4) decision accuracy, (5) the justification correctness, and (6) the number of KPI violations.

Required 3D Model Assets

The following list includes only the physical 3D models required to implement all the training modules. It excludes user interface panels, audio elements, shaders, effects, and logic components.

Industrial Environment

- Factory hall / recycling facility shell
- Robot working cell structure
- Inspection station / worktable
- Human safe corridor structures (rails, markings supports)
- Control console kiosk
- Emergency exit corridor and door
- PPE cabinet
- Wall-mounted factory layout panel
- Vertical safety legend panel
- Battery placement platform inside robot cell

Collaborative Robot System

- Collaborative robot arm (rigged, animated)
- Robot base
- Robot end-effector / inspection tool
- Traffic light tower (red/yellow/green)
- Robot warning beacon

Batteries and Physical Objects

- Intact automotive battery
- Deformed automotive battery
- Leaking automotive battery
- Battery containers (isolation box, reroute crate, approval bin)

Safety and Navigation Props

- Floor zone meshes (green, yellow, red)
- Dynamic zone boundary meshes
- Robot safety volume mesh
- Floor arrows
- Floor target circles (A, B, C)
- Emergency evacuation arrows
- Exit target marker

Human Equipment

- Protective gloves (wearable)
- Optional: helmet, face shield (future extensions)

Interaction and Scenario Props

- Physical control console housing
- Inspection mode selector box (physical panel model)
- Battery rotation pedestal
- Checklist terminal stand
- Dashboard screen frame
- Reflection kiosk